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Combining Environmental Footprint Models, Remote Sensing Data, and Certification Data towards an Integrated Sustainability Risk Analysis for Certification in the Case of Palm Oil

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Received: 6 December 2019; Accepted: 3 October 2020; Published: 8 October 2020

Abstract: Monitoring the potential impacts of the growing Bioeconomy (BE) is a crucial precondition for the development of viable and sustainable strategies. Potential environmental consequences from resource production for the German Bioeconomy can be assessed with the concept of environmental footprint modelling. Furthermore, remote sensing and sustainability certification are tools that can support risk assessment and mitigation i.e., regarding land use (change), biodiversity, carbon stocks, and water consumption. Thus, they can complement the results of footprint models and produce assessment results with a much higher resolution. Among other things, this can enable the development of strategies for more sustainable production practices in high-risk areas and avoid potential bans of biomass imports from entire countries/regions. The conducted case study on palm oil in this paper shows intersections between indicators used in sustainability certification systems and in footprint modelling considering processes on plantation and mill levels. Local best practices for the sustainable production of biomass are identified through a literature review and are extended by a survey, which evaluates the feasibility and conditions of implementing the selected practices on plantations. The conceptual approach outlined in this paper can be seen as a first step towards an integrated sustainability risk analysis of processes and products used within the BE that might be further developed from this starting point. It takes into account footprint modelling data, the use of sustainability certification systems, and data and results from remote sensing analyses. This will enable low-risk producers of renewable resources, who are located in regions generally flagged as high-risk when using environmental footprint modelling, not to be excluded from market activities but to set best practice examples that can then be expanded into these regions.

Keywords: Bioeconomy; environmental footprint models; sustainability certification; risk assessment; remote sensing; palm oil

1. Introduction

Mitigation of climate change and reduction of the negative impacts on the environment from economic production and industry are key global duties. The energy sector alone is responsible for 30% of global greenhouse gas (GHG) emissions entering the atmosphere [1]. The Bioeconomy (BE) is seen as an opportunity by researchers, governments, and the industry to supersede the era of non-renewable resources and technologies, to improve the health and nutrition of a growing world population, and to secure a sustainable supply of energy, water, and raw materials, while preserving soils, the climate, and the environment [2]. There is no commonly agreed-upon definition of the term Bioeconomy. The Federal Ministry for Food and Agriculture (BMEL), for instance, defines it as “the knowledge-based production and utilization of renewable resources, in order to provide products, processes and services in all economic sectors within the context of a future-capable economic system” [3]. Through a functioning and continuously developing Bioeconomy, ecologically responsible resource extraction and production of bio-based products can be linked to the maintenance or enhancement of environmental functions, which contribute to global sustainable development.

The intended transformation is characterized by economic, environmental, and social challenges and opportunities and is understood as a social transition process towards a sustainable, bio-based, and nature-oriented economy [4]. Management and control of this transition need appropriate instruments, indicators, and assessment tools to cover not only the BE as a whole, but also specific dimensions of BE development. In order to eliminate, or at least significantly reduce, the negative impacts of this transition, all parts of the supply chain must be considered and included in any research and analysis. From sourcing to final distribution, all production sites and countries involved in the supply of a resource or product must be considered [5].

Comprehensive concepts for risk and impact assessments of products and production processes need to be developed and implemented. This also helps to detect and address environmental vulnerabilities (i.e., water stress, biodiversity loss, deforestation, direct and indirect land use change) within the production and supply chains of import goods such as palm oil. Concepts which combine approaches from different research fields (sustainability science and certification, remote sensing, nature protection etc.) and operational or spatial levels, such as macroscale and product scale, are of high relevance to get the most out of collected knowledge. Data analysis at different levels helps to reduce the environmental impact of global resource production and especially of goods produced where there are significant potential risks for the environment (i.e., import goods produced in regions of high biodiversity). The implementation of concepts connecting different approaches should contribute to the assurance of sustainability in the BE.

In the energy sector, governmental regulations and directives are already building the baseline for a sustainable BE and for the implementation of measures and new technologies to control and foster sustainability. The European Union’s (EU) Renewable Energy Directive (RED) and RED II set binding targets for the use of renewable energies in transport (RED, RED II), as well as in electricity and heat production (RED II). Biofuels are covered by sustainability and GHG saving requirements that must be fulfilled and verified by recognized third party sustainability certification systems [6,7]. At the same time, the RED and the respective sustainability certification systems also serve as a guide for other sectors that process biomass, waste, and residual materials, also beyond the EU, and have become part of the development of a global BE [4].

