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Comparing the agricultural development of Mexico to selected Latin American countries between 1994 and 2015 by developing indicators of a Sustainable Agriculture Index

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Affidavit

I, **LISA BUTZENLECHNER**, hereby declare

1. that I am the sole author of the present Master's Thesis, "COMPARING THE AGRICULTURAL DEVELOPMENT OF MEXICO TO SELECTED LATIN AMERICAN COUNTRIES BETWEEN 1994 AND 2015 BY DEVELOPING INDICATORS OF A SUSTAINABLE AGRICULTURE INDEX", 70 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

The Mexican agriculture is often taken as an example for adverse consequences of a free trade agreement such as the North American Free Trade Agreement (NAFTA). Nevertheless, for a holistic assessment of the consequences of such an agreement on the sustainable development of the agricultural sector, one hast to look at economic, social and ecological aspects. Hence, this thesis develops a framework to compare the agricultural development of five Latin American countries over a time period of the past 20 years. The countries were chosen based on similar economic parameters in 1994, i.e. Brazil, Colombia, Cuba, Mexico and Panama. National data for the quantitative empirical analysis have been taken from international organizations including the FAO and the World Bank Group. The quantitative method includes a scheme for normalization, aggregation and weighting for eight indicators in three sub-indices (economic, social and ecological) and one overall Sustainable Agriculture Index (SAI), which is developed based on literature on agricultural and non-agricultural Sustainability Assessments. With help of this framework, the development of the agricultural sector in the five LA countries is assessed and shows – in comparison to the other countries – a recent downward trend for Mexico. This is mainly due to low scores in the social dimension because of high rural poverty rates. For the ecological dimension, rather good scores are computed for Mexico, which were only better for Brazil. The economic scores showed a decline for most countries, except for Cuba and Brazil having a rather stable development. The values and scores observed are compared to literature and reports on the agricultural development in Latin American countries. Consequences of the liberalization process and structural change, which culminated in the adoption of NAFTA, are reflected in the results of the Sustainable Agriculture Index.

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List of abbreviations

Organizations and general abbreviations

AEI	Agro-environmental indicators
CEFP	Centro de Estudios de las Finanzas Públicas [Center for the Study of Public Finances]
DPSIR	Driving forces-Pressures-States-Impacts-Responses Model
ECLAC	Economic Commission for Latin America and the Caribbean
ECNC	European Centre for Nature Conservation
Eds.	Editors
EEA	European Environment Agency
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organization of the United Nations
FAOStat	Statistics Division of FAO
FDI	Foreign Direct Investment
FTA	Free Trade Agreement
GDP	Gross Domestic Product
GHG	Greenhouse gases
GNI	Gross National Income
HDI	Human Development Index
IBGE	Instituto Brasileiro de Geografia e Estatística [Brazilian Statistics and Geography Institute]
IFAD	International Fund for Agricultural Development
IICA	Instituto Interamericano de Cooperación para la Agricultura [Inter-American Institute for Cooperation on Agriculture]
IIED	Institute for Environment and Development
IUCN	International Union for Conservation of Nature and Natural Resources
IWGIA	International Work Group for Indigenous Affairs
LA	Latin America(n)
LCA	Life Cycle Assessment
MDG	Millennium Development Goals
NAFTA	North American Free Trade Agreement
OECD	Organisation for Economic Co-operation and Development
PCGTW	Public Citizen Global Trade Watch
PONR	Privately optimal N input rate
PSE	Producer Support Estimate
PSR	Pressure-State-Response Model
R&D	Research and Development
RTA	Regional Trade Agreement
SA	Sustainability assessment
SAFA	Sustainability Assessment of Food and Agriculture Systems
SARH	Secretaría de Agricultura y Recursos Hidráulicos [State Secretariat for agriculture and hydraulic resources]
SD	Sustainable development

SONR	Socially optimal N input rate
SSI	Sustainable Society Index
TPP	Trans-Pacific Partnership
TTIP	Transatlantic Trade and Investment Partnership
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNICEF	United Nations Children's Fund
WTO	World Trade Organization

Variables and units

EcolSI	Ecological Sustainability Index
EconSI	Economic Sustainability Index
EcoX	Aggregated environmental indicator values for resource depletion and environmental impacts
ha	metric hectare (10 000 m2)
H_{in}	Normalized point score for agri-environmental Inputs
H_{nin}	Normalized point score for Nitrogen Consumption
H_{pin}	Normalized point score for Pesticide use
H_{pov}	Normalized point score for rural poverty
H_{prd}	Normalized point score for productivity
H_{trac}	Normalized point score for agricultural investment
H_{vad}	Normalized point score for value added
H_{wax}	Normalized point score for rural improves water sources
H_{wwi}	Normalized point score for water withdrawal for agricultural use
H_{yld}	Normalized point score for yield
in	Agri-Environmental Input
K	Potassium
kg	metric kilogram (1,000 g)
km2	metric square kilometers (1,000,000 m2, 100 ha)
N	Nitrogen
nin	Nitrogen Consumption arable and permanent crop area
P	Phosphor
pin	Pesticides use on arable and permanent crop area
pov	Rural poverty headcount ratio at national poverty lines
pp	Percentage Points
prd	Agricultural Productivity
SAI	Sustainable Agriculture Index
SocSI	Social Sustainability Index
trac	Agricultural machinery
US$	US Dollars
vad	Agriculture value added per worker
wax	Improved water source, rural
wwi	Water withdrawal for agricultural use
yld	Cereal yield

Acknowledgements

Largo camino tienes
que recorrer
atravesando cerros,
vamos mujer.
Vamos mujer, confía,
que hay que llegar
en la ciudad
podremos ver todo el mar.

Quilapayún

Our path sometimes does not feel easy, sometimes it feels even wrong, but we are taking the right one if there are people, who support us, whatever we do and wherever we go.

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1. Introduction

The economic development of Mexico since the entry into force of the North American Free Trade Agreement (NAFTA) has been discussed controversially in both civil society and academia. The Free Trade Agreement (FTA) between Mexico, Canada and the US entered into force in January 1994 and formed what was then, the biggest free trade area in terms of GDP and population with its 360 million people and 6 trillion US$ of GDP (Silva Herzog, 1994). Following the FTA's 20 years anniversary, its performance and consequences for the countries involved have been assessed by different stakeholders including those in the media, politics, science and civil society. Among many others, one such example is the report "NAFTA's 20-Year Legacy and the Fate of the Trans-Pacific Partnership" by the Public Citizen's Global Trade Watch (PCGTW, 2014) as well as the paper carried out by the Centre for Economic and Policy Research "Did NAFTA Help Mexico? An Assessment After 20 Years" (Weisbrot et al., 2014). In addition many newspaper articles have been written on the subject, including "NAFTA at 20: Deeper, better, NAFTA", which was featured in The Economist (The Economist, 2014).

More than ever, when new FTAs are negotiated, like the Transatlantic Trade and Investment Partnership (TTIP) and the Trans-Pacific Partnership (TPP), which are currently under negotiation, the Mexican case is taken as a negative example of an FTA, as the promised improvement for the countries involved have not materialized (e.g. in the report of the Public Citizen Watch (PCGTW, 2014)). In this debate the agricultural and environmental sector are prominent issues due to their importance for food security and resource disposability, but also due to different standards and singularities between the countries. Furthermore, agricultural production provides over singular, economic characteristics, which is why certain scholars argue that classical economic trade theory cannot be applied to the trade of agricultural commodities (Binswanger, 2009). These singular characteristics include the limited growth potential due to limited resource of arable, fertile land, the low demand elasticity of food and the necessity of long-term investments in agriculture (Binswanger, 2009).

In particular, the agricultural sector of Mexico is often used to analyze the negative consequences of an FTA, due to the fact that the improvements that were expected to be seen in the sector when the agreement was signed are argued not to have been fulfilled. Whilst economists before the agreement expected the overall gains from trade for the

Mexican economy to be marginal, they still expected it to multiply by four with the additional capital flows that should be facilitated and encouraged by NAFTA (Ros, 1994). Ten years later, a scientific assessment on the effects of NAFTA by Puyana and Romero (2006) concludes that the net economic effect (estimated gains minus losses) of the FTA after 10 years of NAFTA on the rural sector has been between minus four and twenty percent of the 1994 levels. For small producers, the effects were even worse – their income was reduced by 22 percent (Puyana and Romero, 2006). The Center for Economic and Policy Research concludes that after 20 years of NAFTA, the employment rate in the agricultural sector went down by 19%, relating to the loss of two million jobs (Weisbrot et al., 2014). This experience of the Mexican agricultural sector is taken as an example by Binswanger (2009) in his lecture and book “Globalisierung und Landwirtschaft – Mehr Wohlstand durch weniger Freihandel”. He uses the Mexican example to underline the fact that free trade in agriculture can have negative effects on the trade balance and income of the rural population in developing countries, due to the opening up of their markets. On the other hand, the report to the World Bank stresses the positive outcomes of NAFTA, such as the decline of domestic real prices of agricultural goods, the increased imports and exports with North America and the increased yields (although only on irrigated lands) (Yunez-Naude, 2002). An issue, most scholars agree on, is that NAFTA did not stimulate US investment in the Mexican agricultural sector as it was expected (Yunez-Naude, 2002; Puyana, 2012).

Therefore, the starting point of this thesis is the question: How has the Mexican agriculture developed over the past 20 years compared with other selected Latin American (LA) countries? In evaluating this question, previous studies focused mainly on political or economic issues by comparing single parameters, such as in the report of the Center for Economic and Policy Research (Weisbrot et al., 2014) or the review article “Mexican Agriculture and NAFTA: A 20-Year Balance Sheet” of Puyana (2012). Although a variety of data-sets on these aspects have been made available by different international organizations (like the FAO and the World Bank Group), it is hard to find a sustainability assessment (SA). SAs are efficient tools to cope with complex and dynamic systems by simplifying the relevant information and therefore can give an overview over temporal and spatial developments and can help in the decision-making process. SAs are available for different issues in society, politics, economics etc. (Kumar Singh et al., 2009). For agriculture SAs are available at the national, regional and farm level (Von Wirén-Lehr, 2001). However, there is no prominent example of an international comparison of national agricultural sectors. The aim of this thesis is to assess the development of the Mexican agricultural sector using an integrative approach.

The research questions in this thesis are:

1. What is the procedural approach concerning sustainability definition, indicator selection, normalization, scaling, weighting and aggregation in peer-reviewed and widely recognized sustainability assessments, which are assess, evaluate and compare publicly available national data?

2. How can the data from different international organizations on agriculture and rural development be interpreted and evaluated in a normative and systematic way by developing a Sustainable Agriculture Index (*SAI*)?

3. How has Mexican agriculture developed throughout the past 20 years according to this quantitative SA compared to other LA countries and are the outcomes in accordance with qualitative and quantitative studies on LA agriculture?

An SA allows for an integrative view on the agricultural sector. This is necessary because agriculture influences and is mutually influenced by different aspects of the society, economy and the environment. To assess the development of the Mexican agricultural sector with an integrative approach therefore means analyzing all three dimensions of sustainability. This analysis is performed by developing a Sustainable Agriculture Index (SAI) in the form of an agri-environmental indicator-based SA, which evaluates the current situation and the ex-post development of a country's agricultural sector using data provided by the World Bank Group and the FAO. This is done by applying and combining the methodology used for different available indicator-based SAs for the international comparison of national data and the sustainability approaches of different agricultural SAs. With these indicators, a complex system such as the agricultural sector and its multiple inter-linkages to other systems can be simplified, quantified and interpreted. Individual indicators are aggregated into a single index, which is then used to compare the development of the Mexican agricultural sector to other countries in LA.

In the literature review (Chapter 2), the first question will be answered by investigating firstly how the term and concept of sustainability has evolved (Chapter 2.1), secondly, how sustainability assessments are used and calculated for issues other than agriculture focusing on the methodology and procedural approach (Chapter 2.2), thirdly, the available methodologies and sustainability definitions for sustainable agricultural development are evaluated (Chapter 2.3), and fourthly, the question of how one can approach the conception of an SA is addressed (Chapter 2.4). Afterwards, in the chapter on methodology (Chapter 3), the method for the calculation of the index is developed, applying the knowledge gained in the literature review for the development of the SAI. The following results chapter (4.1) shows and describes the results for selected LA countries when the methodology of Chapter 3 is applied, as well as the results for the sensitivity analysis (Chapter 4.2). The methodology and the results are then critically reviewed, discussed and compared to qualitative and quantitative literature on the selected countries in Chapter 5. The last chapter (6) summarizes and concludes the findings of this thesis.

2. Literature review

2.1. Sustainability

'Sustainability' and 'sustainable development' are terms that are often used, however, the interpretations of both terms are still highly disputed. This means that there is no consensus for clear-cut definitions. They are used in national, international and corporate policies, like in the Rio Declaration on Environment and Development from 1992 (UNCED, 1992), but also for different concepts, associations, organizations and product marketing. The literal meaning of the adjective "sustainable" is to be "able to be maintained at a certain rate or level" or the act of "conserving an ecological balance by avoiding depletion of natural resources" (Oxford Dictionaries, 2014). An early application of the principle of sustainability in the 19th century was in the field of forestry and fishery, both of which deal with renewable resources and hence have the capacity to grow, but may become exhausted if overharvested at a rate beyond their regeneration capacities (Perman et al., 2003). Due to the existence of a regeneration capacity of the resource base of renewable resources, it is necessary to harvest according to the principle of "sustainable yield" to maintain long-term yield capacity (Wiersum, 1995).

Often, the definition from the "Brundtland Commission" formulated in 1987 by the World Commission on Environment and Development is used.[1] Sustainable development (SD) is there described as ''development that meets the needs of the present without compromising the ability of future generations to meet their own needs'' (Brundtland et al., 1987: 27). This definition contains the same two fundamental components as the principle of sustainable yield: the concept of (present and future) needs and the limitation of the world's resources.

The early use of the terms sustainability and sustainable development in the 1970s and '80s resulted in scientific criticism. For example, Lélé (1991) published a critical review, in which he denounces the term for its vagueness and its lack of consistency. Furthermore, he states that the term is often used just as "ecological sustainability", but should also incorporate social aspects and should not be confused with economic growth. Critique like this has led to the three-dimensional concept of SD, which is

[1] The World Commission on Environment and Development is often called the Brundtland's Commission named after the Norwegian Prime Minister Gro Harlem Brundtland, who was the chair of the Commission.

widely accepted and used today. According to Mebratu (1998) in his historical and conceptual review of the paradigm, this definition of three interacting systems was established by the Institute for Environment and Development (IIED, London, UK). Therefore, from a two pillars model (environmental and development concerns) in the Brundtland report, a three-dimensional approach evolved, which separates the development issue into social and economic factors (Pope et al., 2004). The three dimensions are: ecological, social and economic sustainability. These are depicted in different ways, but the most common are:

- Venn diagram, depicting three interconnecting circles (see Figure 1a), which shows that only where all three dimensions overlap, sustainability is achieved. The area where only two of them overlap is partly sustainable (Lozano, 2008) or "viable", "equitable" and "bearable".
- Circles inside each other, where the inner circle is the economic, surrounded by the second circle, which represents the social dimension. Both are imbedded in the circle representing environmental aspects (see Figure 1b). Sometimes the circles are concentric; others depict them as nested, non-concentric circles (like in Figure 1b). This concept focuses more on the source and sink function of finite natural resources and the fact that sustainability is finding a way within this limited system (Pope et al., 2004). Therefore, it focuses more on the integrational perspective of the three dimensions (Lozano, 2008).
- Pillars (IUCN, 2006) (see Figure 1c) symbolize the fact that sustainability is based on all three dimensions equally; they are the foundations of sustainability and if one is weak, the whole system cannot be sustained. Pope et al. (2004) classify this method as another interpretation of the Venn diagram.
- There have also been other attempts at depicting the concept by creating new representations like the Two Tiered Sustainability Equilibriums, including interactions between the dimensions and over time (Lozano, 2008), which have passed widely unnoticed by the general public.

Sustainability therefore incorporates a wide range of ideas and meanings and this is why the concept is often criticized as being 'vague' (Lélé, 1991) or 'ill-defined' (Phillis and Andriantiatsaholiniaina, 2001). The critique stresses the point that the term is often used without even defining it and that there is also a problem of trade-offs between the dimensions, which means that it can always be argued that one dimension has been disregarded in favor of another. Another frequently raised criticism is that (economic) sustainable development should not be equated with economic growth, because there are biophysical and ethico-social limits to growth (Daly, 1996). The basis for key discussions on limits to growth was the eponymous report published by the Club of Rome in 1972, which simulates the development of certain parameters (like population and economic growth) and is updated regularly (Meadows et al., 1972). The paradigm of a world with limited resources, which cannot cope with exponential growth, is also the basis for the steady state economy as formulated by Herman Daly (Daly, 1996).

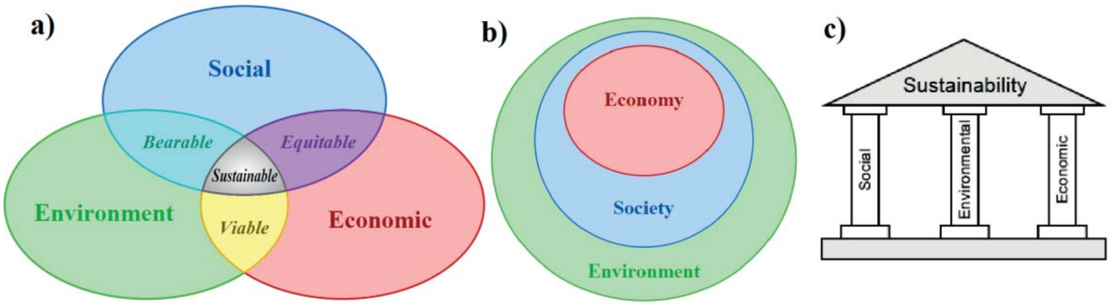


Figure 1: Representations of sustainability (a) Venn diagram, (b) Connected non-centric cycles, (c) Pillars. Source: 1a (Dréo, 2006), 1b (KTucker, 2011), 1c (Thwink.org, 2014).

Apart from that, some scholars argue that it is no more than a catch phrase (Lélé, 1991) and that a concept implying everything ends up meaning nothing (IUCN, 2006). On the other hand, one can elucidate that this room for interpretation is precisely one of the reasons for its wide acceptance (Lélé, 1991). This broad definition has enabled the use of the paradigm in different contexts and has therefore, played an important role in policy making: ‘Our common future’, 1987 and the World Summit on Sustainable Development 2009 used it in an economic and political setting for the discussion on poverty reduction and development. At the Earth Summit in Rio 1992 the global environmental change resulting from biodiversity loss and climate change was at the centre of attention (IUCN, 2006). This suggests that sustainability might be difficult to define and to operationalize in a general, meaningful and practical way, but should rather be viewed as a concept, which tends to be fuzzy until it is used in a concrete context (Pope et al., 2004). When performing an SA, an explicitly-stated definition on how sustainability is to be understood is required. Such a definition is provided in Chapter 3.1, whilst maintaining and awareness of the flaws of the concept in the interpretation and use of the results.

2.2. Sustainability assessment

According to this very broad definition of sustainability, SAs are also used in an extremely wide set of fields. SAs are seen to be efficient and reliable tools, which identify paths towards the transition to sustainability by assessing certain objectives (Ness et al., 2007). SAs are used to cope with complex and dynamic systems by simplifying the relevant information to gain an overview over temporal and spatial development. This means that the complexity of the real world is represented by a set of different measurable and quantifiable indicators and their development over time and space depicts the development of the entire complex and dynamic system. An often used definition (for example in Ness et al., (2007) and Pope et al. (2004)) concerning the general application of SAs, is the one of Devuyst et al. (2001). It states that an SA is "a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable" (Devuyst et al., 2001 in Ness et al., 2007: 499). The idea behind an SA is therefore to assess which activities or policies contribute to sustainable development (Pope et al., 2004).

Most SAs use indicators as proxy data to identify and quantify general objectives like social, ecological and economic sustainability, which are seen as the three dimensions of sustainability. Indicators are therefore mostly quantitative measures of certain objectives, which represent the state of economic, social and environmental development. For the selection of indicators, different criteria have been formulated by scholars. According to Ness et al. (2007), they should provide the following characteristics: being simple, having a wide scope, being quantifiable and being sensitive to changes, thereby allowing trends to be determined. The internal working paper of the European Environment Agency (EEA) lists (among others) the following characterizations of good indicators: they should match the interests of the target audience, be easy to interpret and be representative of the issue, as well as being scientifically well-founded and based on sound statistics (Gabrielsen and Bosch, 2003). Hayati et al. (2010) state that the key properties are that they are realistic, managerially useful and based on the sustainability paradigm. As a consequence, indicators are used to illustrate trends and phenomena by simplifying, quantifying, analyzing and communicating complicated and complex data and information (Kumar Singh et al., 2009). The selected indicators are often aggregated (by different aggregation methods, see below) resulting in composed indicators, often called indices. This simplification can lead to a loss of detail, but helps to demonstrate the overall, general development. Therefore, when selecting indicators, one has to consider the balancing act between parsimony and sufficiency. This means that the system should be as represented in as simple a way as possible (parsimony), whilst remaining as complex as necessary (sufficiency) and still representing the interactions within the system (Binder et al., 2010).

Indicators are chosen according to the goals and scope of an SA and therefore can vary substantially. Still an indicator by itself does not allow judgments on the sustainability of a system “unless a reference value such as a threshold is given to it” (Lancker and Nijkamp, 2000: 114). The reference value can be given on the one hand by an absolute evaluation, where validation is based on the comparison with predefined thresholds or tolerance ranges, which are set by estimation, scientific deduction (e.g. expert interviews or critical loads) (Von Wirén-Lehr, 2001) or stakeholder involvement (Binder et al., 2010). On the other hand, a relative approach can be applied, which is used for the comparison of different systems. This means that there are no margins of tolerance or thresholds defined, but the values of one system are compared, for example, to the mean or the range of the other systems with normalized point scores (e.g. between 0 and 10) (Hayati et al., 2010).