Systemic monitoring is necessary to describe and analyze the development of the BE over time. The results of this monitoring can form the basis for managing and controlling further development of the BE. Overarching environmental footprints can provide a basic understanding of the impacts related to the development of the BE. They are an important component for the analysis and governance of the BE at the country level and can indicate risks to sustainability at a broader scale. Additionally, monitoring based on remote sensing technologies is an important additional data source for a concrete, high resolution spatial analysis on an agricultural level. Remote sensing can be used to detect any type of direct land use change (LUC) effectively over time and within a geographical boundary. In parallel, tools that guarantee the sustainable provision of products within the BE are necessary. Sustainability certification of bio-based products can support the sustainable production of renewable resources and derived products by implementing and controlling sustainability safeguards based on well-defined principles such as the ban of deforestation or the conversion of highly biodiverse or high carbon stock areas (HCSA) into agricultural areas. Sustainability certification does not focus on generic material flows or footprints, but it provides additional specific information on local agricultural practices and concrete information on individual inputs for the production of intermediate and final products for the BE. This detailed information can help to increase sustainability within the BE, allows clear statements on individual product flows, and supports monitoring on a local level.

While the general identification of sustainability risks on a broader scale can be based on environmental footprint models, remote sensing analysis can provide additional higher resolution information and the determination and implementation of specific regional mitigation practices. The identification of best practices can be supported by sustainability certification for biomass production, processing and global supply chains, even including certain producers within identified hot spot areas. All three of these approaches are being actively developed in Germany [8], including national and international sustainability topics, but are not yet very well combined.

Conceptual Approach

This paper presents an initial, theoretical approach for combining sustainability certification, environmental footprint models, and remote sensing technology into an integrated sustainability risk analysis, contributing to the development of sustainable production and products for the BE.

This integrated sustainability risk analysis requires an incremental approach that is indicated in this paper: (1) starting with the analysis of existing certification schemes to elaborate on the relevant indicators, (2) linking those indicators to environmental footprints developed within the SYMOBIO project (Systemic Monitoring and Modelling of BE: compare Section 2.1) and a remote sensing analysis, which gives additional information for sustainability risk analyses. The linkages between the individual components are shown in Figure 1 and the details of the overall approach are explained in the subsequent chapters of the paper.

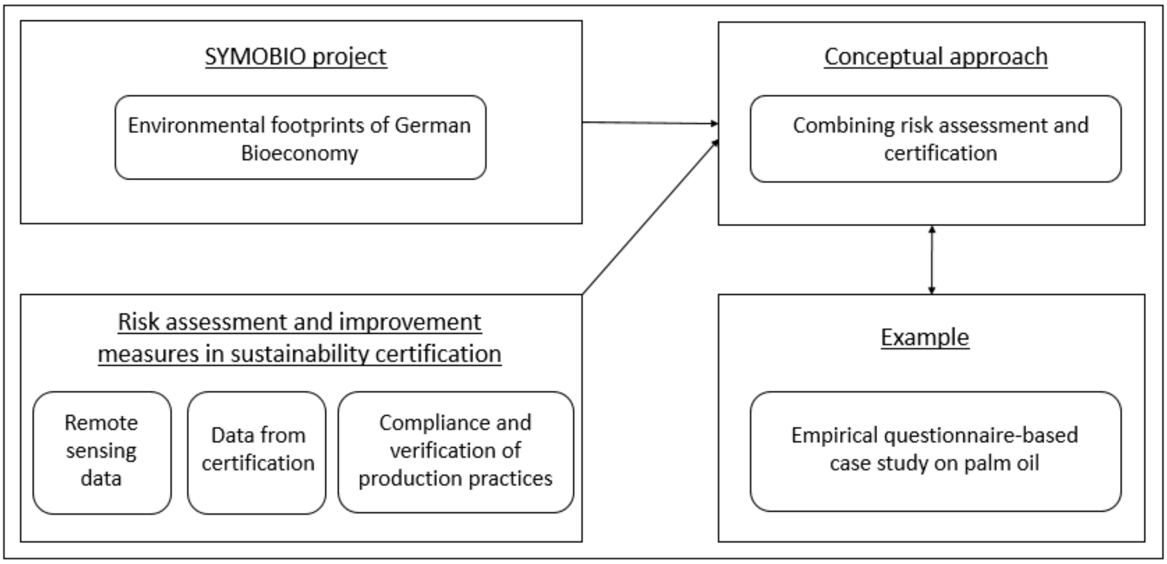

Figure 1. Outline of the conceptual approach for an integrated sustainability risk analysis for certification.

We demonstrate this combined approach for the case study on palm oil as a relevant import commodity of the German BE that is increasingly seen as non-sustainable and that is exported by countries that are often considered as high-risk, leading to a tendency to "blacklist" products or entire countries. A catalogue of production measures for low-risk palm oil production is designed with the support of literature and certification system documents, including new suggestions derived from the knowledge obtained. The suggestions refer to the planting process and oil mill operations.

In this paper and approach, remote sensing technology and the related analysis is considered the most suitable to be combined with environmental footprint models and sustainability certification. This leads to a useful supplementation and extension of the data basis and results. Other existing models are not considered within the scope of the study.

The following research questions shall be answered within this paper: What are the basic elements of an integrated sustainability risk analysis? How can this approach be exemplified for the case of palm oil? What are the main environmental risks of palm oil production on the plantations? Which improved agricultural production measures can potentially reduce these risks in order to improve sustainability in palm oil production? What are the reasons for blacklisting entire regions/countries within a BE supply chain and how can this process be avoided or reduced through an integrated sustainability risk analysis? What recommendations for action can be derived for sustainability certification?

The main body of this paper is divided into four chapters, beginning with an introduction to the background of the different approaches referred to, and continuing with the description of the methodologies used for data gathering and analysis. This leads to the results section and then a discussion of these results and the outlook for the future.

2. Background

To give an introduction to the approach that has been developed, this chapter gives information on the different scales and levels involved, from broader to more specific measures. First, the necessity of BE monitoring concepts and an introduction to the SYMOBIO project is given, followed by background information on environmental footprint modelling and remote sensing technology (macro-scale). Subsequently, the concept of product-level sustainability certification is described and the relevant data for palm oil as the object of the first operationalization of the conceptual approach is given.

2.1. Monitoring of the Bioeconomy

Systemic monitoring is necessary to describe and analyze the development of the BE over time. The results of the monitoring can form the basis for managing and controlling further development of the BE. As part of the SYMOBIO research project (Systemic Monitoring and Modelling of the German Bioeconomy) funded by the German Federal Ministry of Education and Research, an approach for the monitoring and modelling of the German BE is currently being developed [9]. Hereby, both national and international sustainability topics are considered.

Within the SYMOBIO project two reports serve as a starting point for this paper. The first report "Review report on indicators used in current certification schemes" is a comprehensive review of approximately 100 certification schemes, labels, and initiatives aiming to analyze the principles, criteria, and indicators used in current EU BE sustainability certification and compare them against indicators and criteria used for the modelling approach of SYMOBIO. Based on this in-depth review of indicators, the second report ("Report on options to introduce new indicators into certification approaches—Product certification and regional risk assessment") gives recommendations on how a combined methodology of certification and footprint modelling can contribute to more transparent and more sustainable supply chains [10,11].

As part of the SYMOBIO monitoring concept for the BE, environmental footprints are developed and used as instruments to display potential impacts, resource flows, and changes in the BE with a focus on different key aspects such as land, water, or GHG emissions [9]. In order to analyze the availability of data for monitoring the BE in its entirety, the instrument of sustainability certification of global supply chains was also examined as an important and useful data source. Certification systems in the BE do already collect, process, and transfer a significant amount of data regarding certified biomass producers and processors, their supply chains and certified products, and volumes and cultivation areas. In order to determine the potential contribution of existing data in the framework of certification to modelling and monitoring a BE, respective systems were selected, their information and data gathered and analyzed within the SYMOBIO project. Existing criteria and indicators as well as potential new indicators and gaps were detected but are not discussed in this paper.

2.2. Environmental Footprint Models

Modelling environmental risks and footprints usually starts from a broader spatial scale than certification or remote sensing analysis, which can be based on the newest high-resolution satellite data. Monitoring and modelling tools enable statements about environmental risks in countries and regions producing agricultural commodities used in the German BE.