Concerning the scaling or normalization of the indicator, there are different approaches available. Mostly a certain range for the scale is defined (e.g. between 0 and 1 as for the Human Development Index (HDI), or 0 and 10 as for the Sustainable Society Index (SSI) and the Environmental Quality Index) (Kumar Singh et al., 2009)). There can also be non-numerical evaluations, such as presented by Lancker and Nijkamp (2000). These authors introduce a flag-model, where green means “no concern” and black “stop further growth”. Also for the aggregation of the indicators into one index different methods are available. Saisana and Tarantola (2002) identify six different approaches for aggregation in their report on composed indicators. The most common ones are aggregation by taking the sum or taking the (geometric, arithmetic or weighted) average (Kumar Singh et al., 2009). When aggregating, most of the 41 SAs analyzed in Kumar Singh et al. (2009) use equal weighting, which means that when aggregating the indicators into one index, every individual indicator contributes equally. Other SAs apply unequal weights, which are derived through Analytic Hierarchy Processes or by stakeholder involvement, like expert estimations, public polls or user choices. Critical assumptions within the methodology of the SA can be tested with an uncertainty and sensitivity analysis (Saisana et al., 2005). These can help in identifying the uncertainties of the model and give useful insights into the quality, reliability and robustness of the results. In a sensitivity analysis, the critical inputs are varied to investigate the influence on the output. Such critical inputs are for example the contribution of an activity to the objective or the constraining limit (Pannell, 1997).

SA can be found in nearly every field of policy-making, from international development (e.g. HDI) and ecology (e.g. Ecological footprint) to economic indicators on investment and asset management (e.g. Dow Jones sustainability group indices) or product-based Indices (e.g. Life Cycle Index) (Kumar Singh et al., 2009). For this reason, several publications have tried to categorize, compare and evaluate the different approaches of the various SAs. Ness et al. (2007) for example group the different SAs according to their characteristics (ex-post/descriptive or ex-ante/change-oriented), their coverage areas (e.g. product level or policy change) and whether they integrate nature-society systems, hence including all three dimensions of sustainability. With this categorization Ness et al. (2007) define three different areas of SAs: (i) Indicators and Indices, which can be either integrated or non-integrated, (which relates to whether or not the nature-society parameters have been aggregated); (ii) product-related; (iii) integrated assessments, which consist of a collection of tools focusing on policy implementation or change. Another categorization and comparison is achieved by Kumar Singh et al. (2009), who analyze the procedural dimension of 41 different SAs. In doing so, they distinguish between the different methods of normalization, weighting and aggregation of the parameters for each of the indices.

SA approaches can also be defined through their breadth and depth of their analysis. This means that they can be distinguished by their field of application. They are applied in different scopes defined by their system boundaries (e.g. national, regional, product level), which in turn describes their breadth. Furthermore, they are applied to different mechanisms along the chain of environmental effects and have different degrees of quantification; this defines their depth (Hertwich et al., 1997). Between breadth and depth there is a clear trade-off when there are limited resources for the realization of the SA available. Therefore, SAs have to succeed in managing the balancing act between simplicity and complexity, which means being as simple as possible, without losing important information.

SA approaches range from very popular and accepted ones, like the HDI of the United Nations, or Life Cycle Assessments (LCAs) to rather unknown ones, used only in niche fields. The HDI, for example, is often used to compare the development status between countries. It not only takes into account a country’s economic wealth (measured in GDP or GDI per capita), but also life-expectancy and literacy rates. The

HDI compares annual data using the globally observed maximum and minimum values, which are set according to literature (Klugman et al., 2011). The maximum is called the satiation point, beyond which additional increases do not lead to an augment of capabilities and the minimum is the subsistence minimum. In the case of the economic value for example, the minimum is set by taking the lowest value ever observed (Klugman et al., 2011).

A similar, but much broader approach is the Sustainable Society Index, which sets thresholds for different aspects of society and compares national data (Van de Kerk and Manuel, 2008). Both have in common the fact that they regularly review their methods and assumptions by taking into account external reviews and pronounced criticism. The HDI, for example, changed its methodology several times, each time giving detailed explanation for the reasons behind these changes (see Klugman et al. (2011)). The SSI was reviewed by the Joint Research Centre of the European Commission, which also instigated changes in the calculations (see Saisana and Philippas (2012)). Other SAs are very narrow in their application or were developed for a very specific application, such as the index for the "Relative intensity of regional problems in the Community" by the European Commission. They address a single, very specific problem, show problematic areas for improvement and can stimulate policies to improve the situation. Such indices vary widely with regard to their spatial applications, ranging from small-scaled approaches to global applications. Some SAs use an integrated approach taking into account all three dimensions of sustainability. However, Kumar Singh et al. (2009) state that in most of the cases they just focus on one of the three dimensions.

Due to this variety of SAs, the decision of which to choose for a particular assessment can be difficult, especially as this choice can influence the outcome of analysis due to the different assumptions and methods used by each SA. The assumptions used for normalizing, aggregating and weighting need to be stated explicitly and have to be in accordance with the objective of the SA. If tested in a sensitivity analysis, the results become more robust and understandable. This makes the results reproducible and shows how the single indicators contribute to the result (Kumar Singh et al., 2009). This enables and enhances the application and interpretation of the result. The goals and objectives of an SA determine the choice of methods. As a result, the choice of which procedural approach to utilize and assessment of which will produce a useful and robust result is closely connected with the aims of the research question. The appraisal criteria for the usefulness of an SA and its applicability for the end users are, therefore, its method conception, the consistency between indicator values and observed values and the suitability of the indicator in respect to the goals (Payraudeau and Van der Werf, 2005).

2.3. Sustainability assessment in agriculture

As agricultural productivity highly depends on natural conditions like soil fertility, there is a strong interest in sustaining this natural capital in the long-term. Furthermore, especially in developing countries a considerable share of the population is employed in agriculture and as a consequence, it is an important contribution to the economy and an important part of the society. The definition of sustainability from the Food and Agricultural Organization (FAO) of the United Nations includes all these aspects and define SD as

> "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development […] conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (FAO Council, 1988 in: (Hardaker, 1997)).

Derived from this definition, the criteria of the FAO for agriculture to be sustainable are that it meets the basic nutritional conditions for present and future generations, that it provides for long-lasting employment possibilities and generates sufficient income, working conditions and living conditions for people employed in agriculture and that it reduces the vulnerability of the agricultural sector (Hardaker, 1997).

The FAO in 2012 made available a framework for a Sustainability Assessment of Food and Agriculture Systems (SAFA tool). This approach provides a tool for the evaluation of supply chains and enterprises by assessing 116 indicators to achieve the overarching four different dimensions (good governance, environmental integrity, economic resilience and social well-being) (FAO, 2014). The SAFA tool differs from other SAs due to its systemic approach – including the nature-society interaction – which considers indicators of four dimensions and hence uses a holistic approach. In contrast to the SAFA tool, most SAs in the field of agriculture focus on the ecological or environmental components due to the necessity of avoiding negative impacts and due to the dependence on natural and environmental circumstances. In particular, SAs at high spatial and organizational resolution such as at the farm or field level (in contrast to the sectoral, regional or national level) very often focus on the ecological dimension only. Van der Werf and Petit (2002), for example, compare and analyze 12 indicator-based assessment methods at the farm level, of which seven only consider environmental impacts, five also economic issues and only two assess all three components, with the inclusion of social sustainability. This imbalance in (agricultural) SAs, which favors the ecological dimension of sustainability, has been criticized from various sides (e.g. Binder et al., 2010). On the contrary, considering policy making, Wei et al. (2009) argue that in the past there has been an overemphasis on social and economic components due to the importance of the agricultural sector for employment and the economy,[2] which is why an integrated view on all three dimensions is needed.

SAs that have a higher resolution, such as those at the farm or field level, focus mostly on improving farming techniques on this smaller scale and often target farmers as their user group. Concerning the spatial dimension, there are also SAs developed for regional and national scales (Von Wirén-Lehr, 2001). Authors of such SAs can be scientific institutes or individual scientists as well as international organizations (like the EU or the FAO). For SAs that have a bigger spatial scale, such as those at the sectorial level, the target group can range from policy-makers to farmers, researchers, farmer advisors and students (Van der Werf and Petit, 2002).

Within the different spatial scales there are a variety of SAs available. This is why the articles from Van der Werf and Petit (2002) (12 indicator-based SAs on farm levels), Binder et al. (2010) (seven integrative SA methods on regional and farm level) or Paydraudeau and Van der Werf (2005) (six main types of methods for farming regions) compare the available agricultural SAs and methodologies along pre-defined criteria, such as the normative, systemic or procedural approaches. They also compare the indicators and give an overview on the choice of indicator and how these indicators contribute to sustainability. Paydraudeau and Van der Werf (2005) differentiate between six types of regional SAs. There are, for example, standardized approaches like Environmental Impact Assessments (EIA) or LCAs, which follow a strict scheme, defined by ISO norms or legislation, and non-standardized approaches like agro-environmental indicators (AEI), which have the advantage of being able to adapt to the specific context of the problem or use of the SA. While other types can also be indicator-based, Paydraudeau and Van der Werf (2005) classify AEI as a separate category, due to the specific conceptual framework they provide for a set of indicators

[2] Worldwide agriculture contributes 24% to the GDP and offers employment for 22% of the world's population (Wei et al., 2009).

and the variety of different indicators, which can be included for this type of SA. A critical and often scrutinized issue in agricultural SAs is the choice of either cause- or effect-based indicators, particularly as the relationship between different indicators is highly complex in the ecological dimension due to natural mechanisms. This means that environmental impacts (e.g. groundwater quality depletion), although often closely related, might differ from a direct correlation to particular agricultural production practices (e.g. fertilization levels) due to natural factors (e.g. soil type, precipitation). Therefore, according to Van der Werf and Petit (2002), an indicator like "Nitrogen fertilizer input" would be a "means-based indicator," while "nitrate lost to groundwater" would be an "effect-based indicator".[3] The clear advantage of effect-based indicators is the closer linkage between indicator and environmental objective, but the data collection of effect-based indicators is more difficult and therefore more time-intensive and costly. Therefore, the trade-off is between feasibility and environmental relevance (Payraudeau and Van der Werf, 2005). The choice also depends on the goal and scope definition and the intended users of the SA.

2.4. Scheme for the conception of an SA

Von Wirén-Lehr (2001) elaborates a scheme for the process of establishing a sustainability assessment, which is depicted in Figure 2. The fundamental basis for any SA is the goal and scope definition, which has to be made at the beginning and will influence all later steps. For the goal definition, a specific sustainability definition has to be formulated, which condenses the holistic sustainability perception into specific targets and concerned systems and narrows down the definitions on specific principles. The scope of an SA can be defined along three basic dimensions, which are depicted in Table 1 (Von Wirén-Lehr, 2001). Firstly, the normative dimension, which covers the ecological, economic and social dimensions of sustainability and establishes whether the assessment focuses on a single dimension or is multidimensional. Secondly, the spatial dimension differentiates between the conforming levels of local (indicators at field or farm level), regional (characterizing landscapes), national and international scale. Thirdly, the temporal dimension can be established, which indicates whether the

[3] This relationship was also formulated as the Pressure-State-Response (PSR) model by the OECD in 1991 and then reformulated as DPSIR (Driving force-P-S-Impact-R) model, which then acted as the main framework for the European Environment Agency (EEA) assessments (Gabrielsen and Bosch, 2003). Sometimes it is also referred to as pressure vs. state indicators, emissions vs. impact indicators (Payraudeau and Van der Werf, 2005). In this thesis the categories means- and effect-based as nominated by Van der Werf and Petit (2002) are used.

analysis is short-term (several days to weeks) or long term (covering some years and longer), and also whether it assesses the development ex-post or ex-ante (Bockstaller et al., 2008).

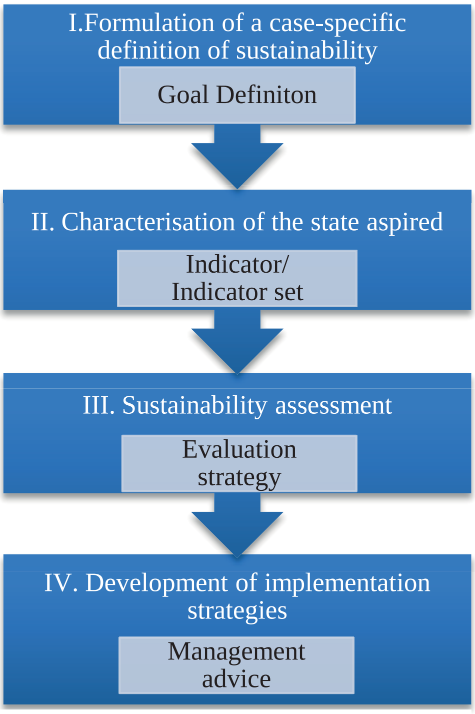


Figure 2: Four-step strategy to assess and implement sustainability in agriculture. Source: Von Wirén-Lehr, 2001.

With this first step of goal and scope definition completed, the system and its boundaries are determined. This then influences the following step of the indicator definition. This boundary definition means that for an indicator-based SA to be useful, three issues have to be considered: the underlying sustainability concept matching the specific targets and problems of the agricultural sector, the goal set and the assessment type (Binder et al., 2010). With respect to the second step, indicators serve to quantify information by aggregation and therefore are able to integrate and simplify the complex information contained within the real system into a single number. The criteria for the selection of indicators have been described in the previous sub-chapters 2.2 and 2.3.

Table 1: Basic dimensions and conforming levels of goal-oriented conceptual approaches to assess and implement sustainability in agriculture. Source: Von Wirén-Lehr, 2001.

Dimensions	Levels
Normative	Ecological aspects Economic aspects Social aspects
Spatial	Local Regional National
Temporal	Long-term Short-term

A crucial, and particularly intricate, step within the conception of an SA according to Von Wirén-Lehr (2001) is the evaluation strategy, which uncovers the sustainability of the system assessed. Based on the previous definitions of the goals, which describe the desirable state or reference system, the evaluation is performed either by an absolute or relative strategy (see definition in the previous sub-chapters). The final assessment of the actual condition can then be assessed either by single indicators or by aggregated indices. Single indicators only provide information on specific parts of the system and therefore elucidate critical points of the system, but do not reflect the complex relations between the subsystems (Saisana and Tarantola, 2002). Composed indicators or indices evaluate the system as a whole by weighting and aggregating single indicators in order to show the full picture. It is possible that composed indicators may send misleading and simplified policy message. Therefore, in order to make a valuable judgment, the assumptions and underlying decisions concerning aggregation, weighting and scaling should be taken into account so that the potential shortcomings of composed indicators or indices can be overcome when the results are analyzed (Saisana and Tarantola, 2002). To exploit the advantages of both approaches, one can look at both the single indicators for the identification of critical points and at the composed indicators for the bigger picture.

The final outcome of the SA as a last step should result in management- or policy-advice and the interpretation of the results for practical application. This can be in the form of the identification of critical points or hot spots, which differ considerably from the desired state, and which therefore should be improved to increase the overall sustainability. It can also be expressed by identifying alternative options or management strategies, which will increase the overall performance (Von Wirén-Lehr, 2001).

The literature review described different methodologies for the conception and development of an SA. Furthermore, it showed different definitions of sustainability as well as outlining criticisms, which identify the shortcomings of the definitions and concept. For the concrete conceptualization of the SA developed in this thesis, the categorizations of SAs as done by Ness et al. (2007) or Payraudeau and Van der Werf (2005) give guidance for the definition and description of the SA. Different procedural approaches and calculation methods as described by Saisana and Tarantola (2002), Von Wirén-Lehr (2001) and Hayati et al. (2010), combined with concrete examples of already existing, renowned and peer-reviewed non-agricultural SAs (like the SSI or HDI) indicate possibilities for the calculation of the indicators. The experiences of agricultural SAs on different spatial and temporal scales show examples of possible methods of indicator selection as well as choices of sustainability definition. The literature review consequently builds the basis for the conception of the SA, which is done in the following Chapter 3, using the scheme from Von Wirén-Lehr (2001) as described in this sub-chapter. The first three steps of this conception scheme (see Figure 2) will be elaborated in the following chapter, while the forth step of the interpretation of results and management and policy advice is performed in chapters 5 and 6.

3. Methodology

3.1. Goal and scope definition

The objective of the SA in this thesis is to establish how Mexican agriculture has developed over the last 20 years compared with other LA countries. Therefore, the scope is the comparison of publicly available, national data of different countries, which are assessed and provided by renowned, international organizations like the Food and Agricultural Organization (FAO) or the World Bank.

For this comparison the approach of AEI as defined by Payraudeau and Van der Werf (2005) is chosen, due to its flexibility of a non-standardized SA, the free choice of indicators and its ability to consider all three dimensions of sustainability in an equal way. The consideration of all three sustainability dimensions in an equal and non-substitutive manner according to the Venn diagram depiction of sustainability (Figure 1a) is the basis for this SA. Therefore, the approach of an integrated index (as defined by Ness et al. (2007)) concerning all three dimensions of sustainability is adopted, whereby a normalized point score system is assigned between 0, which represents total unsustainable development, and 10, where a sustainable state is reached. By developing a defined and bundled set of indicators, critical issues and hot-spots can be identified, which help to identify areas of concerns, where the situation differs considerably from the desired state and from the other countries. The aggregation into a single *SAI* enables the overall performance of the Mexican agriculture to be compared to other LA countries. To enable a sound interpretation of the results, all assumptions are stated explicitly and critique on the sustainability concept (as discussed in Chapter 2.1.) is taken into account.

The sustainability definition used for this SA is the one of the FAO (see Chapter 2.3) and follows an integrative view on sustainability according to the Venn diagram. As stated in this definition, desired development in the sense of sustainable agriculture is the conservation and management of natural resources, such that they are conserved for future generations. In terms of the ecological dimension, the long-term effects of the degradation of the natural capital stock (for example soil fertility, clean air or water) must be evaluated. This implies a minimization of those external inputs that have negative effects on the environment. Furthermore, it means that the natural capital stock has to be maintained and agriculture should not be responsible for its depletion or intensive use. As the SA uses an integrative approach, interactions with the other dimensions are to be taken into account.

The economic dimension measures production, productivity, profitability and stability of farming activities (Zhen, 2003). This means that for an agricultural system to be sustainable, it has to be productive and contribute to the national income. According to an integral view on sustainability, value generated through agriculture also means the creation of income and capabilities for the rural population. Therefore, increasing productivity contributes positively to economic sustainability. For sustainable development, an efficient use of the available resources is required, which is why output is compared to input. Still, there are trade-offs between production and other fields of sustainability. With increasing productivity, the marginal benefits on economic sustainability are decreasing due to the marginal costs from the deteriorating social and natural system. This is due to the fact that maximization of production is often comes at the expense of soil fertility or ecologically non-sustainable practices.

Concerning the social dimension, agricultural production has to be socially acceptable, must provide good living conditions for the rural population and aims at maintaining rural communities and agricultural production areas. Therefore, the quality of life of farmers and in general in rural areas is important for the well-being of present and future generation. This is expressed in the availability of basic needs and livable conditions in rural areas.

3.2. Indicator selection

In order to select indicators appropriate for the assessment, one has to define criteria for this choice. This selection will influence the result of the SA and therefore is a crucial and sensitive step in the assessment. The criteria used in this SA are that indicators and the respective data selected have to be:

- **Relevant** in the sense that the indicators represent the objectives of sustainability, correspond to the definition of sustainability and as an asset are commonly used in other agricultural SAs.
- **Measureable**, meaning that the indicators are to be assessed in quantitative terms and that there can be thresholds and correlations for sustainability assigned, which require that there is a clear positive or negative correlation with sustainability.

- **Comparable**. Data has to be available in comparable units, such as per ha, per worker or as a percentage of the total, in order to have a valid comparison among different countries, which may differ in their size and importance of their agricultural production.
- **Available**. Data eligible has to be publicly available for a wide range of countries and over a sufficient long period of time and should be regularly updated.
- **Reliable**. The selected data has to be ascertained by a renowned international organization or institution equipped with appropriate knowledge and tools for the data acquisition.
- **Balanced**. Equal attention shall be given to all three dimensions of sustainability.

The set of indicators shall therefore cover a wide range of aspects and shall represent the complex system of agricultural production. It shall allow for the comparison of the different countries, albeit limited to the data that is publicly available. The selection should be as simple as possible (parsimony), and as complex as necessary (sufficiency), representing the interactions within the system, which will be considered in the analysis (Binder et al., 2010).

The indicators in Table 2 have been chosen from the “World Development Indicators” from the World Bank in the category “Agriculture & Rural Development” (World Bank Group, 2015) by selecting the ones fitting the criteria as defined above. Furthermore, the data from the Statistic Division of the FAO have also been used (FAOStat, 2015) to complement and balance the indicators according to the three dimensions of sustainability. The data was downloaded on March 29, 2015 for all data sets used for the calculations.

Table 2: Indicator set and their rationale. Source: Own Depiction.

Data name (abbr.)	Unit	Indicator for	Rationale
Economic Dimension			
Agriculture value added per worker (*vad*)	US$ (constant 2005)	Agricultural Productivity	Creates income and capabilities for the rural population; indicates efficiency of production
Cereal yield (*yld*)	kg/ha		
Agricultural machinery (tractors) (*trac*)	Tractors/100 km^2 of arable land	Agricultural Investment	Increases efficiency and facilitates work; decreases work load for the farmers
Social Dimension			
Rural poverty headcount ratio at national poverty lines (*pov*)	% of rural population	Rural Poverty	Improves quality of life and increases living conditions in rural areas, when poverty is eradicated
Improved water source, rural (*wax*)	% of rural population with access	Access to basic infrastructure in rural areas	Contributes to health and quality of life in rural areas; increases living conditions
Ecological Dimension			
Nitrogen Consumption arable and permanent crop area (*nin*)	kg N/ha	Agri-environmental Input	Indicates pressure on natural environment and industrialization of agricultural production although dependent on local production conditions
Pesticides use on arable and permanent crop area (*pin*)	kg/ha		
Water withdrawal for agricultural use (*wwi*)	% of total water withdrawal	Water usage	Indicates pressure on and depletion of water resources

3.3. Evaluation strategy

3.3.1. Categorization into dimensions of sustainability

For the SA, the indicators chosen are attributed to one of the three dimensions of sustainability (see Table 2). This categorization is sometimes difficult due to the complex interactions within the system and as a result, the indicators may cover aspects of more than one dimension. For example for rural poverty, it could be argued that it is also an economic issue and not a purely social one. In this case, the indicators are put into the dimension where they fit best and to which they contribute more than to any other dimension. This is coherent with the indicator selection and categorization done in other agricultural SAs, which are described in the literature review in Chapter 2, especially in 2.3 on agricultural SAs.

3.3.2. Normalization

For the assignment of the normalized point score, normalization has to be undertaken. In this SA, a point score between zero and ten is assigned, where zero signifies an entirely unsustainable state, while at ten sustainable development is reached. The score is given with one decimal place. To calculate the score, thresholds are defined, which determine the desired and undesired state. The distance from to these values (which is assigned with zero and ten) defines the score. It follows the distance-to-target calculation method 6 of Saisana and Tarantola (2002), which compares the particular value to the range of all the values of the same indicator.

Whether the values contribute positively (the higher the values, the higher the score) or negatively (the lower the value, the higher the score),[4] is defined according to literature (e.g. from Paydraudeau and Van der Werf (2005), who compare different agricultural SAs) or are defined according to the sustainability definition. For example, zero percent of people being poor is more sustainable than one hundred percent being below the poverty line, because less poverty increases living conditions and is socially more viable, in accordance with the definition of social sustainability in the goal and scope definition.

For the determination of the desired state or sustainability value, there are different methods used. For the economic parameters, which are given in monetary values (e.g. in US$), a relative approach is used, because money has a relative value, which can be assumed to be equal throughout the world due to globalization. The purchasing power within the countries might differ, but on the world market it is even. Therefore, as all the values are given in the same unit or currency, one can compare the value of one country to the values of all countries worldwide. The methodology for the calculation is derived from the Human Development Index. There, the minimum value is set according to the all-time minimum, while the maximum shifts according to the observed maximum. This enables the comparison over time as to how much the productivity has increased compared with the worldwide increase and whether the increase in productivity in one country has allowed for the closing of the gap between that country and the most productive countries.

The social indicators consists of percentages, where a relative approach is taken, with an absolute goal (e.g. 0% poverty), and the other end of the range also varies according to observed maxima or minima. This calculation methodology for social and economic indicators allows for a comparison of overall development worldwide. For indicators

[4] Lancker and Nijkamp (2000) differentiate between "good" and "bad" indicators, while Payraudeau and Van der Werf (2005) differ between values to be maximized, minimized or optimized.

like value added or water access, which in absolute terms are increasing for the vast majority of countries, this methodology enables the evaluation as to whether this increase is bigger or lower relative to worldwide development.

For the evaluation of the ecological indicators an absolute approach is taken, because for natural systems there are thresholds, which should not be exceeded. Furthermore, a relative approach would mean that increased inputs are justified and become more sustainable just because there are other countries which are performing even worse. Therefore, for the input indicators the threshold values are set according to literature values and adopted to fit the goals of this SA and in the last resort assessed by qualified assumptions.

The correlation between the minimum and maximum, which means whether there is a linear, logarithmic or quadratic correlation between the two thresholds, is adopted according to the nature of the indicators and how their magnitudes contribute to sustainability as defined in the goal and scope definition in Chapter 3.1. According to an integrative view on sustainability, interactions with other dimensions are also considered. For example, for economic indicators, marginal benefits of income are assumed in accordance with the sustainability definition in Chapter 3.1, which is derived from the marginal utility of income and the diminishing returns in the conversion of income into capabilities (Klugman et al., 2011). Therefore, for those indicators having a non-linear correlation, either a logarithmic or a quadratic function is assumed for the correlation between the minimum and maximum value. For logarithmic calculations, the natural logarithm is used in order to enhance familiarity with economic literature. Furthermore, Klugman et al. (2011) have found that there is no significant difference to the results derived from using a decimal or a natural logarithm. Due to the negative outcome when taking the logarithm of values between zero and one and the non-defined result of the logarithm of zero, for values smaller than one, a linear correlation is assumed.[5]

3.3.3. Sensitivity Analysis

A sensitivity analysis is performed for critical assumptions made in the model development, meaning that with this analysis, the 'decision variables' are reviewed. These are those variables over which the model developer has control over and where

[5] This is only relevant for the Indicator "Agricultural machinery", because the value added and the cereal yield is always bigger than one.

an optimal level has to be established with regards to the model framework (Pannell, 1997). Decision variables concerning the normalization are for example optimal, minimum or maximum values. Another critical assumption to be tested is the aggregation and weighting, as there are different options for this step, which can be tested against each other (Saisana et al., 2005).

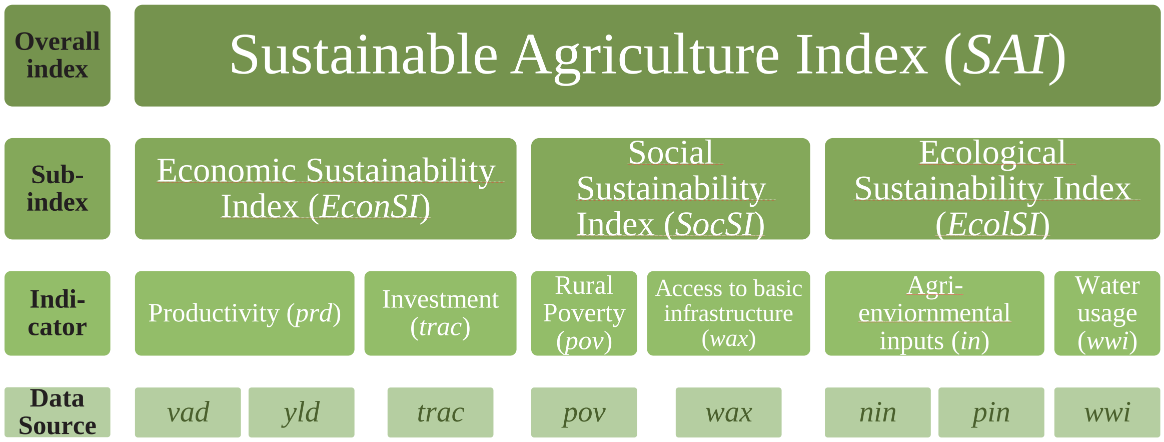
The basic principle of a sensitivity analysis is to change the decision variable and observe how it changes the output of the model. One of the easiest ways to depict this change is to work with elasticities, whereby the percentage change in the decision variable is compared with the change in the output value and a resulting elasticity value below one is inelastic and above one is elastic (Pannell, 1997). In this SA, in addition to the elasticities and percentage changes, the change in absolute point scores is also analyzed. Changes in absolute point scores, which are smaller than 0.3, are assumed 'negligible', smaller than 0.6 are 'small' changes, smaller than 1.0 'acceptable' changes and everything above are 'major changes', which have to be analyzed in more detail.

3.3.4. Aggregation and Weighting

Composed indicators are those indicators, where more than one data set contributes to one indicator. This is the case for agricultural productivity, where both the 'Cereal yield' and the 'Value added per worker' form the composed indicator productivity, but also for the agri-environmental inputs, where two aspects of the same indicator are taken into account (see Table 2 and Figure 3). This is done because each of the data sets depicts a different aspect of the same indicator. For example, value added can be influenced by the worldwide commodity prices for agricultural goods and yield may be influenced by climatic conditions. The average of both, therefore, includes both aspects and better depicts the situation of agricultural productivity. In this case, the geometric mean of the two normalized scores is the score for the composed indicator.

In Figure 3, one can see how the single data sets form the composed indicators (*prd* and *in*) and the (Sub-)Indices. For the aggregation into the three sub-indices (see Formula 2a (Economic Index), 2b (Social Index) and 2c (Ecological Index)) and the overall national score (see Formula 1 for the Sustainable Agriculture Index), all underlying indicators are equally considered, which means that there is an equal weighting. When there are missing data for one country (for the values of the data sets see Appendix A Table 1), the normalized scores of the other underlying indicators form the index (for the normalization scheme and calculation method see Appendix A Table

4). To monitor the influence of data gaps, a separate calculation scheme calculates with estimated point scores. The estimates are the same scores as of the previous or following period of the respective countries (average between predecessor and successor if both are available). For those countries, where there is no data available for none of the time periods, the average of all other countries for this indicator is taken.



Note: For an explanation of abbreviations see Table 2.

Figure 3: Aggregation scheme: The eight data sources form six indicators, which are aggregated to the three sub-indices, representing the three dimensions of sustainability. The overall Sustainable Agriculture Index (*SAI*) is formed aggregating all six indicators. Source: Own depiction.

For the aggregation, the geometrical mean of the underlying indicator scores is used (see Formulas 1 and 2a-c), which is a common method for SAs. Both, the HDI (see Klugman et al. (2011)) and the SSI (see Saisana and Philippas (2012)) changed recently (in 2010 and 2012 respectively) from the arithmetic mean to the geometric mean, due to a review of their methods. The geometric mean is used because it inhibits substitutability between the indicators. This substitutability is a frequently raised criticism (see Chapter 2.1 on sustainability) and should be avoided when using the sustainability concept depicted by the Venn diagram. Nevertheless, a sensitivity analysis is performed to monitor the influence of the aggregation method.

All calculations of normalization, aggregation and weighting, as well as the sensitivity analysis were done with Microsoft Office Excel 2007 using data downloaded on March 29, 2015 from FAOStat (2015) and the World Bank Group (2015).

$$(1)\ H_{SAI} = f(prd, trac, pov, wax, in, wwi);$$

$$H_{SAI} = \sqrt[n]{H_{prd} * H_{trac} * \mathrm{H}_{pov} * H_{wax} * H_{in} * H_{wwi}}$$

$$(2a)\ H_{EconSI} = f(prd, trac);\ H_{EconSI} = \sqrt[2]{H_{prd} * H_{trac}}$$

$$(2b)\ H_{SocSI} = f(pov, wax);\ H_{SocSI} = \sqrt[2]{\mathrm{H}_{pov} * \mathrm{H}_{wax}}$$

$$(2c)\ H_{EcolSI} = f(in, wwi);\ H_{EcolSI} = \sqrt[2]{H_{in} * H_{wwi}}$$

3.3.5. Temporal and Spatial Comparison

The temporal comparison is going to be made between three different time periods. As the available data are sometimes fragmented and the data of one year can be an outlier of the general trend, the arithmetic mean of the previous and subsequent years is used. The first period assessed is 1994 (average of 1993 to 1995), the second one is 2003 (average of 2002 to 2004) and the third is the most recent data available for Mexico (average of the most recent year and the previous year) called '2015' in the tables for reasons of simplicity.[6] For the data of water input, the time slots used are different due to the lack of available data for 2003 and 1994.[7]

Regarding the spatial comparison, the data from Mexico is compared to other LA countries,[8] which showed a similar economic structure in 1994. To define a finite group of countries for the comparison, the data of four economic parameters (data from the World Bank Development Indicators) in 1994 (average 1993 till 1995) are analyzed. Those LA countries having similar values (+/– 20% of the Mexican value, see Table 3) in two or more parameters are selected. The countries determined with this methodology are: Brazil (1, 2 and 4), Colombia (2 and 3), Cuba (3 and 4) and Panama (1, 3 and 4), where the numbers in brackets represent the parameters they have in common with Mexico.

Table 3: Economic parameters for the selection of Latin American countries for the comparison. Source: Own Depiction. Data: World Bank Group, 2015.

Economic Parameter	Mexico (average 93-95)	Range (+/–)
(1) Agricultural machinery (tractors per 100 sq. km of arable land)	119	24
(2) Cereal yield (kg per hectare)	2559	512
(3) Agriculture value added per worker (constant 2005 US$)	2732	546
(4) Employment in agriculture (% of total employment)	25	5

3.4. Indicator Sets

This chapter describes the single data sets that are used as indicators, explains why they have been chosen, as well as the rationale behind the calculation of their

[6] For *vad*, *yld* and *pov* 2013, for *wax* 2012, for *nin* and *pin* 2010, for *wwi* 2009 and for *trac* 2007 is the most recent year available (see also Appendix A Table 2).
[7] *Wwi* uses the years 1995-1996, 2000-2002 and 2007-2009.
[8] There are different definitions for LA or Latin American and Caribbean (LAC) countries. Here all sovereign states (therefore, excluding for example Puerto Rico), where Spanish or Portuguese is an official language according to the data on languages of CIA world factbook (CIA, 2015), are taken into consideration.

normalization. The overview of the calculation basis of all indicators can be found in Table 4 at the end of this chapter and in more detail in Table 4 of Appendix A.

3.4.1. Agricultural Productivity

The agricultural productivity (*prd*) measures the ratio of outputs per unit of input. In this analysis, this value is measured by the parameter of agricultural value added per worker (*vad*) and by the cereal yield per hectare (*yld*)(see Formula 3). In the former, the unit of input is the workforce of one worker in agriculture. Value added in agriculture results from the output of the primary sector (forestry, hunting, fishing, crop and livestock) subtracted by the value of intermediate inputs in US-dollars (constant 2005) (World Bank Group, 2015). In the latter data set, the input is the harvested land, while the output is cereal yield measured as kilograms per hectare. The data defines "cereals" as crops harvested for dry grain (therefore not including crops for hay or harvested green for food, feed, silage, or grazing), which includes wheat, rice, maize, barley, oats, rye, millet, sorghum, buckwheat, and mixed grains (World Bank Group, 2015). The data on cereals is used because cereals are produced and consumed constituting staple food in most countries (albeit to varying extents).

The two parameters measure different aspects of agricultural productivity. *Vad*, as a mere monetary value, is an indicator for the contribution of agriculture to the general national income and the value created by agriculture. As it is measured per worker, it indirectly reflects the income of the workers in the agricultural sector, although it does not say anything about the distribution of this value added among the people working in agriculture. *Yld* on the other hand – especially if compared internationally – indicates the intensity of the production and the productive capacity of the land. It may be influenced by the natural fertility or climatic conditions of the cultivated land, as well as by the knowledge and management skills of farmers, and by external inputs to increase the yield such as agri-industrial measures of fertilization, pesticide-input or technological input (Hayati et al., 2010).

According to the sustainability definition, increased value added and increased yield contributes positively to economic sustainability, but the correlation is assumed to be natural logarithmic due to the diminishing gross marginal benefits of increasing output or income. This assumption of declining marginal benefits is applied by several SA approaches for the evaluation of income generation and value added. The HDI and the SSI calculate the GNI and the GDP, which is comparable to the Value added, because all three describe the per capita (gross) value added – one of the primary sector, the other two of the entire economy. The HDI and the SSI both calculate the evaluation of the GNI and the GDP per capita with a natural logarithmic function and a negative exponential function respectively, therefore, both assuming decreasing marginal benefits.

The calculation method (see Formula 4a and 4b) for the assessment is based on the calculation of the HDI. As a very prominent SA, the methodology has been re-evaluated and adopted several times due to calculation flaws and as a reaction to diverse criticism, which is why the calculation method is regarded as reliable today. The most recent change was in 2010, when the calculation method for the GNI per capita was switched to a fixed minimum,[9] representing a "subsistence minimum" and a floating maximum which corresponds to the observed maximum (for further explication see (Klugman et al., 2011)). The fixed subsistence minimum is attained by taking the all-time minimum since 1994, which in the case of *vad* is the one of Djibouti in the year 2000 with 81 $ (constant 2005). For *yld*, it is 110 kg/ha cereal yield of Capo Verde in 2007.[10] The maximum is the observed maximum, which for the respective years can be found in Appendix A Table 2. Having a fixed minimum and a floating maximum enables the comparison of the increase in productivity between countries, and the evaluation of whether a country's increase could manage to close the gap between itself and the best-performing country.

$$(3)\ H_{prd} = \sqrt[2]{H_{vad} * H_{yld}}$$

$$(4a)\ \ H_{vad} = \frac{\ln(vad) - \ln(vad_{\min})}{\ln(vad_{\max}) - \ln(vad_{\min})} * 10$$

$$(4b)\ H_{yld} = \frac{\ln(yld) - \ln(yld_{\min})}{\ln(yld_{\max}) - \ln(yld_{\min})} * 10$$

3.4.2. Agricultural Investment

Agricultural investment can be expressed in different measures – from know-how generation through investment in agricultural research institutions, to input related investments in irrigation infrastructure or agricultural machinery. As investment in know-how is difficult to measure in quantitative terms and the necessity and

[9] Until 2010, the living standard was measured real GDP per capita and then changed to GNI per capita (Klugman et al., 2011).

[10] The assumption that the subsistence level is the minimum observed can be justified by the fact that although levels were that low, agriculture was still sustained in the following years in these countries and they could increase their output in the subsequent years.

effectiveness of irrigation techniques differs very much according to climatic conditions, a more robust parameter is to measure agricultural machinery. Here it is indicated by “Agricultural machinery, tractors per 100 sq. km of arable land” (*trac*). Especially, for non-industrialized countries, where a lot of work is still done manually, the investment in machinery can increase labor productivity by substituting and facilitating manual work. Purchasing tractors is one of the most basic machinery investments in agriculture in both developing and industrialized countries. Consequently, it is a good indicator for investment to compare between the countries. The increase in productivity for the first investments in machinery is likely to be higher than for further investments, although fossil fuel input remains the same for the first and all further purchased tractors. Consequently, marginal benefits are decreasing, which is calculated in the form of a natural logarithmic correlation (see Formula 5a).

Agricultural machinery is measured in wheel and crawler tractors used in agriculture per 100 square kilometers of arable land, which excludes garden tractors. Arable land is defined according to the FAO as area under temporary crops, temporary meadows for mowing or pasture, land under market or kitchen gardens, and land temporarily fallow (FAOStat, 2015). The minimum observed in the past 20 years is close to zero (0.09 in 1998 in Niger), which is why zero is the minimum threshold and the maximum is the maximum observed (World Bank Group, 2015). For values smaller than one, the natural logarithm would result in a negative value, which is why a linear correlation between zero and one is assumed (see Formula 5b).

$$(5a) H_{trac} = \frac{\ln(trac)}{\ln(trac_{\max})} * 10$$

$$(5b) trac < 1: H_{trac} = \frac{trac}{trac_{\max}} * 10$$

3.4.3. Rural Poverty

An important social indicator is rural poverty – it gives information on the quality of the living conditions in rural areas, which is a basic prerequisite for agricultural development in many regions.[11] Poverty can either be measured by simply counting the number of people below the national poverty line (headcount ratio), or by measuring the intensity of poverty through the average percentage shortfall in income for the population from the poverty line (poverty gap index). The Global Poverty Working

[11] There are also successful implementations of urban agriculture, as it was promoted and implemented in Cuba during the special period (Funes-Monzote, 2006) (more detail in Chapter 5.2.).

Group of the World Bank provides data for both parameters of rural poverty for non-industrialized countries based on the World Bank's country poverty assessment and country Poverty Reduction Strategies (World Bank Group, 2015). As there is no data available on the rural poverty gap in Mexico, the "Rural poverty headcount ratio at national poverty lines" (*pov*) in percent of the rural population is taken as an indicator for the rural poverty. As the ratio is measured using the national poverty line, which is country-specific, a higher rural poverty means a higher urban-rural poverty gap. An urban-rural poverty gap has negative impacts on rural areas and often results in emigration and urbanization.

The contribution to sustainability is assumed to be a negative linear correlation (see Formula 6), with zero percent poverty as the desired state. The maximum, where zero sustainability is reached, is floating according to the overall maximum, which allows a comparison with the worldwide development.

$$(6)\ H_{pov} = \left(1 - \frac{pov}{pov_{\max}}\right) * 10$$

3.4.4. Access to basic infrastructure in rural areas

Another indicator for livable conditions in rural areas, especially in non-industrialized countries, is the access to basic infrastructure, such as drinking water or energy infrastructure. This indicator is also used for the UN Millennium Development Goals, were the goal 7 is to ensure environmental sustainability. One of the four targets (7C) that was set to be reached by 2015 was that the share of people (in rural and non-rural areas) not having access to improved drinking water facilities was to be halved. According to the report from 2014 on the MDGs, this goal was reached in 2010, but there is also a trend that rural areas tend to face unsafe water and sanitation facilities more often (UN, 2014a). This underlines the need for an improvement in this basic access and is hence a crucial indicator for socially viable development in rural areas.

In this SA the percentage of the rural population, which have access to improved water sources (*wax*) indicates the availability of basic infrastructure, because the access to clean drinking water is the most basic requirement for a healthy and therefore dignified life, which is the basis for viable living conditions in rural areas. Improved water sources takes into account piped water on premises, located inside the consumer's dwelling, plot or yard and other improved sources like public taps, protected dug wells or springs etc.

The correlation with sustainability is a positive and linear one, where the desired state is that 100% of the rural population has access to improved drinking water quality (see Formula 7). The minimum level, which is completely unsustainable, is the floating minimum.

$$(7)\ H_{wax} = \frac{wax - wax_{\min}}{wax_{\max} - wax_{\min}} * 10$$

3.4.5. Agri-environmental Input

Agri-environmental inputs (*in*) are driving-force indicators according to the DPSIR model of the EEA (Gabrielsen and Bosch, 2003) or a means-based indicator according to the definition of Van der Werf and Petit (2002). An increased use can indicate pressures on the environmental system and a rather industrialized, input-intense agriculture. In this SA, two agri-environmental inputs are considered – fertilizer and pesticides usage, which are both ascertained and provided by the FAO.

$$(8)\ H_{in} = \sqrt[2]{H_{nin} * H_{pin}}$$

3.4.5.1. Fertilizers

Nutrients are essential elements for plant growth and due to their removal with the harvest addition of fertilizers is required to sustain yield and soil fertility. Still, application of fertilizers can lead to negative environmental effects in the form of greenhouse gases (GHG), leakage to ground and surface water and impacts on human health (Brink and van Grinsven, 2011). The measurement of sustainability of fertilizer application can be assessed by using input or “means-based” indicators (like fertilizer input per hectare) or “effect-based” (like emissions indicators of GHG per hectare or impact indicators like the amount of leakage, the eutrophication effects etc.). Due to these manifold effects of fertilizer use, which are hard to measure and simplify, the means-based indicator of nutrient input is used, which is reasonable due to the rather strong correlation between pressure indicators of nitrogen input and state indicators of nitrogen concentration in rivers and groundwater (ECNC, 2000). The FAO only provides agri-environmental input data on nitrogen (N) and phosphorus (P) consumption per area from 2002 onwards, which is due to a change in the assessment methodology. This inhibits the comparison of data pre- and post-2002 (FAOStat, 2015). Nutrient input is a crucial indicator for the assessment of the state of a country’s agriculture as inadequate fertilization is often a constraint for crop yields and contributes to soil degradation (FAO, 2006). This is confirmed with the wide use of this indicator in agricultural SAs (Payraudeau and Van der Werf, 2005). Since there is no widely assessed effect-based data available, the means-based input indicator is nevertheless used in this study.

The environmental impacts of fertilization are measured with the data of nitrogen input per hectare of arable and permanent crop area (*nin*) provided by the FAO. N is used because it is the “motor of plant growth” and often preferred by farmers (FAO, 2006); it is the main nutrient necessary for plant and animal growth but can lead to environmental damage due to its high mobility. Additionally, high relevance has been awarded to nitrogen-related indicators by a survey of the ECNC project on sustainability indicators (ECNC, 2000).

For the assessment of sustainability, an optimal level has to be assumed, as in comparable agricultural SAs (Payraudeau and Van der Werf, 2005), due to the fact that both over- and undersupply leads to decreasing resource efficiency. Brentrup et al. (2004), for example, assessed the environmental impacts and resource depletion of nitrogen fertilizer rates for winter wheat production in the UK with EcoX values, using an LCA approach. EcoX values are the aggregated environmental indicator values, which are higher for increased environmental impacts. They found that the EcoX for the fertilization levels of 0, 240 and 288 kg N/ha were 100-232% higher than for 96 kg N/ha, which had the lowest figure, therefore having more than twice the level of environmental impact.[12] Also the study by Brink and van Grinsven (2011) on the costs and benefits of nitrogen corresponds to these results. They find that the socially optimal N input rate (SONR)[13] is between 35 and 90 kg N/ha lower than the privately optimal N input rate (PONR) for oilseed rape and winter wheat in Germany. They therefore suggest a cut back of the N fertilization rates for crop production in North West-Europe by at least 50 kg N /ha. The current EU legislation in this regard prescribes a maximum of 170 kg N/ha, which means a reduction to 120 kg N/ha. Lancker and Nijkamp (2000), on the other hand, define a maximum threshold value for Nitrogen input of 15-25 kg/ha in their agricultural SA for Nepal. The precise value therefore depends very much on the area and it is difficult to generalize. Although the optimal levels for fertilization can differ depending on the natural conditions (soil and crop type, climate etc.), these calculations give an indication. The FAO found in the N balance of Brazil in 2002 that,

[12] The treatments tested were 0, 48, 96, 144, 192, 240 and 288 kg N/ha; 28, 96 and 144 scored the best results (lowest EcoX values).

[13] PONR compare the prices for fertilizers to their benefits, while SONR also include costs for negative effects on human life or health, on ecosystem services and the greenhouse gas emissions.

depending on the region, the optimal application rate (when assuming a 60% application efficiency) was between 34.7 and 97 kg N/ha (FAO, 2004).[14] In the report on Cuba, the recommended rate of nutrient application for the cereals maize and rice was 85 and 138 kg/ha respectively (FAO, 2003a). Brazil, as the biggest country of LA in terms of area, contains a variety of different natural, climatic conditions. Therefore, these estimates are a good indication for the requirements in the other Latin American countries.

Taking these recommendations and studies into account, the optimal input of N fertilizers is assumed to be 81 kg N/ha. With this value, all recommended fertilization levels for the Brazilian regions score greater than or equal to the score of seven and the Cuban cereals recommendation score greater than or equal to the score of five.[15] Between 0 and 81 there is a positive correlation, while above 81 it turns negative (see Formula 9a and 9b and Figure 4).

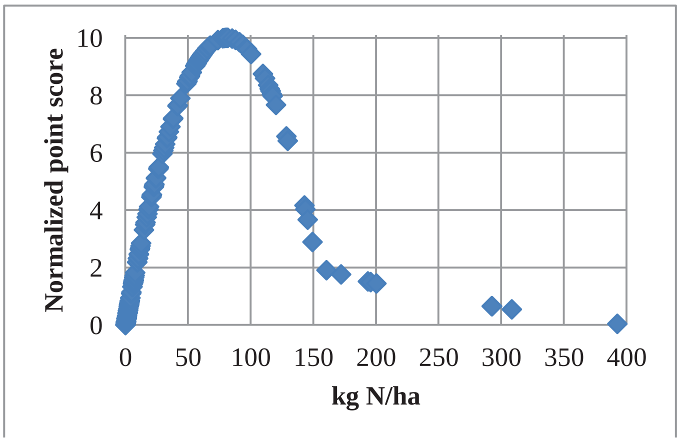


Figure 4: Correlation between data values and point scores for the N fertilizer use worldwide in 2003 (average 2002-2004) for all values <400 kg/ha. Source: Own Depiction. Data: FAOStat, 2015.

The correlation is a quadratic relationship, because the marginal benefits of increased fertilizations are higher at a lower level of input. These decreasing marginal benefits can be easily seen when comparing the fertilizer input in different countries to the amount of yield, which clearly shows that the benefits from fertilization decrease with increasing amounts of N input (Tilman et al., 2002). For the consideration of higher levels of fertilization, and to avoid minimum-value problems, a logarithmic function with a maximum of 400 kg/ha is assumed beyond a point score of two, which corresponds to the value of 153.5 (Calculation see Formulas 9a and 9b, distribution see Figure 4).[16]

$$(9a)\ nin \leq 153.5: \quad H_{nin} = -0.00152 * nin^2 + 0.2469 * nin$$

$$(9b) nin > 153.5: H_{nin} = \frac{\ln(nin) - \ln(153.5)}{\ln(nin_{\max}) - \ln(153.5)} * 2$$

[14] Values and calculations can be found in Appendix B Table 4.

[15] With this assumed optimum all recommended N levels for Brazilian regions and for Cuban rice and maize result in a score higher than five (for 138 kg/h). The recommendations for the Brazilian regions were assumed to be more important, because they address entire regions, while the Cuban one is for single crops, therefore a field approach.

[16] The point scores for the above mentioned values: 34.7 kg/ha (6.7), 97 kg/ha (9.6), 138 kg/ha (5).

3.4.5.2. Pesticides

Another highly relevant indicator for agricultural sustainability according to the ECNC (2000) is the data on pesticide usage, which is also used in a lot of agricultural SAs as an input indicator (Payraudeau and Van der Werf, 2005). Due to the lack of national data on effect-based indicators, the means-based indicator of 'pesticides use per arable and permanent crop area' (*pin*) is used. The FAO sums up the amount of active ingredients (without other components of the final product) of all pesticides reported, which consist of insecticides, herbicides, fungicides and others (such as growth regulators) and divides them through the agricultural area (FAOStat, 2015). Although one can argue that an optimal value for pesticides should be assumed similar to N fertilization, due to their positive effects on production,[17] a negative contribution to sustainability is assumed, as is also done in the 11 studies compared by Payraudeau and Van der Werf (2005) and the 12 SAs compared by Van der Werf and Petit (2002). This can also be justified by the fact that most of the pesticides used do not reach the target pest, but the wider environment, instead[18] where they can have negative effects on water quality, biodiversity, human and animal health (Horrigan et al., 2002). Nevertheless, decreasing marginal benefits are assumed with a quadratic function, which levels out with a logarithmic one (see Formula 9c and 9d).

The target value for pesticides usage is therefore 0 kg/ha. Due to the generalized data of the FAO summing up very different substances in a single parameter, it is hard to set a maximum target value, where zero sustainability is reached. As an approximation the maximum of 14 kg is assumed, which is the 95%-Quantile of all values for the years 2009-10, 2002-2004 and 1993-1995.[19] The correlation with sustainability is assumed to be negative and quadratic due to the increasing marginal costs of pesticide use. As the minimum value is critical when using the geometric mean for the aggregation and to differentiate between the higher levels of pesticide use, beyond a point score of two

[17] The ECNC (2000) for example argue that due to the high variability of pesticides and their application and interaction with the soil, a reduction of usage doesn't automatically lead to a risk reduction for the environment. As more detailed data on the different types of pesticides is not available, the summarized one of the FAO has to be taken for this study. Also the FAO argues in the indicator description that risk varies according to the pesticide type, management and environmental conditions (FAO, 2013).

[18] According to estimations by David Pimentel and colleagues, only 0.1% of applied pesticides reach the target pests (Horrigan et al., 2002).

[19] The range for pesticide usage is very wide, with extreme outliers, which is why the quantile was used: 14kg is the 95% of all values worldwide of all three time periods, which was used to have a bigger n. Looking at the single time slots, it shows a similar picture: 14 is the 96% quantile in 2009-10 and 1993-95 and the 94% quantile in 2002-04.

(therefore, a value of 12.5) a logarithmic function with a maximum of 30 kg/ha is assumed.

$$(9c)\ pin \leq 12.5{:}\ H_{pin} = -0.051 * pin^2 + 10$$

$$(9d)\ pin > 12.5:\ \mathrm{H_{pin}} = \frac{\ln(pin) - \ln(12.5)}{\ln(pin_{\max}) - \ln(12.5)} * 2$$

3.4.6. Water usage

Water, as an important source for the life of humans and the environment, is a limited resource. Lack of precipitation and availability for the plants is of concern in a lot of countries, especially in arid and semi-arid areas. Therefore, water is often taken to irrigate certain crops, which makes the agricultural sector in most countries the main user of water resources. While on the one hand, irrigation secures the yield, which is crucial for food security and the income of farmers, it is on the other hand, the reason for water depletion and pollution. Furthermore, increased agricultural water consumption constitutes a concurrence for the private consumption, which is especially important in arid- and semiarid areas, and irrigation mismanagement, which can lead to water logging and salinization (FAO, 2013). The amount of water worldwide used for agriculture has increased sharply in the last decades from around 1350 km^3/year in the middle of the last century, to around 3800 km^3/year in the beginning of the 21st century (FAO, 2013).

For this indicator the FAO provides data on the share of agricultural withdrawals from total withdrawals (*wwi*). This is a good indicator for the pressure the agricultural sector puts on the water resources and shows how much of the water is used in agriculture. The correlation with the contribution to sustainability is a negative and quadratic one (see Formula 10), since as the percentage increases, the marginal damage for sustainability increases. A certain share of water taken for agriculture is necessary and important for the yield, but with increasing amounts taken for agriculture, the competition for personal use and the pressure on the resource is increasing.

$$(10)\ H_{wwi} = 10 - \frac{wwi^2}{1000}$$

Table 4: Overview of the data sets, abbreviations, units and how the point scores are calculated (correlation, minimum and maximum values and formulas). Source: Own Depiction.

Data Source	Abbr.	Unit	Source (down-loaded from)	Correlation		Min	Max	Formula for normalization
Agricultural Productivity	*prd*							(3) $H_{prd} = \sqrt[2]{H_{vad} * H_{yld}}$
Agriculture value added per worker	*vad*	US$ (constant 2005)	World bank/ FAO (World bank)	+	ln	81	Max obs.	$(4a)\ H_{vad} = \frac{\ln(vad) - \ln(vad_{\min})}{\ln(vad_{\max}) - \ln(vad_{\min})} * 10$
Cereal yield	*yld*	kg per hectare	FAO (World bank)	+	ln	110	Max obs.	$(4b)\ H_{yld} = \frac{\ln(yld) - \ln(yld_{\min})}{\ln(yld_{\max}) - \ln(yld_{\min})} * 10$
Agricultural machinery	*trac*	tractors per 100 km² of arable land	FAO (World bank)	+	ln	0	Max obs.	$(5a) H_{trac} = \frac{\ln(trac)}{\ln\ (trac_{max})} * 10$ $(5b) trac < 1\!: H_{trac} = \frac{trac}{trac_{\max}} * 10$
Rural poverty headcount ratio at national poverty lines	*pov*	% of rural population	World bank (World bank)	–	linear	0	Max obs.	$(6)\ H_{pov} = \left(1 - \frac{pov}{pov_{\max}}\right) * 10$
Improved water source, rural	*wax*	% of rural population with access	WHO/UNICEF (World bank)	+	linear	Min obs.	100	$(7)\ H_{wax} = \frac{wax - wax_{min}}{wax_{\max} - wax_{min}} * 10$
Agri-Environmental Input	*in*							(8) $H_{in} = \sqrt[2]{H_{nin} * H_{pin}}$
Nitrogen Consumption arable and permanent crop area	*nin*	kg N/ha	FAO (FAO)	Opt.	neg. quadratic	Opt. = 81	400	$(9a)\ nin \leq 153.5$: $H_{nin} = -0.00152 * nin^2 + 0.2469 * nin$ $(9b)\ nin > 153.5$: $H_{nin} = \frac{\ln(nin) - \ln(153.5)}{\ln(nin_{\max}) - \ln(153.5)} * 2$
Pesticides use on arable and permanent crop area	*pin*	kg/ha	FAO (FAO)	–	neg. quadratic		30	(9c) $pin \leq 12.5$: $H_{pin} = -0.051 * pin^2 + 10$ $(9d)\ pin > 12.5:\ H_{pin} = \frac{\ln(pin) - \ln(12.5)}{\ln(pin_{\max}) - \ln(12.5)} * 2$
Water withdrawal for agricultural use	*wwi*	% of total water withdrawal	FAO (FAO)	–	neg. quadratic	0	100	$(10)\ H_{wwi} = 10 - \frac{wwi^2}{1000}$

4. Results

4.1. Sustainability Assessment

Table 5 shows the results of the calculations as propounded in the previous methodology chapter. It shows the normalized point scores of the five countries in the three time periods of all indicators and sub-indices and the overall Sustainable Agriculture Index (*SAI*) using only the data as available from the FAO and World Bank. Figure 5 summarize graphically the results at country and indicator level.

Table 3 in Appendix A calculates including the estimated gap scores,[20] which are the average of the scores of the previous or following year of the respective country. If there is no country data available for none of the three periods, the average of the available data of the other four countries are used, which enables the assessment of the influence of data gaps.

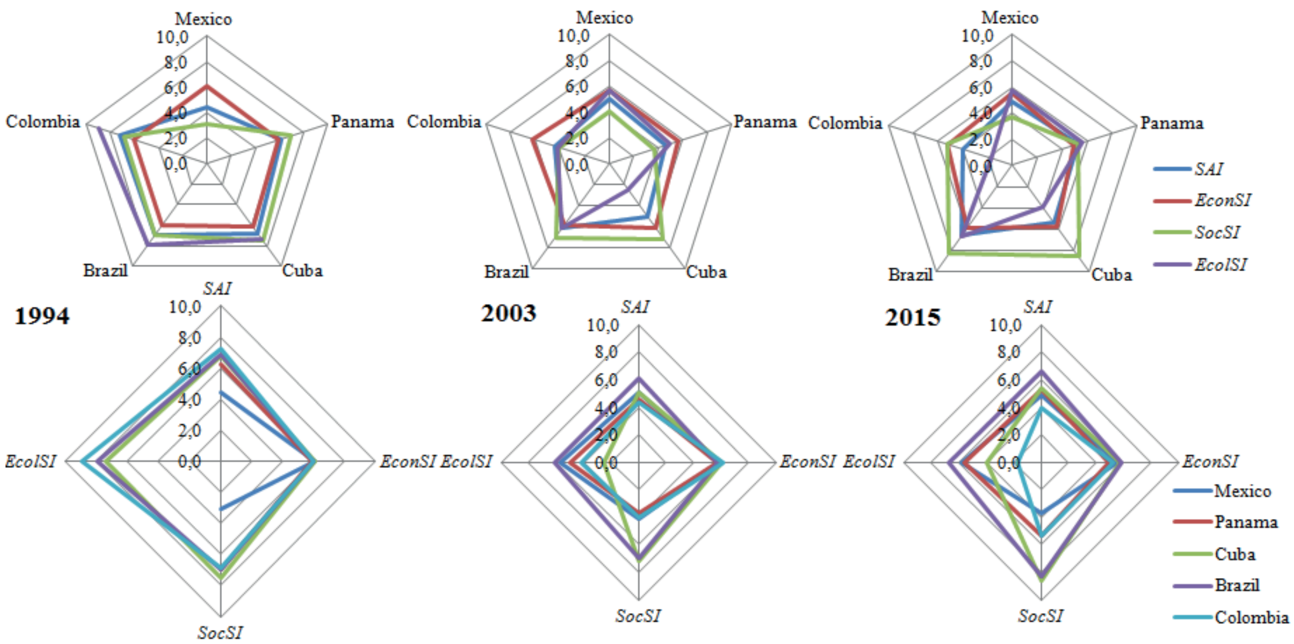


Figure 5: (Sub-)Indicator results for the five LA countries using the available data as provided by FAO and World Bank Group. Source: Own depiction.

For 1994, Mexico has the lowest overall *SAI* score of 4.4 and the difference between it and the best performing country (Colombia with 7.2) is 2.8 point scores. The most homogenous situation is in 2003, where Colombia has the lowest score (4.4), with a difference of only 1.7 points from Brazil (6.1). The most recent data also shows a rather

[20] The analysis refers to the estimated scores only if it is explicitly stated; if not there is talk of the results without the estimates.

large gap of 2.6 points between the highest point score of Brazil (6.6) and the lowest of Colombia (4.0)(see Figure 5). This implies that Colombia has the sharpest, and the only steady, decrease over the time considered, declining from the best performing country to the worst in 2015. For the overall development throughout the three time periods, Cuba, Panama and Brazil show a decrease in 2003, but increase later again. Mexico, by contrast, is the only country, which first shows an increase and then a decrease. The overall highest scores over the three periods are those of Brazil (between 6.1 and 6.9), while the lowest are the ones of Mexico (between 4.4 and 5.1). Colombia has both the highest overall (in 1994: 7.2) and the lowest score (for 2015: 4.0).

When including the estimated data, the development over time of the *SAI* remains the same for all countries except Cuba, whose overall development remains on a steady level over the three periods (in contrast to first decreasing, then increasing). Furthermore, the difference between the estimated indices and the regular results are that the estimates values result in less extreme scores. This means that the highest values (e.g. Colombia 1994) are lower and the lower values are higher (e.g. Mexico 1994), but the overall direction of the indices, namely whether they increase or decrease, remains the same.[21] The highest changes can be observed for the early years, especially in 1994, which is due to the fact that for this period, there are a lot of data gaps. The absolute and relative changes when using the estimates can be found in Appendix B Table 3.

Looking more closely at the sub-indices of Table 5, in the case of Mexico, one can see that the score for the economic index is steadily decreasing (6.1 in 1994 to 5.5 for 2015), while the ecological one remains steady (5.7 in 2003 and 5.8 for 2015) and the social index first increases, then decreases again (3.1, 4.1 and 3.7). This economic downward trend can be observed for all five countries in the comparison between 1994 and 2015, but Mexico shows the steepest decrease with a difference of 1.6 point scores. The trend for Cuba and Brazil, although slightly declining by 0.3 and 0.1 respectively, can be regarded as steady. Panama and Colombia show a more pronounced downward trend (minus 1.0 and minus 0.8 respectively). This decrease in economic terms can be traced back to the overall bad performance in the yield of up to minus 1.1 point scores between 1994 and 2015 for Mexico and Panama. Also the value added predominantly shows a decreasing development, except for the case of Brazil, as the only country to experience a

[21] For the underlying sub-indicators, most deviations are for the *EcolSI* where Cuba and Brazil show a different development, for *SocSI* only Panama and for EconSI only Colombia. The Mexican development remains the same for all indices.

positive and steady development (+0.4 over the 20 years). Colombia faced the biggest negative change of –0.9 points between 1994 and today. Concerning the indicator of agricultural investment, all countries providing data over all three time periods (Cuba, Mexico and Brazil) show a decrease between 1994 and 2003 of –0.3 to –0.4 points, which continue to increase until the present today (between 0.5 and 0.7). As there are hardly any data gaps for the economic data, the only change when using the estimated values are for Colombia in 2003, which witnessed a steadily declining development (in contrast with the initial slight increase and then decrease as given by the original calculations).

For the social index in Table 5, one can observe an increase (0.6-1.3) between 1994 and today for all countries but Colombia and Panama. While the increase for Brazil is the only steady one (7.0, 7.0 and 8.3), the one of Cuba first decreases, then increases (7.5, 7.2 and 8.6) and the Mexican shows the opposite development (3.1, 4.1 and 3.7). This development is influenced by data gaps. While the water access shows rather high scores (6.3 and higher) and an overall positive development (between +0.2 in Colombia and +2.5 in Mexico) between 1994 and today, the scores for rural poverty are quite low (4.0 and lower) and fragmented. This means that for those periods and countries where rural poverty data is available, it reduces the *SocSI*. When looking at the data including the estimations, values for Panama and Colombia are at first stable (Colombia decreases only slightly), then increase. Therefore, one can see an increasing performance for this indicator for the countries with available rural poverty development data (Panama, Colombia and Mexico), with the exception of Mexico, which increases between 1994 and 2003 and then decreases again, and has during all three time periods lower or comparable scores than the other countries.

The ecological indices mostly increase between 2003 and 2015. They do so only slightly for Mexico (0.1), a bit more significantly for Panama and Brazil (0.6) and considerably for Cuba (+1.4). Only Colombia has a negative, quite drastic development (–2.5). The results including the estimates (Appendix A Table 3) allow for the comparison between 1994 and 2015, where for Brazil and Cuba, the development is rather stable (+/– 0.2) and for Colombia the same drastic decline can be observed. The point scores of nitrogen inputs follow an upward trend for most countries due to increased fertilizer input, with the exceptions of Cuba and Colombia. Cuba experiences a decrease due to slightly decreased agricultural inputs, while Colombia saw a drastic decrease between 2003 and 2015 due to an extreme rise in input levels exceeding by far the assumed optimum rate. Regarding the pesticides consumption, the FAO unfortunately does not provide data for Cuba and the data is also rather fragmented for the other countries. The scores are rather high (above 7), except for Colombia in the two most recent time periods. Mexico and Colombia show a decrease, which is due to increased consumption of pesticides in these countries. For water withdrawal the scores are mostly rather high (above 6), apart from Panama and Mexico (between 4.0 and 4.3). They are rather steady (+/– 0.1) for Mexico, Colombia and Brazil and slightly decreasing for Cuba (–0.5).

Table 5: Point Scores of the underlying indicators and sub-indices, as well as the overall Sustainable Agriculture Index for the five countries over the three analyzed periods.
Source: Own calculations.

	Mexico			Panama			Cuba			Brazil			Colombia		
	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015
SAI	4.4	5.1	4.9	6.2	4.6	5.3	6.8	5.1	5.4	6.9	6.1	6.6	7.2	4.4	4.0
EconSI	6.1	5.7	5.5	5.9	5.7	4.9	6.1	6.1	5.8	6.0	5.8	5.9	6.0	6.2	5.2
Prd	6.5	6.0	5.3	6.1	5.7	4.9	5.9	6.1	5.0	6.2	6.0	5.7	6.7	6.2	5.2
Vad	5.7	5.4	5.3	5.6	5.5	5.2	5.4	5.4		5.2	5.4	5.6	6.0	5.2	5.1
Yld	7.4	6.7	5.3	6.7	5.8	4.6	6.5	6.8	5.0	7.3	6.8	5.8	7.4	7.3	5.4
Trac	5.7	5.3	5.8	5.7			6.4	6.1	6.8	5.9	5.5	6.1	5.4		
SocSI	3.1	4.1	3.7	7.0	3.7	5.3	7.5	7.2	8.6	7.0	7.0	8.3	6.9	4.0	5.3
Pov	1.6	2.3	1.5		2.0	3.4								2.5	4.0
Wax	6.4	7.4	8.9	7.0	7.1	8.5	7.5	7.2	8.6	7.0	7.0	8.3	6.9	6.3	7.1
EcolSI		5.7	5.8		5.0	5.6	7.4	2.5	3.9	7.9	6.1	6.7	8.9	4.2	1.7
In		8.0	8.2		5.9	5.6		2.5	2.2	10.0	6.1	6.7	9.3	2.0	1.7
Nin		6.5	7.4		4.8	5.6		2.5	2.2		6.1	6.7		9.6	1.9
Pin		9.9	8.9		7.2					10.0			9.3	0.4	1.6
Wwi*		4.0	4.1		4.3		7.4		6.9	6.3	6.2		8.6	8.5	

Explanations:
Green Background: Composed indicators or aggregated indices do not provide over all the data (for the *SAI*: the darker the more data is missing – dark green: three indicators missing, lighter green: two indicators are missing, grayish green: one indicator is missing)
Yellow Background: changed years (2006-07)
*****Different comparison years: 1995-96, 2000-2002, 2007-2009

4.2. Sensitivity Analysis

For the interpretation of the results and how they are influenced by the specific methodology, a sensitivity analysis has been performed. The sensitivity analysis included the assessment of indicator aggregation H*in* and H*prd* (Appendix B Table 2), the sub-indices and the overall index (Appendix B Table 1). Furthermore, the alterations using estimated values have been calculated (Appendix B Table 3), which were discussed together with the main results in the previous sub-chapter (4.1). A full representation of the results for the sensitivity analysis (as described in Chapter 3.3.1) showing absolute and relative changes resulting from the variation in the calculation scheme can be found in Appendix B. Additionally, critical assumptions concerning the choice of optimal values for the ecological indicators have been tested (Appendix B Table 4-6) presented as elasticities alongside the absolute changes.

In the sensitivity analysis concerning the aggregated indicators, the difference between using the geometrical and the arithmetic mean is tested (see Appendix B, Table 2). For the agricultural productivity, the change when using the alternative arithmetic mean was extremely low (between 0 and 1.4% or maximum 0.1 point scores for Colombia in the year 2003). This indicates that H*vad* and H*yld* correlate follow fairly similar developments and hence coincide very well with each other. For the agri-environmental input indicator, the differences between the arithmetic and geometric mean result in rather high alterations in some cases, which is due to divergent underlying indicators.[22]

The maximum absolute and relative differences between aggregation with the arithmetic and geometric mean for the four (sub-)indices can be found in Table 6 (entire sensitivity analysis in Appendix B Table 1). The changes for the *EconSI* were negligible (maximum 1.1% or 0.1 point scores difference) and acceptable for the overall *SAI* (0.7 points, 13–13.4%). By contrast, the highest changes were observed for the *EcolSI* (21.1% or 1.1 points) and *SocSI* (29.6% or 1.5 points), which is based on the differences of the underlying scores forming the index. This is due to the fact that the dimensions consist of different aspects, which have divergent developments in a country over time. For example, when looking at the Social Index of ‘Mexico 2015’, one observes an extremely good performance in water access (8.9), but a rather bad one for rural poverty (1.5), which results in the difference between using arithmetic and geometric mean.

[22] Colombia 2003 results in a difference in score of three point scores, which is due to very high pesticide inputs (very low H*pin*) and close-to-optimal fertilizer inputs (very high H*nin*).

Table 6: Maximum absolute and relative differences when changing the aggregation from geometric to arithmetic mean for the four indices. Source: Own depiction.

Index	Data	Difference [%]	Difference (absolute)
EconSI	Cuba 2015	1.1%	0.1
SocSI	Mexico 2015	29.6%	1.5
EcolSI	Colombia 2003	21.1%	1.1
SAI	Mexico 2015	13.0%	0.7
	Colombia 2003	13.4%	0.7

Regarding the threshold levels for the calculations of the ecological dimension, the impacts from assuming an optimum level for both fertilization and pesticides have been tested by changing the assumed optimum levels (i.e. 81 kg N/ha for fertilizers and 14 kg/ha for pesticides) by +/– 10% (see Appendix B Table 5 and 6). For the fertilization, low input levels (up to 40 kg N/ha) were rather inelastic (between 0.66 and 0.94). On the contrary, the high value of Colombia 2015 (160 kg N/ha) showed very elastic behavior with an elasticity of over 4 when increasing the optimum by 10% (the ranges when changing the optimum can also be seen in Figure 6). The elasticities of varying the pesticides' optimums show a similar picture, although this time there is a continuous correlation between the magnitude of the values and elasticities – the higher the input of pesticides, the higher the elasticity. Therefore, elastic behavior for the highest values of Colombia 2015 (14.9 kg/ha) and 2003 (24.9 kg/ha).[23] This means that higher values are rather sensitive to changes, which implies that particular care must be taken with the results for these values.

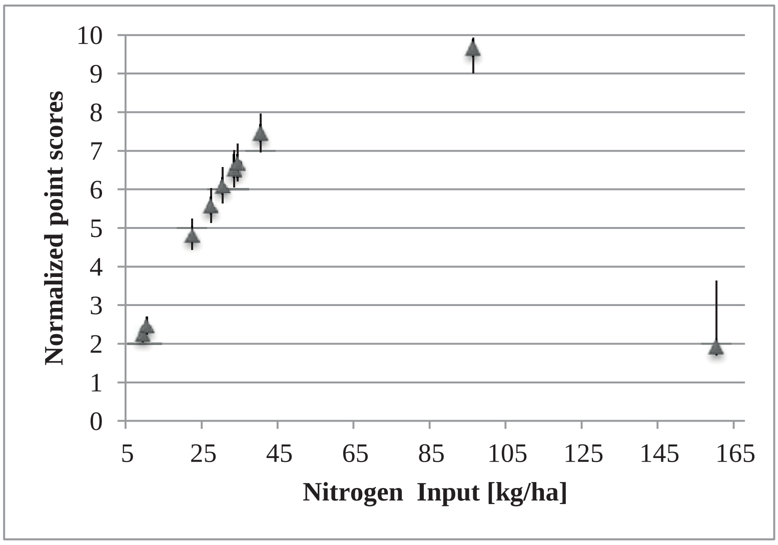


Figure 6: Ranges of point scores for the different N inputs of the five countries, when changing the optimum +/– 10%; the black markers indicate the original score (Optimum 81 kg N/ha). Source: Own Depiction. Data: FAOStat, 2015.

[23] Higher input levels (higher than 7 kg/ha) show an increasing sensitivity with higher elasticities, but they reach only 1.15, which is rather low.

5. Discussion

5.1. Discussion of the methodology

This assessment reviews the development of the Mexican agriculture after 20 years of NAFTA. However, indicators on trade (such as trade balance or agricultural exports etc.) are not part of this assessment because trade itself is not per se sustainable or unsustainable. It is the consequences trade has on different aspects of the agricultural sector (such as agricultural investment, rural living conditions etc.), which have to be considered. This SA, therefore, shows fields of interest, which are important for the development of a country's agriculture and may be influenced by an FTA and the liberalization process, which often accompanies such an agreement.

This Sustainable Agricultural Index *(SAI)* can be regarded as a simplified depiction of a nation's agricultural production. Although it is a simplification, it allows for a general overview of the issue. Within the scope of a Master thesis, it can be seen as a first assessment of how to approach a general SAI, because for a holistic assessment additional indicators should be developed to include more aspects of the three dimensions of sustainability. For example other indicators like GHGs emitted by agriculture, energy use, foreign trade balance, food security, nutritional situation, biodiversity, etc. should also be taken into account. Apart from that, a more detailed index could also integrate indicators of good governance, as a fourth dimension, including issues like access to land and human rights issues as the SAFA tool of the FAO does.

Regarding the methodology of this SA, there are certain issues, which have to be discussed and reviewed critically. For example, the definition of simple threshold values and correlation between them sometimes does not do justice to the complexity of the real world. For example, in the case of yield, this index assumes that an increased yield always contributes positively to sustainability. This is a reasonable argument considering the rising world population and limited arable land, which means that increased efficiency is paramount to feed the world. However, this ignores the criticism that one should not simple equate economic sustainability with economic growth, as described in Chapter 2.1. Therefore, one has to scrutinize the mechanisms causing an increasing yield, which can be achieved by increasing, sometimes excessively, the use of agri-environmental inputs (like pesticides, fertilizers or irrigation, etc.), which raises the yield at the expense of the natural environment and therefore, should not be regarded as sustainable. On the contrary, increased yield can also be achieved by increased knowledge of soil, irrigation or fertilizer application. This would be much more sustainable, because increased yield can be achieved without compromising the environment and by empowering the people working in the sector. Depending on whether one evaluates it from a social, economic, ecological, or food security point of view, the assumed optimum value would change accordingly. In this SA, the indicators are put into the dimensions that they fit best (in accordance with the literature review) and the optimum and correlation is then assumed according to this methodology.

To include various aspects within the agricultural development of the respective country, the indicators are aggregated into one overall index with a geometric mean. This means that the overall index includes some of these tradeoffs e.g. including economic and ecological aspects. The geometric mean is the better method for the aggregation as it prevents substitutability and provides incentives to improve badly performing indicators (Saisana and Philippas, 2012). This could be shown with the sensitivity analysis (see Chapter 4.2). The alterations using the arithmetic mean were quite high for indices that aggregate very different aspects and which develop independently from each other. For example, when looking at the *SocSI* of 'Mexico 2015', one observes an extremely good performance in water access (8.9), but a rather bad one for rural poverty (1.5), which results in a difference of 1.5 points, when using the arithmetic mean instead of the geometric one. However, the water access cannot substitute the rural poverty, which is the reason why the geometric mean is used, following the Venn diagram approach of non-substitutability (compare to Figure 1a).

Another issue is that the data on cereal yield expressed in kg per hectare does not reveal any information on the quality of this yield. This is why *yld* and *vad* are aggregated, because *vad* is more sensitive to quality changes. Therefore, for the consideration of these underlying trade-offs and interactions, which is hard to achieve with a simple correlation, different data sources on the different dimensions form aggregated indicators and indices.

Furthermore, the need to assign threshold values and assume a correlation between them also excludes certain issues and potential indicators. Different countries have different problems: some countries face famine and malnourishment, while in others obesity is the prevailing problem. This can lead to difficulties when defining a sustainable nutritional situation. Also other issues, influencing the social and economic structures of agriculture, such as property situation, working conditions and access to land for agricultural employees and farmers, could not be included in the *SAI* as they are hard to assess in numeric terms and to compare with each other. These examples show that certain issues and factors cannot be expressed in simple quantitative assessments, but have to be considered within the framework of agricultural policies and general national development.

Additionally, when taking the national data assessed by international organizations, this is the average of an entire country. The actual situation can then differ very much within the country, especially for bigger countries and countries where there are large differences between agricultural structures. This is often the case for developing and newly industrialized states, where there are, on the one hand, subsistence farmers, who use very little additional inputs and have rather low yields and productivity. On the other hand, there are large landowners, which engage in sophisticated agricultural production techniques.[24] Apart from economic differences within a country, the natural environment and climate, as well as factors such as the soil fertility and precipitation can also vary considerably within a country. This raises difficulties when setting threshold values for agri-environmental inputs, for which optimal levels can vary according to these natural conditions.

Another problem, which arose during this assessment, was the issue of data gaps and the continuing assessment of data. The change in methodology of Nitrogen input data made by the FAO from 2002 onwards prevents the comparison of the data pre-2002, which does not provide data on fertilizer input in kg N/ha, to the one afterwards. Furthermore, the pesticides input data does not provide data for Cuba at all and the rural poverty ratio is not assessed for all countries either. These data gaps are not coincidental. One can clearly see that the economic indicators, which are available for almost every country in the world, are more often assessed than the ecological ones. Also data on water access, which is one of the indicators for the MDGs, covers a wide range of time and space. Furthermore, an improvement for this indicator is desired and there are policies to increase the figures, which is why there is a positive development over time for all countries considered. This is taken into consideration with the comparison to the range of values.

These gaps may bias the outcome, because here the indices are calculated even without the missing data. This means that the economic indicators are given more weight,

[24] This dual structure in the single countries is discussed in the following sub-chapter 5.2.

simply because of the data gaps. This bias is tackled by elaborating an alternative estimation procedure filling in the gaps with estimates. In this thesis the estimates are derived from the previous and following values. Alternative methods would be to derive expert judgments, as is done by the SSI (Saisana and Philippas, 2012). Such expert judgments may generate better results, because they would better approximate the concrete situation in the countries. For example in the case of Cuba, there is reasonable doubt that the estimates as applied in this SA lead to a worse outcome than the real numbers would. The economic constraints in Cuba (see following sub-chapters 5.2) led to very low agri-environmental inputs, which means that the pesticides input scores would probably be quite high in Cuba. Also for poverty, the scores would most likely be much higher, because one of the prioritized objectives of the socialist rural policies was to eradicate rural poverty (Funes-Monzote, 2006) and the International Fund for Agricultural Development (IFAD) states in the Rural Poverty Portal that in Cuba there was zero rural poverty in 2012 (IFAD, s.a.). Furthermore, the statistical coherence and robustness of the selected indicators and their influence on the outcome could be tested with additional analysis as done by Saisana and Philippas (2012) for the SSI.

Another critical issue is that this SA does not question the data provided by the international organizations concerning data flaws or problems with the assessment. For example, the data for nitrogen consumption is assessed by the FAO through questionnaires in the individual countries. The product weight as declared by the single countries are then converted into nutrients and validated for consistency. Supply is assumed to be equal to consumption, which is then simply divided by the amount of arable land (FAO, 2013). This method may lead to irregularities and unwanted outcomes differing from the real situation, due to different assessment methods by the individual countries in terms of the amount supplied or the arable land present. For example, traditional fertilization methods or biological fertilizers, which are often applied by rural, indigenous techniques and are likely less harming to the environment and biodiversity (UNEP, 2006), are probably not recorded with this kind of assessment. Additionally, these uncertainties make it difficult to assume the optimum levels, which also depend upon whether social optimum or ecological optima are chosen. In this SA, the optima as stated by the FAO for Brazil have been taken as the main reference, because a large country like Brazil contains a variety of natural and climatic conditions. This is why, the recommendation of this country was chosen, as this variety resembles the conditions in the other countries analyzed.

For the economic indicators, the efficiency depends a lot on the comparison. The value added cannot only be expressed as per worker, but also per hectare, or the tractors not per area, but per worker, which would probably lead to different results. In this SA, the data as provided by the international organizations is used and no combinations of different data sets are made.

Moreover, in this SA all ecological indicators are input indicators, due to the lack of alternative effect-based indicators. This is reasonable as there is frequently a close relation between means- and effect-based indicators. Furthermore, they are the funding objective in many agri-environmental programs. However, effect-base indicators would have higher significance when it comes to environmental or ecological effects, also because the correlation between inputs and environmental effects depends a lot on the natural conditions (such as precipitation, soil etc.). In particular, the assessment of pesticide use was rather difficult, because all pesticides are compiled into one number, whether they are (highly) hazardous or not. This makes the definition of thresholds very difficult, because the effects of the pesticides may vary considerably. This indicator and its significance have to be reviewed in the light of these shortcomings.

Therefore, when using the SA one has to be aware of these shortcomings and has to interpret the *SAI* as an approximation, which can identify critical issues and which is able to compare different countries over time. For a more detailed analysis of the underlying causes and mechanisms beneath this outcome, one has to take a closer look at the data, at the nation's peculiarities and compare it to qualitative studies and research for the single countries, which is done in the following sub-chapter.

5.2. Discussion of the results

As agriculture is interconnected with economic development, natural conditions and social and political occurrences, one has to consider it within a holistic picture. For an interpretation of the results, one therefore has to take a closer look at the underlying mechanisms, which influence the data of the single countries and therefore influence the outcome. A simple tracing back of the results to the existence of one FTA is not possible, especially because every country has FTAs with other countries as well (see Appendix C Table 1). Mexico for example has Regional Trade Agreements (RTA) notified to the WTO concluded with 59 countries (counting the EU as one) (WTO, 2015). With this amount, Mexico is the country of the five analyzed, having the highest number of RTAs. Of those five countries, the only ones not having an agreement with either the US or the

EU are Cuba and Brazil. Furthermore, the agreements of Panama and Colombia with these two biggest economies in the world have just recently entered into force (in 2012 with the US, in 2013 with the EU) and therefore probably did not have any effect on the values of this assessment.[25] Furthermore, it is not only the FTA itself, but also national policies, which accompany the conclusion of such an agreement.

In this chapter, the results of the SAI are compared to existing literature and reports on the development of the agriculture in the five countries offering possible explanations for the results of the SA. Whether, and to what extent, they actually contribute to the indicators, would be the task of econometric studies. The focus of this analysis lies in the Mexican development, the examples of the other countries are taken to explain and compare.

5.2.1. Economic development

For the economic development, one can observe an overall negative trend for all countries over time, except Brazil and Cuba, which both experienced a rather constant development. Considering the calculation method, this means that the gains in productivity and investment for these countries have not been as pronounced as the increase for the maximum, therefore the best-performing, most productive countries worldwide. This means that although the countries may have increased their productivity in absolute terms they could not decrease the distance between them and the most productive countries.

For the interpretation of these numbers, one has to consider the economic situation, which prevailed during and previous to the respective analyzed time period. Figure 7 shows the timeframes of the GDP crises for the different countries, as well as their durations and intensities. This data provided by Vegh and Vuletin (2014) is only available for the 'LAC-7' (Argentina, Brazil, Chile, Colombia, Mexico, Peru and Venezuela).[26]

With this timeline of crises, one can see that for Mexico and Brazil, all three periods considered in this thesis are either during or directly in the aftermath of an economic crisis. For Colombia, however, only the two most recent periods are influenced by an

[25] Only the productivity indicators, the poverty data (all 2012/13) and the water access data (2011/12) use that recent data.
[26] The definition for the duration is „beginning in the quarter in which real GDP falls below the preceding 4-quarter moving average and ending in the quarter in which real GDP reaches the pre-crisis level.“ (Vegh and Vuletin, 2014: 6).

economic recession, which could explain the bad performance and drastic decrease observed in this SA. These crises also offer an explanation for the Mexican SAI development, because in 2003 the highest value can be observed, which is during the crisis with the lowest intensity and duration for Mexico.

The 2015 data on productivity [27] is influenced to a large extent by the consequences of the global financial crisis beginning in 2008/09, which led to an increased volatility for agricultural commodity prices (see Figure 8 showing the price development for the most important crops cultivated in the five countries). This volatility influences particularly the indicator of value added and export-orientated countries are especially sensible to these price changes (ECLAC et al., 2012). These price fluctuations enhance variability in revenue-collection having impacts on public spending and policies (ECLAC et al., 2014). Furthermore, one can see with this timeline of crises that the Tequila Crisis in Mexico did not have any consequences in Colombia and only affected Brazil to a minor degree, while international crisis like the Asian and Russian Crisis and the Global Financial Crisis had more severe consequences on the LA countries' GDP growths. Countries having strong economic ties to the US and EU were confronted with the most rigorous consequences of the crisis. This can be observed for Mexico, which faced a longer and more severe economic recession than the other two LA counties due to its strong trade relationships with the US (Angeles Villarreal, 2010). Both Mexican imports and exports are to a large extent exchanged with the USA (70% and 85% respectively in 2010) and the agricultural sector shows an even higher degree of openness than the overall economy (Puyana, 2012). Mexico therefore experiences strong economic ties and a connected economic development with the US, which are mostly one-sided.

During the decade of the 1990s the situation in Cuba was also marked by economic crisis and recession due to its strong economic ties with the Socialist bloc countries. In Cuba, the official name for this time is the "special period", during which the country experienced an economic crisis and shortages due to the dissolution of the Soviet Union and the Comecon. This geopolitical change had severe consequences in the agricultural structure of the country, due to the strong interconnection concerning agricultural imports and exports of commodities and agri-environmental inputs needed for agriculture (Funes-

[27] The '2015' data for the productivity indicators (*yld* and *vad*) takes the average from 2012 and 2013, while the investment indicator *trac* uses 2006 and 2007 data.

Monzote, 2006).[28] The prompt cut-off of this supply in the beginning of the 1990s led to structural reforms, which led to higher private ownership, urban agricultural structures, and programs for biological fertilizers (Funes-Monzote, 2006). This special situation in Cuba can also be observed in the economic indicators, where there was an increase for the productivity indicators between 1994 (therefore during the special period) and 2003 (when Cuba's agriculture managed to adapt to the new situation).

	1993				1994				1995				1996				1997				1998				1999			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Brazil	-6.8%										-1.7%													-1.5%				
Colombia																							Asian and …					
Mexico									Tequila Crisis (-9.8%)																			

	2000				2001				2002				2007				2008				2009				2010			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Brazil							-0.7%													- 5.4%								
Colombia	… Russian Crisis (-6.8%)																			- 1.1%								
Mexico						-2.7%														Global Fin. C. (-7.9%)								

Figure 7: Times of economic crisis and the intensity of the GDP crisis [%] in Brazil, Colombia and Mexico as defined by Vegh and Vuletin (2014) (in blue the analyzed periods). Source: Own Depiction. Data: Vegh and Vuletin, 2014.

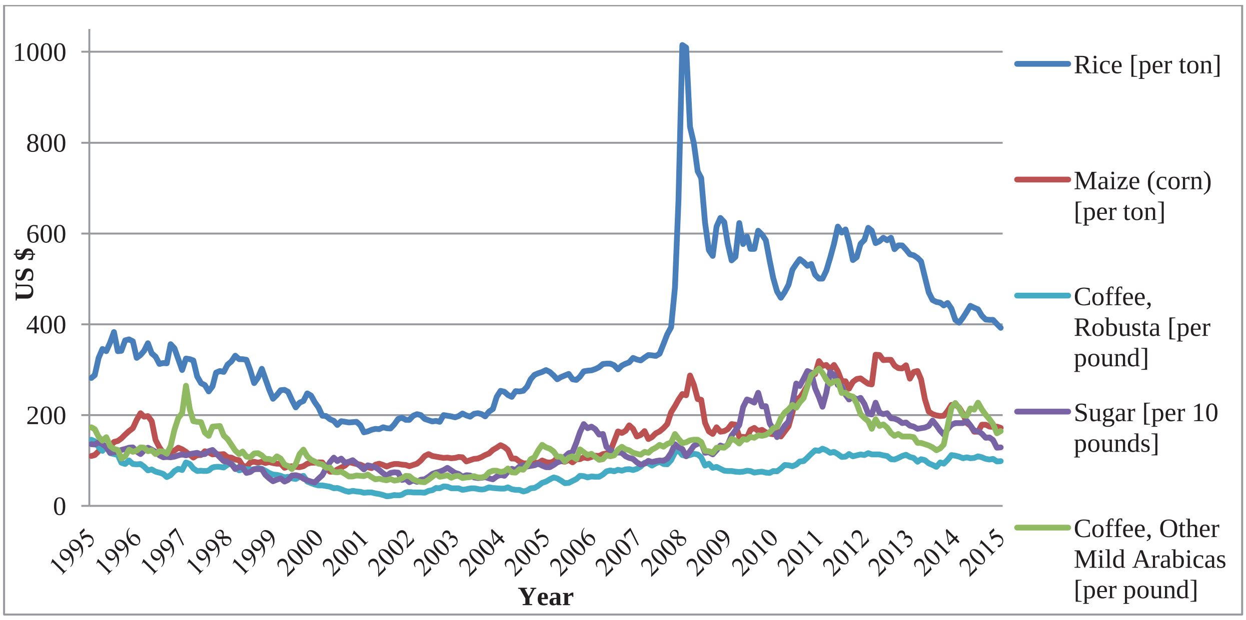


Figure 8: Agricultural commodity prices of the most important crops in the five countries (being among the major crops as defined by the CIA factbook (CIA, 2015) in at least three of the five countries). Source: Own Depiction. Data: Index Mundi, 2014.

[28] The food supply in Cuba was heavily depending on the socialist bloc countries: it imported 57% of its protein requirements and more than 50% of energy, fertilizers, herbicides, livestock feed, dairy products and meats (Funes-Monzote, 2006).

In Mexico, the 1990s were defined by the financial crisis of 1994–95 (often named 'Tequila Crisis'). This crisis emerged due to a capital flight, in reaction to events affecting Mexico in 1994 (like the Chiapas conflict, the increase of federal funds rate by US Federal Reserve, appointment of president Zedillo, violence and assassinations) (Musacchio, 1012). The liberalized, rather fragile banking sector, joined with the political response of "borrowing their way out of the crisis" led to a depreciation of the Mexican peso, followed by a marked recession and a sizeable banking crisis (Musacchio, 1012). This economic instability is also reflected in the outcomes of the SA, where all economic indicators are seen to decline between 1994 and 2003. This shows that the crisis also brought instability for the agricultural sector. The data of 1994 and 2003 probably also depict the situation of the structural adjustment in the agricultural sector, which started in the 1980s (Menéndez Gámin and Palacio Muñoz, 2014) and the first consequences of the trade liberalization due to NAFTA. Until then, Mexican agriculture had a rather special structure, originating in the Mexican revolution of 1910, which led to the adoption of the Mexican Constitution in 1917, which set the cornerstone for latter Agrarian Reforms in Article 27.[29] During the different implementation steps of this reform between 1917 and 1992, 100 million hectares, which is half of the Mexican territory and around two thirds of the rural property, were distributed among rural peasant farmers. Furthermore, 30,000 *ejidos* (village communal holdings) and communities for more than three million families were established (Warman, 2003). The liberalization of the agricultural sector from the 1980s onwards, included measures like the abolishment of support prices for all basic crops (behalf maize and beans) in 1989 and the reformation of Article 27 in 1992, which allowed private ownership of land and joint ventures between *ejidatarios* and private capital (Appendini, 1994). This privatization and liberalization process in the agricultural sector was one of the reasons for the Zapatista uprising in 1994 in Chiapas.

As well as experiencing economic development, the country is also subjected to climatic events, such as El Niño/La Niña, which can affect yields to a great extent. The most recent La Niña event, which led to harvest losses for Latin American countries in late 2011 and early 2012, could have an influence on the cereal yield data. According to the agricultural outlook of the ECLAC, FAO and IICA (2012) the greatest losses have occurred in Brazil (maize) and Mexico (maize, wheat and beans), both of which show a

[29] The first paragraph of Article 27 in its original version says „Ownership of the lands and waters within the boundaries of the national territory is vested originally in the Nation, which has had, and has, the right to transmit title thereof to private persons, thereby constituting private property.“ (Constitution of Mexico, 1917).

decline in their score between 2003 and 2015. In addition to climatic conditions, other natural influences must also be considered, such as diseases, which can influence the performance of the countries. For example, an outbreak of the coffee rust disease occurred through large parts of Central America, the Dominican Republic, Peru and Colombia (ECLAC et al., 2014). This resulted in negative social and economic impacts throughout the years 2013 and 2014 and can explain the rather bad performance of Colombia in the 2015 data.

When looking at the results for the aggregated productivity indicator, one can observe that those countries, which have larger agricultural areas (Brazil, Mexico and Colombia)[30] have slightly better scores for productivity than the smaller countries (Panama and Cuba), when the averages over the three periods are compared with each other. This may be traced back to economies of scales, concerning the export orientation and trade possibilities of a country.

Even if there are similarities between the Latin American countries concerning historical development, there are huge differences between the single countries and even within them when it comes to agriculture. Characteristics like the composition of the crops cultivated are influenced by climatic conditions, parent material, soil fertility, relief and altitude, etc. In Cuba, for example, sugar cane plantations dominate agriculture with approximately half of the cultivated area (FAO, 2003a). Such a specialization on just a few crops can lead to high dependencies on the world prices for agricultural commodities, which were especially volatile after the recent economic crisis and can therefore influence very specialized countries to a large extent (ECLAC et al., 2012). The prices for sugar rose significantly between 2006 and 2011, which offers an explanation behind the rather strong performance of Cuba, as well as Brazil, which is also a major producer and exporter of sugar and showed the only steady increase for value added.

In addition to the vulnerability from international prices, another disadvantage of the specialization in just a few crops is the vulnerability to natural influences like diseases, as shown with the example of the coffee rust disease. This disease affected Central America, Colombia and Peru and its consequences have been felt throughout 2012 and 2013, which is the period, the 2015 data analyses (ECLAC et al., 2014). This may explain the bad performance of Colombia, whose major crop cultivated is coffee (see country profiles in

[30] In order of magnitude of agricultural land as defined by the FAO: Brazil (2.76 Mio. km^2), Mexico (1.07 Mio. km^2), Colombia (426,000 km^2), Panama (226,000 km^2), Cuba (64,000 km^2).

Table 2 in Appendix C). Worldwide, the most important coffee producer is Brazil (Daviron and Ponte, 2005), which in contrast with Colombia, performed best throughout the three periods. Brazil was not affected by the coffee rust disease (ECLAC et al., 2014), which buoyed prices (especially, for Arabica, see Figure 8) and therefore, profited from the situation, which explains the good performance of the value added. Brazil consists of a lot of different climates and soil types and therefore, has the natural possibility of cultivating a much bigger variety of crops than an island-country like Cuba. Still, as a competitive exporter having relatively open trade policies, Brazil concentrates on the plantation of few export crops (OECD, 2013). In Brazil, three quarters of the agricultural area is cultivated with grains and legumes (rice, maize, soybean, common beans, sorghum and wheat). Along with sugar cane, coffee, cassava and citrus, these crops account for just over 95% of the agricultural area (FAO, 2004).

For agricultural investment, one can see that all countries first decrease (between 1994 and 2003) and then increase between 2003 and 2015. This is partly due to the lower maximum value for the 2015 data, to which the countries are compared (relative approach). Here one can see that the decrease (between 1994 and 2003) for Mexico, Cuba and Brazil is rather equal, but the increase for Mexico (between 2003 and 2015) is less than that of Cuba and Brazil and the scores are somewhat lower than the ones of those two countries. As this indicator only takes into account investments in agricultural machinery, it is hard to make conclusions for general investment in these countries. However, it indicates a trend, which can be compared to literature on the development.

For Mexico, the literature shows that the investment and credit structure changed considerably with the liberalization process starting in the 1980s and the completion of NAFTA. The Producer Support Estimate (PSE)[31] decreased immediately after the entry into force of the agreement, which was mostly due to the 'Tequila crisis' and has since then (until 2012) increased, but has not reached the levels of 1986–88 (OECD, 2013). Furthermore, this public spending in the agricultural sector was evaluated recently by the OECD to be relatively ineffective (OECD, 2014). The OECD report from 2013 on agriculture in emerging economies, for example, concludes that the agricultural support should shift towards innovation and infrastructure in concordance with environmental sustainability, instead of subsidies on inputs (OECD, 2013). The 'Tequila crisis' also

[31] The definition of the OECD for PSE is „The Producer Support Estimate (PSE) is an indicator of the annual monetary value of gross transfers from consumers and taxpayers to support agricultural producers, measured at farm gate level, arising from policy measures, regardless of their nature, objectives or impacts on farm production or income." (OECDStats, 2003)

limited the US inversion, which remained low, although was expected to rise with the conclusion of NAFTA (Yunez-Naude, 2002). Additionally, the Law on Sustainable Rural Development, abolished the General Law on Rural Credits in 2001 and the creation of a new rural funding was still not implemented in 2014 (Menéndez Gámin and Palacio Muñoz, 2014). Concerning credits to agriculture, total credits (annual average) shrank by one third between the time periods 1990-96 and 1996-2000.[32] The public share of it decreased drastically from 55% in the 1980s, to 25% during the 1990s (Yunez-Naude, 2002). These decreasing investment and credit flows, both from the private and state sector, are also reflected with the outcome of the SA reflecting worse development than Brazil and Cuba (which had at all times a higher score than Mexico). On the contrary, Brazil has a wide range of policies in place, according to the assessment of the OECD (2013). These include guaranteed minimum prices and a credit system providing credits at preferential rates and debt rescheduling for farmers, which is also reflected in a remarkable increase of the H_{trac} between 2003 and 2015.

The main objectives of NAFTA as stated by the State Secretariat for agriculture and hydraulic resources (SARH) in 1992 were to favor capitalization in the countryside, promote crop restructuring and develop the agro-industry (Appendini, 1994). An increased foreign investment in the national agricultural sector should multiply the expected gains from trade (Ros, 1994). When looking at the foreign direct investment (FDI) in Mexico in the primary sector, one can observe that in absolute and relative terms (compared to total investment) investment is fluctuating, but still remaining at a low level, especially when compared with other Latin American countries. In the report of the Center for the Study of Public Finances (CEFP, 2005) of the Mexican government, the FDI in Mexico is compared to five other LA countries (Argentina, Brazil, Chile, Colombia and Ecuador). This comparison shows that the investment in absolute terms in the period 1996 to 2003 for Mexico was always the lowest, except for the years 1996 and 2000, where it was lower for Colombia. The aggregated FDI for Mexico over this period of eight years was between three (Colombia) and 22 (Argentina) times lower than for all the other countries. Furthermore, the negotiators hoped that the agreement would bring economic and political stability, but it actually led to the Chiapas conflict, which was a reaction to the amendment of Article 27 and the liberalization of agriculture having adverse effects on the rural, mostly indigenous, population of Chiapas. It initiated the

[32] In the period 1990-94 annual average of total credit to agriculture was around 55 (Mio of 1995 pesos), 1994-96 59 Mio and 1996-2000 35 Mio (Yunez-Naude, 2002).

same day as the agreement entered into force and also fostered the development of the crisis of 1994/95 (Musacchio, 1012). Furthermore, the huge difference in public support and subsidies of the agricultural sector between the parties to the FTA, which are between two (Canada in 2001) and four times (USA in 2001) higher than the ones for Mexico, led to what scholars who oppose the FTA call 'structural defect' of the FTA (Puyana and Romero, 2006). This is also reflected by the economic indicators of the SA, which shows a clear decline over time and a development, which lies behind the one of comparable Latin American countries, like Brazil or Cuba.

5.2.2. Social development

Looking at the development of the social index of those countries where sufficient data is available (Panama and Colombia 2003 and 2015 and Mexico over all three periods), we can see that for both Panama and Colombia the situation was improving. Contrary, for Mexico it was deteriorating between 2003 and 2015, which can be traced back to the bad performance of the rural poverty indicator.

The water access in rural areas was increasing in all countries and reached a score of more than 8.5 for all countries for the 2015 data, with the exception of Colombia (7.4). Mexico had the highest score with 9.0. This is in accordance with the report on the MDG from 2014, which states that the goal to half the share of the people who did not have sustainable access to improved sources of safe drinking water had already been met in 2012 (UN, 2014a). With an average percentage of 94 percent in 2012, the LAC region is the region with the highest share of all non-developed regions. Due to this general improvement and high standard for all countries, the second social indicator of rural poverty, although available for few countries, is of greater meaning to assess the development of the social dimension.

For both Panama and Colombia, rural poverty increased significantly between 2003 and 2015 (albeit starting from a very low level). It must be noted that these two assessment periods encompasses the economic crises. At the same time, Mexico fell back to a level even lower than the score of 1994. The report on rural poverty of the IFAD (2010) affirms that one generally can observe great dynamism around the poverty line. This means that people move in and out of poverty rather quickly. This dynamism may have caused the drastic increase in poverty for Mexico as poverty is often linked to the overall performance of an economy (ECLAC et al., 2012) and the Mexican economy was affected to a large extent by the worldwide economic crisis, beginning in 2008. The

Mexican GDP showed the sharpest decline of all Latin American countries of –6.6% in 2009, which was mostly due to the economic ties and dependencies on the USA (Angeles Villarreal, 2010). A confirmation of this theory could be given with data on the rural poverty gap index, which assesses the average poverty gap in the population as a proportion of the poverty line, therefore depicting the intensity of poverty. This data over time is unfortunately neither available for Mexico, nor for the other countries assessed.

Furthermore, some groups, like women and indigenous peoples, tend to have a higher risk of being poor in rural areas due to exclusion and power inequalities in many societies (IFAD, 2010). This gap between the indigenous and non-indigenous population was confirmed for Mexico and Panama in household surveys and appeared to be increasing in Panama between 2002 and 2010, and was much higher for Panama (around 40%) than for Mexico (around 10%) (ECLAC et al., 2012). Mexico is the country with the largest indigenous population on the entire American continent, with more than 15 Million people,[33] according to the report of the International Work Group for Indigenous Affairs (IWGIA, 2012). Panama (418 thousand or 12.7%), Colombia (1.45 Mio or 3.5% of the total population) and Brazil (817 000 or 0.42%) have a (much) lower absolute and relative amount of indigenous population (IWGIA, 2012).[34] The share of indigenous people corresponds to the order of magnitude the countries reached in the SA in 2015, corresponding to Mexico (13%, 1.5), Panama (12.7%, 3.4) and Colombia (3.5%, 4.0). In the proposal of the Open Working group on Sustainable Development Goals (UN, 2014b), one of the proposed targets is to double the productivity and incomes of small-scale food producers, with a particular focus on indigenous people and women (UN, 2014b). This underlines the importance of these groups for sustainable rural development.

Another explanation for rural poverty is given by the report of the ECLAC et al. (2012), which finds that the poverty rate is generally higher for those households depending on agricultural income or transfers. The report distinguishes between agricultural, non-agricultural and pluri-active rural households and comes to the conclusion that for Panama and Mexico, agricultural-dependent households have a much higher poverty ratio than those with a non-agricultural income. This implies that if non-agricultural income possibilities are created in rural areas, people could escape from poverty. The poverty report of the IFAD (2010) stated that the non-farm income in rural

[33] This would be a percentage of 13% of the total population, when using the population data as provided by the World Bank Indicators for 2010 (World Bank Group, 2015).
[34] For Cuba there is no country report available, probably due to the low numbers of indigenous people.

Mexico increased significantly between 1992 and 2002, which provides an explanation for the increase between 1994 and 2003. Unfortunately, there is no data for more recent development available.

Connected to the issue of sources of income, is the issue of structural change. This relates to the process of a decreasing share of people working in agriculture (often connected to subsistence farming) and an increasing economic importance of the goods and services producing sector. This process is often connected to productivity increases in agriculture and the creation of large-scaled agricultural structures. While in 2001 all countries, but Mexico, had a percentage of employment in agriculture beyond 20%, the most recent data[35] (Mexico (13%), Brazil (15%), Panama (17%), Colombia (17%) and Cuba (20%)) shows a much lower share (see country profiles in Appendix C Table 2). Still, there is no clear correlation between structural change and rural poverty, as high rates of rural poverty were found for both countries with high and low agricultural employment (ECLAC et al., 2012). A working paper of the National Bureau of economic research of the US on structural change, found that in Latin American countries, structural change has often been growth reducing, in contrast to most Asian countries (McMillan and Rodrik, 2011). This is evidence for high heterogeneity and different effects structural change can have on the countries. Structural change enhances the differences between coexisting small-scale, subsistence farmers and export-oriented large-scaled producers, which can be observed in nearly all Latin American countries. This dual structure or structural differences are pronounced in all countries, but to different extents, with the exception of Cuba due to the specific political situation after the revolution. In Cuba, the large farms (*latifundios*) were eliminated and the maximum landholding limit was set first to around 400 ha and in the Second Agrarian Reform of 1963 to 67 ha for individuals (Funes-Monzote, 2006).

This dual structure is also influenced and characterized by the colonial administration, presence of indigenous population and agricultural reforms. As an example, in Brazil standing under the Portuguese Crown during the colonial administration, land could initially only be acquired through donations by the Crown, which fostered the development of illegal, small-scaled subsistence farming, especially in the south(east) of the country next to large *latifundios* (FAO, 2004). In Mexico, on the other hand, the agricultural structure was, and still is to a certain extent, influenced by the Mexican

[35] Most recent data is for Brazil, Cuba and Mexico 2011 and for Colombia and Panama 2012.

Revolution, whose leading slogan was 'Tierra y Libertad' – 'Land and Freedom', which invokes the collective memory concerning land property and rural development. Community farming like in the *ejidos* is mainly done for subsistence farming and was meant as a strategy to reduce poverty in rural areas. Nowadays, they exist next to large-scale farming entities. A targeted agricultural policy has to address this dual structure and has to respond to the different needs of commercial producers and subsistence farmers, as was recommended for Mexico by the OECD in its latest report on agriculture (OECD, 2014).

According to the report of the ECLAC et al. (2012), structural change can also be seen as a chance to reduce development gaps by offering non-agricultural employment. This leads towards higher equality when productive development policies are applied and agricultural development is integrated within social protection policies, labor market policies, the introduction of new technology and a focus on the promotion of education in rural areas. An important issue here is the diversification of the rural economy, especially in sectors with high internal and external demand, including also the strengthening of already existing agricultural activities, especially in countries like Mexico where the percentage of people working in agriculture is already relatively low. In this sense, the access to markets, information and infrastructure of small holders is crucial (UNEP, 2006). The rural poverty report, for example, states that in Mexico smallholders are only marginally engaged with markets (IFAD, 2010). As a result, the integration of women and young people (e.g. taking advantages of new technologies and increasing education possibilities) into the labor market is crucial, as these groups tend to be exposed to poverty more often (ECLAC et al., 2012). This increased importance of salaried labor in rural areas requires an integration of agricultural policies with labor policies. In addition, family farming continues to play an important role in Latin American countries and hence should be enhanced to increase the diversification of the rural economy, which should be done on a territorial level rather than by sectoral policies (ECLAC et al., 2012).

Mexico has been undergoing this structural change roughly for the past 20 years, during which time it halved the share of people working in agriculture from 26% (1991) to 13% (2011) (World Bank Group, 2015) and obtained an increasing productivity in its primary sector (for agriculture 23.4% increased efficiency between 1993 and 2001 (Puyana and Romero, 2006)). Already in 1994, economists were predicting that the agreement would have negative effects on rural employment (Ros, 1994) and that the main losers of the agreement would be small farmers (Puyana, 2012). The main problem was that too few working opportunities were created in other sectors, which could have absorbed the then workless farmers, who subsequently became unemployed (Puyana and Romero, 2006). As a consequence, the occupation in the informal sector was increasing, while real wages were decreasing despite the improved productivity (Puyana and Romero, 2006). This missed opportunity of taking advantage of the structural change is probably one of the reasons for the extremely high rural poverty in Mexico.

5.2.3. Ecological development

The ecological dimension is somewhat difficult to interpret as there are data gaps making it hard to compare the aggregated index over time, which is why one should rather focus on the underlying indicators. For Mexico, an increase between 2003 and 2015 for all the indicators but for the pesticide input can be observed. For Cuba, the two available indicators *nin* and *wwi* declined and Colombia also showed a decline between the 1994 and 2015 levels. As there is no data for Cuban pesticide inputs available, the aggregation into the *EcolSI* is biased, because the pesticide scores are rather high for the other countries, resulting in a raised aggregated index.[36]

As there are absolute optima set in the ecological dimension, one has to consider the evaluation methodology when interpreting the results. All the countries, except Colombia in 2015, have an N use below the level assumed optimal. The increase in score for Mexico, Panama and Brazil was therefore due to an increased consumption of fertilizers. For the decreasing scores of Cuba and Colombia, there are different reasons at stake – for Cuba it was due to a decreasing usage, while for Colombia it was due to a dramatic increase of inputs exceeding the assumed optimum (from 96 kg/ha in 2003 to 160 kg/ha in 2009/10). The underlying reasons can be found in the economics of fertilization stating that fertilization rates are closely related to crop output prices. Low and unstable commodity prices are the main constraints for fertilizer use, especially for small-scale farmers (FAO, 2006). Another constraint is the access to credits, market integration and green revolution models or policies introduced in the single countries (UNEP, 2006). This means that the agricultural structures and farming systems as described in the previous sub-chapters influence the amount of fertilizers used. Large privately owned farms have a fertilizer use of close to the optimum, while smallholders and subsistence farmers consume very little fertilizers (FAO, 2006). However, the use of fertilizers

[36] This can be proven when looking at the estimates, where the Cuban scores are much higher than in the original calculations and the overall *EcolSI* shows a rather steady, slightly declining development.

depends a lot on the application and the know-how, which is why the use of means-based data has its short-comings.

Furthermore, (geo-) political issues affect the supply and usage of fertilizers: in Cuba for example, all the fertilizers have to be imported, as the lack of raw materials and spare parts have resulted in the fertilizer-producing plants in Cuba being out-of-use for some years. The economic constraints in this country led to an increased use of organic manures and biofertilizers (e.g. worm humus and compost). However, they could not get close to the recommended fertilization levels as defined by agricultural institutions in Cuba (FAO, 2003a), which is reflected in the declining fertilization score of Cuba in the SA. Also, subsidies and support programs for small-scale farmers, as well as investments in agricultural research and development, are crucial. In Mexico for example, there has been a progressive disengagement of the state in agricultural R&D, which declined by 95% between 1982 and 2001 (FAO, 2006). Also the decline in PSE and the decrease of a rural credit system as described in the previous sub-chapters influences the possibilities of investing in agri-environmental inputs.

Additionally, local peculiarities should be taken into account, especially concerning the natural conditions. In Brazil, for example, N usage in relation to that of P and K is comparably low when compared to international standards. This is due to the fact that regions with increased cultivations have P as the limiting factor (FAO, 2006). Additionally, soy beans, which account for a large part of Brazilian cash crops being legumes, do not need mineral N fertilization (FAO, 2004). Still, the fertilizer levels in Brazil are rather close to the optimum with a score between 6.1 and 6.7. This can also be traced back to national investment programs and agricultural policies: In Brazil there is a wide range of policies in place, including guaranteed minimum prices and a credit system providing credits at preferential rates and debt rescheduling for farmers (OECD, 2013). As shown by the report of the FAO (2006) on “Fertilizer use per crop” there is a close relationship between stable crop prices and increased fertilization. Measures like this can help to support small-scale farmers to invest in infrastructure and technology, which increases efficiency, but also facilitates the work of the farmers.

Concerning pesticide use, the scores were mostly decreasing (except for Colombia in the period 2003 to 2015, which increased from a very low level in 2003: 0.4 to 1.6 for 2015) and are mostly on a fairly high level (seven and above) (again, other than Colombia, which has very low scores for the two most recent periods). This means that the countries have increased their pesticides input, but from a fairly low level. Input-related increases are strongly connected to investment in agriculture and to industrialization of the agriculture sector (FAO, 2013) and like fertilizer use, are more typical for larger-scale agricultural systems. The access and knowledge on agricultural technology is often distributed unevenly within the countries. In Brazil, as mentioned in the previous sub-chapters, the average field and farm sizes vary depending on their location – it is rather small in the Northeast (with 68% of the farms having less than 10 ha in 1995/96), while the Centre-West contains mostly large-scale farming systems (4% more than 2000ha, 15% more than 500ha). These differences are also reflected in the usage of agricultural technology and inputs, such as lime and fertilizers, irrigation and pest control, as assessed by the Brazilian Statistics Institute (IBGE) in 2003 (FAO, 2004). This suggests that it would make sense to look at a more detailed depiction on the regional or local level, especially for the agricultural input indicators.

Concerning the water input, Mexico (although slightly increasing from 4.0 in 2003 to 4.1 in 2015) and Panama both have a rather low score, which in absolute terms means that more than three quarters of the water used is employed in agriculture. Unfortunately, this score does not provide information on the absolute amount of freshwater available in the countries. Looking at the annual natural renewable freshwater resources of the five countries analyzed, one can see that Cuba has the lowest, followed by Panama, Mexico, Colombia and Brazil.[37] The score for Mexico is therefore particularly concerning, when considering that Mexico, compared with its population and size, has only 450 km^2 per year (FAO, 2003b). In addition, the water shortages are also distributed unevenly throughout the country. Mexico has arid and semi-arid regions particularly in the North of the country, where precipitation is scarce (FAO, 2003b). This underlines the necessity of investigating the development at a higher resolution on a regional level.

The stable, but rather low, scores for Mexico can also be traced back to the fact that with the abolishment of subsidies and fixed prices for basic crops and staple food like maize and beans, the fairly water-intensive fruits and vegetables, which are exported, increased in number. At the beginning of the 1990s, fruits and vegetables already represented 20% of the total value of Mexican agricultural exports and were mostly cultivated on irrigated land on the Northern pacific coast (Appendini, 1994). In particular, during the 1980s and the beginning of the 1990s, cultivated and cropped area endowed

[37] Brazil as the water richest country has 8200km2, Colombia also being among the top-10 water richest country has 2100 km2, Mexico 450 km2, Panama 150 km2 and Cuba 40km2 per year (FAO, 2003b).

with irrigation facilities increased and then decreased between 1995 and 2000 (Yunez-Naude, 2002). This irrigation practice explains the high percentage of water use in the agricultural sector for Mexico, which led to the rather low scores.

6. Summary and Conclusion

In this thesis, an agricultural sustainability assessment (SA) was developed to compare the development of five Latin American (LA) countries over the past 20 years, in order to answer the question as to whether Mexico has experienced a poorer development than the other four countries, i.e. Brazil, Colombia, Cuba and Panama.

The literature review investigates the methodology and the calculation methods for normalization, aggregation and weighting used for renowned, peer-reviewed, non-agricultural SA such as the HDI and the SSI. Additionally, literature on the theoretical conception of the methodology of an SA, like the conception model of Von Wirén-Lehr (2001) or the methodology for sensitivity analysis and aggregation methods of Saisana et al. (2005) are analyzed. This methodology as used for different SAs described in the literature review was adjusted to compare national, agricultural data. Furthermore, the indicator selection criteria from different agricultural SAs were adapted using the sustainability definition for agriculture as formulated by the FAO. The selection of the indicators was constrained by the existing data sets provided by the FAO and the World Bank and did not consider indicators on trade. This is because trade itself should not be evaluated as sustainable or unsustainable. For the evaluation, one has to consider the effects trade has on the different aspects of agricultural production.

In order to analyze these effects, a holistic assessment is necessary, because agricultural development is a cross-sectional matter, which influences and is mutually influenced by a variety of sectors and issues. Issues of rural development and poverty are as influential as investment in agriculture, rural infrastructure and agri-environmental inputs. All these issues influence the development of the primary sector and define its sustainability and hence none of it should be disregarded when assessing the SD of a country's agriculture. In addition to the indicators considered here, other matters should also be regarded when performing a more detailed SA, which would be beyond the scope of a Master thesis. A broadening of the issues concerned can be achieved by gathering new data, rather than relying on existing data. Additionally, non-quantitative information on issues like access to information and markets for small-scale farmers or the regulation of right of ownership of land could also be included.

According to the overall *SAI*, Mexico had its best score in 2003, while all the other countries had their best performance in 1994, which is the year Mexico had the worst performance. A possible explanation is the severe crisis Mexico was facing in 1994/1995, which also had consequences on the agricultural development. However, the best score of Mexico (5.1 in 2003) is much lower than the best scores of the other four countries. Regarding the economic development, two of the compared countries (Brazil and Cuba) perform better and the other two (Colombia and Panama) perform worse than Mexico concerning the development over the last 20 years, up until the current situation. In the social dimension, the Mexican scores for 2015 are a lot lower than the other four countries and also with regard to the development over time, Mexico performs worse than most of the analyzed countries, which is mainly due to the extremely high rural poverty rate. Concerning the ecological dimension, data gaps and difficulties concerning the determination of thresholds prompt the need for an increase of the resolution of the assessment scale considering regional, natural and climatic differences at higher spatial resolution. However, the Mexican score for the ecological sub-index for the most recent data ranks second (after Brazil) and a quite stable development can be observed for the index and the individual ecological indicators.

Due to the fact that this SA gives only a descriptive picture on the development of agricultural sector in these countries, but does not explain the reasons causing it, the discussion compares the empirical results to existing publications about the countries analyzed. This comparison showed that the Mexican economy is strongly tied to the economic development of the USA, which was strengthened further with NAFTA. This makes the Mexican economy more vulnerable to recessions in the USA than the other LA countries, which can be seen with the longer duration and the higher intensity of the global financial crisis in Mexico. To decrease this vulnerability, a further trade partner and commodity diversification of the exports should be accomplished.

Another critical issue was the structural change and transition in agriculture in Mexico. When looking at the data on employment in agriculture, Mexico has the lowest share both in 1994 and today. This implies that structural change started earlier and probably faster than in the other four countries. Such a structural change can help to get rural people out of poverty, but can also deepen the poverty gap. Major changes like the transition from an agricultural society to an industrialized country (or emerging country), therefore requires policies in place to shape the future development. An FTA always produces winners and losers, which the latter should be compensated for. Therefore, policies should be implemented to mitigate the negative effects and foster non-agricultural incomes in rural areas. Additionally, non-agricultural income can strengthen rural structures and decrease poverty. Furthermore, the dual structure of a co-existence of small-scale (often indigenous, often subsistence) and large-scale farmers, which is rather pronounced in Mexico, but also in the other countries analyzed, has to be approached with targeted policies.

If progress in agricultural development is desired, investments in the agricultural sector and rural infrastructure, agricultural research and technology development are essential. This means that rural producers need access to credits, technology and intermediary inputs, which are facilitated by the extension and improvement of rural infrastructure. In Mexico, with the liberalization process beginning in the 1980s and to a much larger extent with the conclusion of NAFTA and the Tequila Crisis in the mid-90s, the national and foreign investments and rural credits, as well as investment into agricultural research retreated. This deepened the dual structure even more, and increased rural poverty, explaining the low scores for this indicator and the low social sub-index.

With the establishment of an FTA with the highly industrialized neighboring countries USA and Canada, Mexican officials wanted to encourage the country's economic and political development. Its agricultural development seemed to be less of a priority because, already prior to the conclusion of the FTA, the agricultural sector, especially small-scale farmers, were expected to be among the losers. This treatment resulted in foregone chances of structural change, which (with appropriate policies in place) could have offered a possibility for rural areas.

This master thesis elaborates an option how agricultural development could be evaluated. Such a monitoring or evaluation is also one of the emerging questions, which have to be answered for the development of the Sustainable Development Goals by the UN, which are being negotiated at the moment, i.e. in 2015. One of the proposed goals addresses the promotion of sustainable agriculture and food security. For a thorough assessment of the primary sector, a more detailed analysis should be performed and other factors influencing the outcome have to be tested. For the comparison, the targets of ecological indicators should be effect-based and the target values adjusted to the natural situation in the countries. Furthermore, the Mexican data might be influenced to a greater extent by the economic situation, because all three assessment periods coincide with an economic recession or its direct aftermath, but also the other countries faced to different extents serious crises in the assessment periods. These framework conditions might influence the outcome of the comparison. However the analysis provides a first insight and can describe various issues at stake in the countries analyzed.

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Appendix A- Calculations, Methodology and Data

Table 1: Data of for all selected indicators. Source: FAO, 2015 and World Bank Group, 2015.

	Unit	Brazil			Colombia			Cuba			Mexico			Panama		
		1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015
vad	US$	2024.0	3249.4	5304.6	3195.1	2985.5	3698.2	2258.5	3385.0		2732.3	3360.9	4169.9	2447.3	3667.7	3955.2
yld	kg/ha	2384.0	3120.9	4678.4	2551.8	3904.2	3632.7	1697.5	3077.8	2867.0	2559.1	2985.2	3419.7	1863.1	1887.3	2165.6
trac	nr./100km^2	143.5	123.2	116.9	92.2			208.3	201.6	205.3	121.4	103.0	98.6	118.7		
pov	%					58.9	44.8				69.3	60.9	63.6		63.4	49.7
wax	%	70.9	78.1	84.9	69.6	71.6	73.5	75.6	79.8	86.9	64.6	77.7	90.1	70.6	78.6	86.2
nin	kg N/ha		30.2	34.3		96.3	160.1		10.7	9.6		33.1	40.0		22.6	27.0
pin	kg/ha	0.6			3.8	24.9	14.9					1.4	4.6		7.4	
wwi*	%	60.9	61.8		37.0	38.9		51.3		56.1		77.3	76.8		75.8	

Explanation: **Yellow Background**: 2006-07; *Different comparison years: 1995-96, 2000-2002, 2007-2009;

Table 2: Most recent year for Mexican data available, which are used for 2015; minimum or maximum values worldwide only for those indicators they are necessary for the calculations. Source: Own depiction. Data: FAO, 2015 and World Bank Group, 2015.

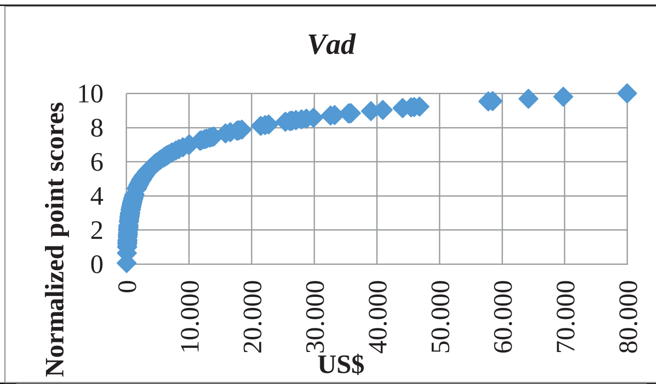
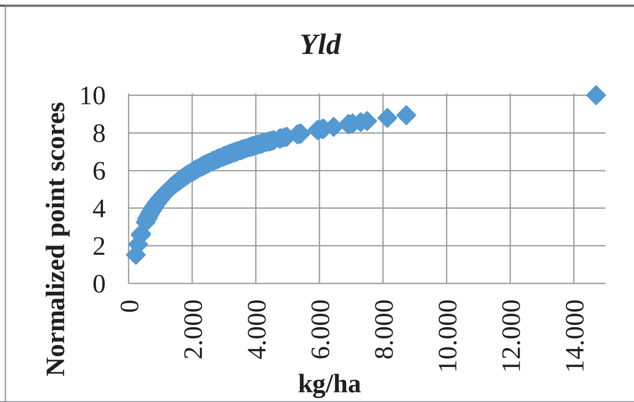
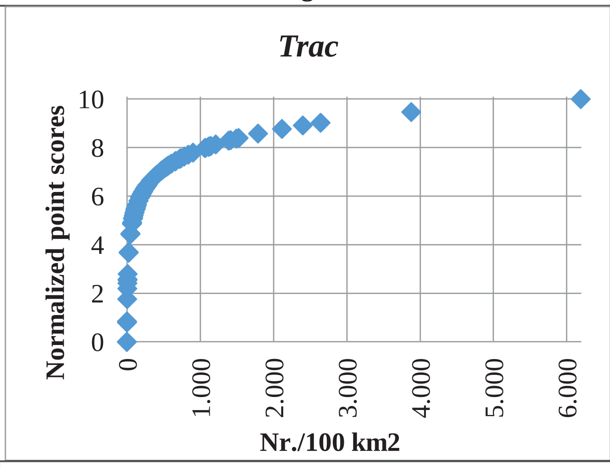
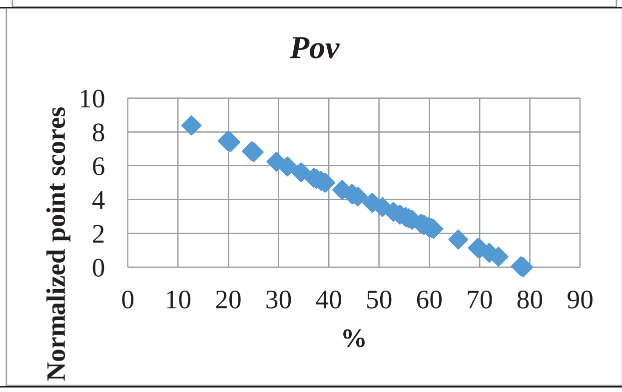
	Unit	Year used for 2015	Minimum or Maximum	Min/Max observed 1994	Min/Max observed 2003	Min/Max observed 2015
vad	US$	2012-2013	Max	37241.6	80010.8	143485.1
yld	kg/ha	2012-2013	Max	7644.0	14708.8	74146.7
trac	nr./100km^2	2006-2007	Max	4454.1	6195.4	2613.3
pov	%	2012-2013	Max	82.1	78.8	74.9
wax	%	2011-2012	Min	2.8	13.1	8.8
nin	kg N/ha	2009-2010				
pin	kg/ha	2009-2010				
wwi*	%	2007-2009				

Table 3: Point Scores of the underlying indicators and sub-indices, as well as the overall Sustainable Agriculture Index for the five countries over three periods of time for the estimated values, which have a green or red background. Source: Own calculations.

	Mexico			Panama			Cuba			Brazil			Colombia		
	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015
SAI	**4.8**	**5.1**	**4.9**	**4.8**	**4.7**	**5.3**	**5.3**	**5.2**	**5.2**	**5.6**	**5.5**	**5.8**	**6.1**	**4.6**	**4.8**
EconSI	**6.1**	**5.7**	**5.5**	**5.9**	**5.7**	**5.3**	**6.1**	**6.1**	**5.9**	**6.0**	**5.8**	**5.9**	**6.0**	**5.8**	**5.3**
Prd	**6.5**	**6.0**	**5.3**	**6.1**	**5.7**	**4.9**	**5.9**	**6.1**	**5.2**	**6.2**	**6.0**	**5.7**	**6.7**	**6.2**	**5.2**
Vad	5.7	5.4	5.3	5.6	5.5	5.2	5.4	5.4	5.4	5.2	5.4	5.6	6.0	5.2	5.1
Yld	7.4	6.7	5.3	6.7	5.8	4.6	6.5	6.8	5.0	7.3	6.8	5.8	7.4	7.3	5.4
Trac	**5.7**	**5.3**	**5.8**	**5.7**	**5.7**	**5.7**	**6.4**	**6.1**	**6.8**	**5.9**	**5.5**	**6.1**	**5.4**	**5.4**	**5.4**
SocSI	**3.1**	**4.1**	**3.7**	**3.7**	**3.7**	**5.3**	**4.3**	**4.2**	**4.6**	**4.2**	**4.2**	**4.6**	**4.2**	**4.0**	**5.3**
Pov	**1.6**	**2.3**	**1.5**	**2.0**	**2.0**	**3.4**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**2.5**	**4.0**
Wax	**6.4**	**7.4**	**8.9**	**7.0**	**7.1**	**8.5**	**7.5**	**7.2**	**8.6**	**7.0**	**7.0**	**8.3**	**6.9**	**6.3**	**7.1**
EcolSI	**5.7**	**5.7**	**5.8**	**5.0**	**5.0**	**5.2**	**5.5**	**5.4**	**5.2**	**7.0**	**6.9**	**7.1**	**9.0**	**4.2**	**3.9**
In	**8.0**	**8.0**	**8.2**	**5.9**	**5.9**	**6.3**	**4.1**	**4.1**	**3.9**	**7.8**	**7.8**	**8.2**	**9.5**	**2.0**	**1.7**
Nin	6.5	6.5	7.4	4.8	4.8	5.6	2.5	2.5	2.2	6.1	6.1	6.7	9.6	9.6	1.9
Pin	9.9	9.9	8.9	7.2	7.2	7.2	6.8	6.8	6.8	10.0	10.0	10.0	9.3	0.4	1.6
Wwi*	**4.0**	**4.0**	**4.1**	**4.3**	**4.3**	**4.3**	**7.4**	**7.1**	**6.9**	**6.3**	**6.2**	**6.2**	**8.6**	**8.5**	**8.5**

Explanations:
Red Background: Estimates (scores of the previous or following period of the respective countries or average of predecessor and successor if both are available)
Green Background: where there is no data available for none of the time periods, the average of the data of the other four countries for this indicator is taken
Yellow Background: changed years (2006-07)
*****Different comparison years: 1995-96, 2000-2002, 2007-2009

Table 4: Indicators, description of their calculation and correlation between values and score for all countries in 2003. Source: Own Depiction. Data: FAO, 2015 and World Bank Group, 2015

Indicator	Correlation between values and scores for all countries worldwide in 2003 (average 2002-2004)
Agricultural productivity (*prd*) **Formula:** $H_{prd} = \sqrt[2]{H_{vad} * H_{yld}}$	
Agriculture value added per worker (*vad*) [US$] **Formula:** $H_{vad} = \frac{\ln(vad) - \ln(81)}{\ln(vad_{\max}) - \ln(81)}$ vad_{max} (1994)= 37,241.6 vad_{max} (2003)= 80,010.8 vad_{max} (2015)= 143,485.1 **Range of validity**: $81 \leq vad \leq vad_{max}$	
Cereal yield (*yld*) [kg/ha] **Formula:** $H_{yld} = \frac{\ln(yld) - \ln(110)}{\ln(yld_{\max}) - \ln(110)} * 10$ yld_{max} (1994)= 7,644 yld_{max} (2003)= 14,708.8 yld_{max} (2015)= 74,146.7 **Range of validity**: $110 \leq yld \leq yld_{max}$	
Agricultural machinery (*trac*) [Nr. per 100 km²] **Formula:** For $trac \geq 1$: $H_{trac} = \frac{\ln(trac)}{\ln(trac_{max})} * 10$ For $trac < 1$: $H_{trac} = 0$ $trac_{max}$ (1994)= 4,454.1 $trac_{max}$ (2003)= 6,195.4 $trac_{max}$ (2015)= 2,613.3 **Range of validity**: $0 \leq trac \leq trac_{max}$	
Rural poverty headcount ratio at national poverty lines (*pov*) [%] **Formula:** $H_{pov} = \left(1 - \frac{pov}{pov_{max}}\right) * 10$ pov_{max} (1994)= 82.1 pov_{max} (2003)= 78.1 pov_{max} (2015)= 74.9 **Range of validity**: $0 \leq pov \leq pov_{max}$	

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Improved water source, rural (*wax*)
[%]

Formula:

$$H_{wax} = \frac{wax - wax_{min}}{100 - wax_{min}} * 10$$

wax_{min} (1994)= 2.8
wax_{min} (2003)= 13.1
wax_{min} (2015)= 8.8

Range of validity: $wax_{min} \leq wax \leq 100$

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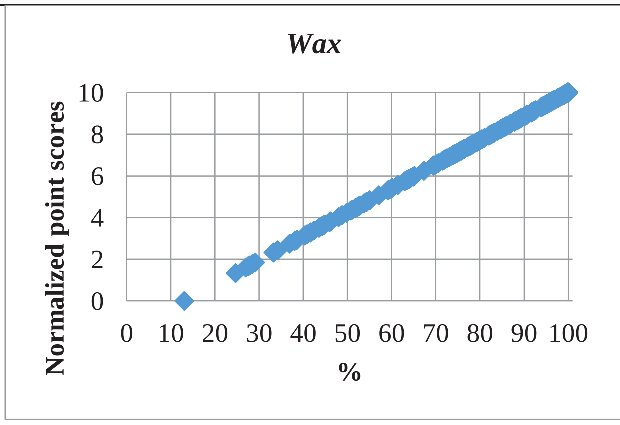

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Agri-Environmental Input (*in*)
Formula:

$$H_{in} = \sqrt[2]{H_{nin} * H_{pin}}$$

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Nitrogen Consumption arable and permanent crop area (*nin*)
[kg N/ha]
Formula:
For $nin \leq 153.5$:

$$H_{nin} = -0.00152 * nin^2 + 0.2469 * nin$$

For $nin > 153.5$:

$$H_{nin} = \frac{\ln(nin) - \ln(153.5)}{\ln(400) - \ln(153.5)}$$

Range of validity: $0 \leq nin \leq 400$

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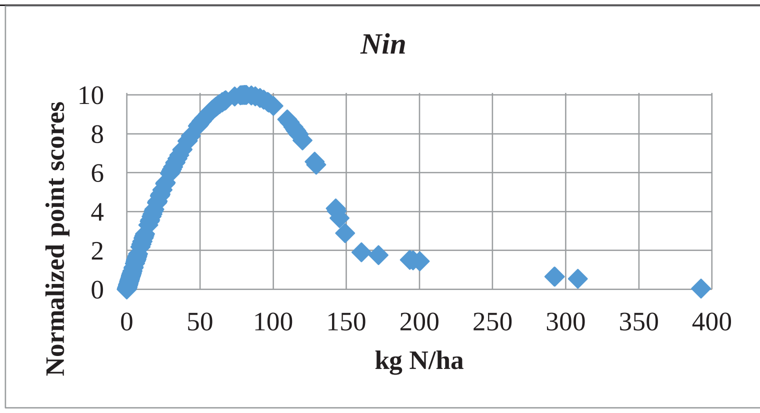

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Pesticides use on arable and permanent crop area (*pin*)
[kg/ha]

Formula:

For $pin \leq 12.5$:

$$H_{pin} = -0.051 * pin^2 + 10$$

For $pin > 12.5$: $\mathrm{H_{pin}} =$

Range of validity: $0 \leq pin \leq 30$

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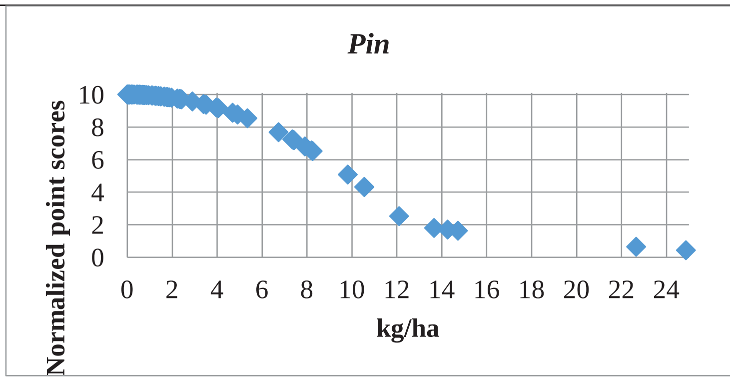

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Water withdrawal for agricultural use (*wwi*)
[%]

Formula:

$$H_{wwi} = 10 - \frac{wwi^2}{1000}$$

Range of validity: $0 \leq wwi \leq 100$

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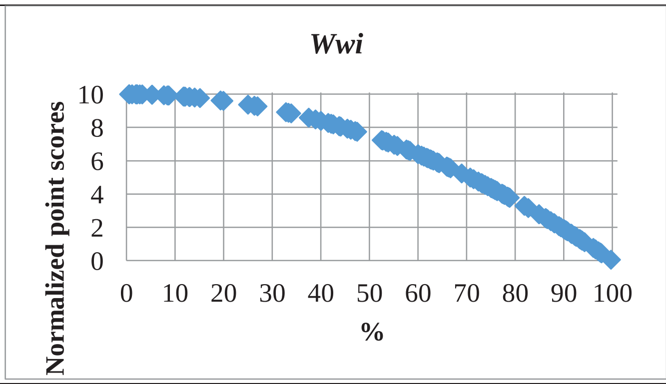

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Appendix B- Sensitivity Analysis

Explanation: Red Background: maximum deviation per row

Table 1: Sensitivity Analysis for the aggregation of the (sub-)indices. Source: Own Depiction.

	Mexico			Panama			Cuba			Brazil			Colombia		
	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015
***EconSI* (geometric)**	6.1	5.7	5.5	5.9	5.7	4.9	6.1	6.1	5.8	6.0	5.8	5.9	6.0	6.2	5.2
***EconSI* (arithmetic)**	6.1	5.7	5.6	5.9	5.7	4.9	6.1	6.1	5.9	6.0	5.8	5.9	6.0	6.2	5.2
Relative change (%)	0.2%	0.2%	0.1%	0.1%	0.0%	0.0%	0.1%	0.0%	1.1%	0.0%	0.1%	0.1%	0.6%	0.0%	0.0%
Absolute change (points)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
***SocSI* (geometric)**	3.1	4.1	3.7	7.0	3.7	5.3	7.5	7.2	8.6	7.0	7.0	8.3	6.9	4.0	5.3
***SocSI* (arithmetic)**	4.0	4.9	5.2	7.0	4.5	5.9	7.5	7.2	8.6	7.0	7.0	8.3	6.9	4.4	5.6
Relative change (%)	20.5%	15.4%	29.6%	0.0%	17.7%	9.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	9.7%	3.9%
Absolute change (points)	0.8	0.7	1.5	0.0	0.8	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2
***EcolSI* (geometric)**		5.7	5.8		5.0	5.6	7.4	2.5	3.9	7.9	6.1	6.7	8.9	4.2	1.7
***EcolSI* (arithmetic)**		6.0	6.1		5.1	5.6	7.4	2.5	4.5	8.1	6.1	6.7	9.0	5.3	1.7
Relative change (%)		5.7%	5.6%		1.3%	0.0%	0.0%	0.0%	14.0%	2.6%	0.0%	0.0%	0.1%	21.1%	0.0%
Absolute change (points)		0.3	0.3		0.1	0.0	0.0	0.0	0.6	0.2	0.0	0.0	0.0	1.1	0.0
***SAI* (geometric)**	4.4	5.1	4.9	6.4	4.8	5.3	7.0	4.9	5.8	7.0	6.5	6.9	7.2	4.8	3.7
***SAI* (arithmetic)**	4.6	5.2	5.0	6.5	4.8	5.3	7.0	5.5	6.1	7.0	6.6	7.0	7.3	4.8	4.1
Relative change (%)	5.1%	1.1%	1.9%	0.4%	1.3%	0.2%	0.4%	10.6%	5.1%	0.6%	0.9%	1.2%	1.4%	1.8%	11.2%
Absolute change (points)	0.2	0.1	0.1	0.0	0.1	0.0	0.0	0.6	0.3	0.0	0.1	0.1	0.1	0.1	0.5

Table 2: Sensitivity Analysis for the aggregated indicators. Source: Own Depiction.

	Mexico			Panama			Cuba			Brazil			Colombia		
	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015
Prd (arithmetic)	6.6	6.1	5.3	6.1	5.7	4.9	5.9	6.1	5.0	6.3	6.1	5.7	6.7	6.3	5.2
Prd (geometric)	6.5	6.0	5.3	6.1	5.7	4.9	5.9	6.1	5.0	6.2	6.0	5.7	6.7	6.2	5.2
Relative change (%)	0.8%	0.6%	0.0%	0.4%	0.0%	0.2%	0.4%	0.7%	0.0%	1.3%	0.7%	0.0%	0.6%	1.4%	0.0%
Absolute change (points)	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0
In (arithmetic)		8.2	8.2		6.0	5.6		2.5	2.2	10.0	6.0	6.7	9.3	5.0	1.7
In (geometric)		8.0	8.2		5.9	5.6		2.5	2.2	10.0	6.0	6.7	9.3	2.0	1.7
Relative change (%)		2.2%	0.4%		2.0%	0.0%		0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	59.7%	0.4%
Absolute change (points)		0.2	0.0		0.1	0.0		0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0

Table 3: Sensitivity analysis for the estimated values. Source: Own Depiction.

	Mexico			Panama			Cuba			Brazil			Colombia		
	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015	1994	2003	2015
SAI	4,4	5,1	4,9	6,2	4,6	5,3	6,8	5,1	5,4	6,9	6,1	6,6	7,2	4,4	4,0
SAI (estim.)	4,8	5,1	4,9	4,8	4,7	5,3	5,3	5,2	5,2	5,6	5,5	5,8	6,1	4,6	4,8
Relative change (%)	8,3%	0,0%	0,0%	-30,6%	3,6%	-0,2%	-28,4%	2,4%	-2,8%	-23,6%	-11,5%	-15,0%	-18,9%	3,2%	15,9%
Absolute change (points)	0,4	0,0	0,0	-1,5	0,2	0,0	-1,5	0,1	-0,1	-1,3	-0,6	-0,9	-1,1	0,1	0,8
EconSI	6,1	5,7	5,5	5,9	5,7	5,3	6,1	6,1	5,9	6,0	5,8	5,9	6,0	5,8	5,3
EconSI (estim.)	6,1	5,7	5,5	5,9	5,7	4,9	6,1	6,1	5,8	6,0	5,8	5,9	6,0	6,2	5,2
Relative change (%)	0,0%	0,0%	0,0%	0,0%	-0,2%	-8,0%	0,0%	0,0%	-2,0%	0,0%	0,0%	0,0%	0,0%	6,6%	-1,4%
Absolute change (points)	0,0	0,0	0,0	0,0	0,0	-0,4	0,0	0,0	-0,1	0,0	0,0	0,0	0,0	0,4	-0,1
SocSI	3,1	4,1	3,7	7,0	3,7	5,3	7,5	7,2	8,6	7,0	7,0	8,3	6,9	4,0	5,3
SocSI (estim.)	3,1	4,1	3,7	3,7	3,7	5,3	4,3	4,2	4,6	4,2	4,2	4,6	4,2	4,0	5,3
Relative change (%)	0,0%	0,0%	0,0%	-89,2%	0,0%	0,0%	-73,1%	-69,4%	-85,0%	-67,4%	-67,4%	-82,7%	-65,5%	0,0%	0,0%
Absolute change (points)	0,0	0,0	0,0	-3,3	0,0	0,0	-3,2	-2,9	-3,9	-2,8	-2,8	-3,8	-2,7	0,0	0,0
EcolSI		5,7	5,8		5,0	5,6	7,4	2,5	3,9	7,9	6,1	6,7	8,9	4,2	1,7
EcolSI (estim.)	5,7	5,7	5,8	5,0	5,0	5,2	5,5	5,4	5,2	7,0	6,9	7,1	9,0	4,2	3,9
Relative change (%)	100,0%	0,0%	0,0%	100,0%	0,0%	-7,2%	-34,5%	54,4%	24,3%	-13,2%	11,7%	6,1%	1,0%	0,0%	54,6%
Absolute change (points)	5,7	0,0	0,0	5,0	0,0	-0,4	-1,9	2,9	1,2	-0,9	0,8	0,4	0,1	0,0	2,1

Table 4: Nitrogen balance and actual inputs for Brazilian regions and recommendations for Cuban cereals. Source: FAO, 2003a (*) and FAO, 2004

	Nitrogen balance [kg N/ha]	Actual Input [kg N/ha]	Application rate for 60% efficiency	Point score for application rate
North	–21.4	7	42.7	7.8
Northeast	–11.8	15	34.7	6.7
Centre West	–8.6	22	36.3	7.0
Southeast	–20.4	63	97.0	9.6
South	–20.9	31	65.8	9.6
Brazil	–16.2	31	58.0	9.2
Maize (Cuba)*			85	10.0
Rice (Cuba)*			138	5.0

Table 5: Sensitivity Analysis for Nitrogen Inputs. Source: Own Depiction. Data: FAO, 2015

	Value	Original	Optimum -10%	Elasticity for Optimum -10%	Optimum +10%	Elasticity for Optimum +10%
Optimum		**81**	**72.9**		**89.1**	
Point Score 2		**153.5**	**138**		**169**	
Cuba 2015	9.6	2.2	2.5	–0.94	2.0	–0.94
Cuba 2003	10.7	2.5	2.7	–0.93	2.2	–0.93
Panama 2003	*22.6*	4.8	5.2	–0.83	4.4	–0.84
Panama 2015	*27.0*	5.6	6.0	–0.80	5.1	–0.80
Brazil 2003	*30.2*	6.1	6.6	–0.76	5.6	–0.78
Mexico 2003	*33.1*	6.5	7.0	–0.74	6.1	–0.75
Brazil 2015	*34.3*	6.7	7.2	–0.72	6.2	–0.74
Mexico 2015	*40.0*	7.4	8.0	–0.66	7.0	–0.68
Colombia 2003	*96.3*	9.6	9.0	0.75	9.9	0.29
Colombia 2015	*160.1*	1.9	1.7	0.91	3.6	4.78

Table 6: Sensitivity analysis for pesticides inputs. Source: Own Depiction. Data: FAO, 2015

	Value	Original	Optimum – 10%	Elasticity for – 10%	Optimum +10%	Elasticity for +10%
Optimum		**14.0**	**12.6**		**15.4**	
Point Score 2		**12.5**	**11.3**		**13.8**	
Brazil 1994	*0.55*	10.0	10.0	0.00	10.0	0.00
Mexico 2003	*1.40*	9.9	9.9	0.02	9.9	0.02
Colombia 1994	*3.76*	9.3	9.1	0.19	9.4	0.13
Mexico 2015	*4.55*	8.9	8.7	0.28	9.1	0.20
Panama 2003	*7.43*	7.2	6.5	1.01	7.7	0.64
Colombia 2015	*14.92*	1.6	1.4	1.15	1.8	1.13
Colombia 2003	*24.88*	0.4	0.4	1.15	0.5	1.13

Appendix C – Country data for Interpretation

Table 1: Number of countries, with whom the LA countries have a FTA agreements concluded and notified to the WTO. Source: WTO, 2015.

	LAC	USA Canada	Africa	Europe	Asia and Oceania	Total
Brazil	14	0	14	2	17	47
Colombia	17	2	14	6	15	54
Cuba	15	0	14	1	15	45
Mexico	18	2	14	7	18	59
Panama	7	2	0	5	2	16

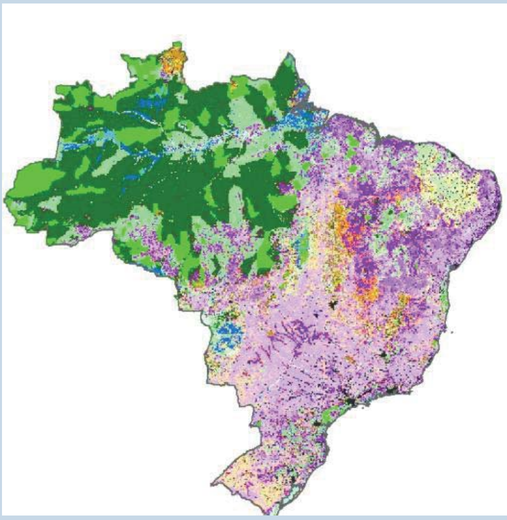
Table 2: Country data and land use maps of the five countries. Source: Own Depiction. Data: World Bank Group, 2015, CIA, 2013 and FAO, 2010.

Country Data
(CIA, 2013; World Bank Group, 2015)

Landuse Map (FAO, 2010), Legend in Figure 1 (Appendix C)

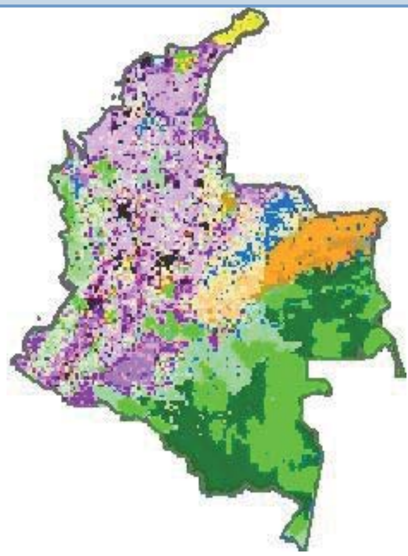
Brazil

Land area [km2]: 8,358,140
Agricultural land [% of land area]: 33.0 (2012), +0.9 pp (+2.7%) since 2003, +2.9 pp (+9.6%) since 1994
Arable Land [% of land area]: 8.7 (2012)
[hectares per person]: 0.4 (2012)
Land under cereal production [hectares]: 20,906,133 (2013)
Agricultural Value Added [% of GDP]: 5.7 GDP (2013)
Employment in Agriculture [% of total]: 15.3 (2011), -5.4 pp (-26%) since 2003, -10.8pp (-41%) since 1995
Rural Population: 29,711,670 (2013)
[% of total population]: 14.8 (2013), -3 pp (-16.7%) since 2003, -8.3 pp (-35.8%) since 1994
Major crops: coffee, soybeans, wheat, rice, corn, sugarcane, cocoa, citrus



Colombia

Land area [km2]: 1,109,500
Agricultural land [% of land area]: 38.4 (2012), +0.5 pp (+1.3%) since 2003, -2 pp (-5 %) since 1994
Arable Land [% of land area]: 1.4 (2012)
[hectares per person]: 0.03 (2012)
Land under cereal production [hectares]: 1,176,198 (2013)
Agricultural Value Added [% of GDP]: 6.1 (2013)
Employment in Agriculture [% of total]: 16.9 (2012), -4.9 pp (-22%) since 2003
Rural Population: 11,653,673 (2013)
[% of total population]: 24.1 (2013), -2.9 pp (-10.7%) since 2003, -5.7 pp (-19.1%) since 1994
Major crops: coffee, cut flowers, bananas, rice, tobacco, corn, sugarcane, cocoa beans, oilseed, vegetables

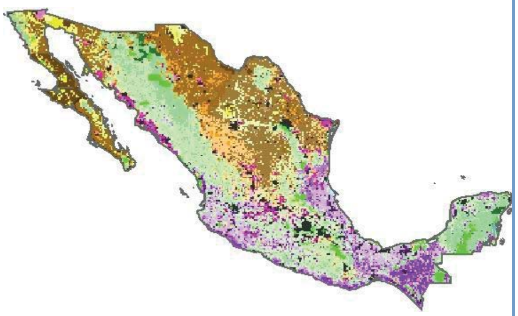


Cuba

Land area [km2]: 106,440
Agricultural land [% of land area]: 60.2 (2012), -2.2 pp (-3.5%) since 2003, -2.1 pp (-3.3%) since 1994
Arable Land [% of land area]: 30.1 (2012)
[hectares per person]: 0.3 (2012)
Land under cereal production [hectares]: 376,146 (2013)
Agricultural Value Added [% of GDP]: 5.0 (2011)
Employment in Agriculture [% of total]: 19.7 (2011), -2 pp (-9%) since 2003, -5.4 pp (-22%) since 1995
Rural Population: 2,605,515 (2013)
[% of total population]: 23.1 (2013), -0.9 pp (-3.8%) since 2003, -2.7 pp (-10.6%) since 1994
Major crops: sugar, tobacco, citrus, coffee, rice, potatoes, beans

Mexico

Land area [km2]: 1,943,950
Agricultural land [% of land area]: 54.9 (2012), +0.1 pp (+0.1%) since 2003, +0.3 pp (+0.5%) since 1994
Arable Land [% of land area]: 11.9 (2012)
[hectares per person]: 0.2 (2012)
Land under cereal production [hectares]: 9,806,421 (2013)
Agricultural Value Added [% of GDP]: 3.5 (2013)
Employment in Agriculture [% of total]: 13.4 (2011), -3.4 pp (-20%) since 2003, -10.4 pp (-44%) since 1995
Rural Population: 26,067,811 (2013)
[% of total population]: 21.3 (2013), -3.0 pp (-12.4%) since 2003, -5.7 pp (-21.1%) since 1994
Major crops: corn, wheat, soybeans, rice, beans, cotton, coffee, fruit, tomatoes



Panama

Land area [km2]: 74,340
Agricultural land [% of land area]: 30.5 (2012), +0.3 pp (+1%) since 2003, +1.7 pp (+6.1%) since 1994
Arable Land [% of land area]: 7.2 (2012)
[hectares per person]: 0.1 (2012)
Land under cereal production [hectares]: 150180 (2013)
Agricultural Value Added [% of GDP]: 3.5 (2012)
Employment in Agriculture [% of total]: 16.7 (2012), -4.4 pp (-21%) since 2003, -4.1 pp (-20%) since 1995
Rural Population: 1,314,050 (2013)
[% of total population]: 34.0 (2013), -2.9 pp (-7.9%) since 2003, -8.7 pp (-20.4%) since 1994
Major crops: bananas, rice, corn, coffee, sugarcane, vegetables

Definitions:
Arable Land: Arable land includes land under temporary crops, temporary meadows for mowing or for pasture, land under market or kitchen gardens, and land temporarily fallow
Agricultural land: arable land, land under permanent crops, and land under permanent pastures (World Bank Group, 2015)

Legend for land use maps:

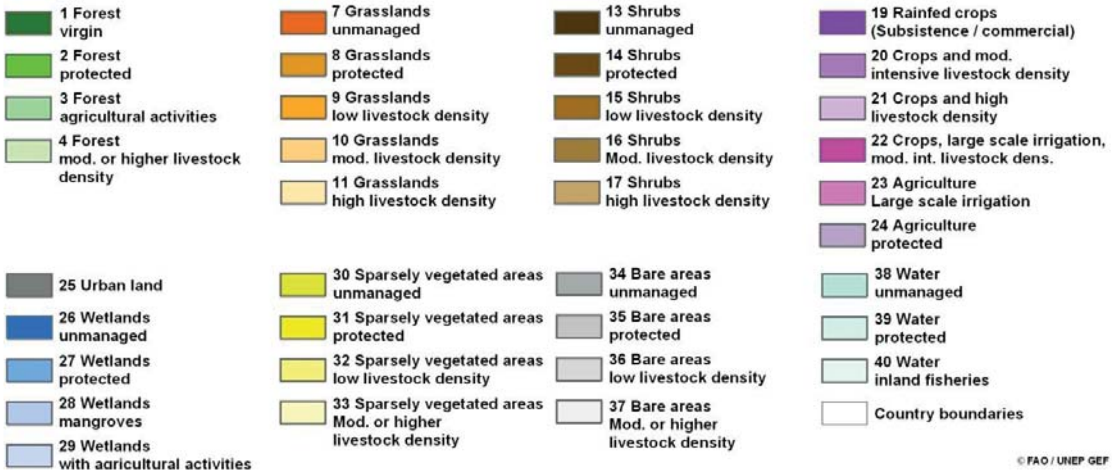


Figure 1: Land use systems legend. Source: FAO, 2010.