Environmental footprints within the SYMOBIO research project are derived from data on material flows in production, consumption, and foreign trade. These material flows are used to develop a model covering all relevant biotic and abiotic flows in the economy, for instance for the German economy. Material trade flows with other countries and broader regions are also included in the model in order to provide a comprehensive assessment of economic, social, and environmental impacts. The result of these footprint analyses will be the extent (in hectares) of crop and pastureland used by the German BE domestically and abroad [12]. Environmental footprints can be calculated for different resources or consumptions such as water, land, GHG etc.

Environmental footprints can be derived, for example, from a modelling framework to examine global past, present, and future biomass flows that can be assigned to the German BE. Within the SYMOBIO project, these flows are derived from EXIOBASE—a database with multi-regional input–output (MRIO)—that provides a detailed illustration of global interconnections with respect to trade, resource use and energy, including emissions, for 200 producing sectors in 49 countries, whereof 17 sub-sections are agricultural. The material flow model, e.g., for the water footprint, is based on historic analyses of data from the time period between 1995 and 2010 in a five-year cycle for eight categories of field crops. In addition to EXIOBASE (MRIO) agricultural and forestry statistics, as well as global land cover maps, serve as databases. As an example, the extended blue water footprint contains information such as [13]:

- Determination of the amount of biomass directly and indirectly exported to Germany separated by field crops
- Spatial allocation of irrigated land for field crops in country of origin
- Calculation of the amount of water withdrawal for irrigation
- Assignment of water amount to catchment areas including water stress categories
- Allocation of water amounts to fraction of biomass directly or indirectly exported to Germany

As a result, statistics for a high, medium, or low agricultural blue water footprint for the selected crop show water used for import commodities of German BE. These findings are also presented in maps illustrating the water footprint with or without consideration of water stress [13].

Footprint monitoring produces a large scale, cross-regional representation of material flows and environmental influences that indicate general environmental risks in regions or countries. However, the resolution of the data is low and therefore does not allow for analyses at the local level. This lack of detail can lead to "blacklisting" of entire countries, if footprint results alone are being used to support decision-making processes.

2.3. Remote Sensing Technology

Remote sensing is a measurement technique that enables the collection of data without physical contact with the object of interest. The technology is mainly based on powerful space- and airborne cameras called sensors. Sensors are mounted on satellites which orbit the earth at a constant speed. Sensors take images of the Earth's surface at regular intervals (e.g., every five days), enabling regular monitoring of large areas (e.g., the Amazon Basin). Currently, there is a wealth of freely available satellite imagery (e.g., Sentinel, Landsat) that can be used to conduct objective, desk-based, and cost-efficient sustainability assessments and monitoring of agricultural regions all over the world [14]. Satellite imagery can be used for land cover mapping, monitoring of biomass and carbon stock, and detection of fires, in different spatial resolutions (e.g., field to country) [15]. In addition, the land history of an area of interest can be analyzed, LUC (such as deforestation) identified, and land degradation detected. The technology can be complemented by other geospatial datasets to identify protected areas, peatlands, wetlands or potentially high-biodiverse grasslands, which are all relevant to sustainability certification [16].

Automated risk assessments can be conducted for defined regions, e.g., sourcing areas around country elevators. Based on the detailed analysis of remote sensing and other geospatial data, a risk index with an appropriate weighting method that considers different risk factors is developed. Such risk factors are defined for each analysis individually but can include the International Union for Conservation of Nature (IUCN) management categories for protected areas [17], levels of carbon stock in biomass, land cover types e.g., forest, peatland, and existing LUC in the respective area of interest. The resulting risk index indicates sustainability risks associated with agricultural production in a certain area of interest and is therefore an indispensable element of a holistic risk assessment approach, which in turn can be used to better steer certification approaches on the cultivation level.

For analysis via remote sensing, an extensive pool of satellite and radar data is available (e.g., Sentinel, Landsat, Palsar). The quality and resolution of the available data is constantly increasing so that analyses can be performed on the basis of high-resolution spatial and temporal images. A lot of data is freely accessible on a global level and without user restrictions. However, the processing and evaluation of the data often involves a great deal of effort and requires high capacities and technical performance in order to be able to deliver useful results. The use of this data is highly recommended and should be integrated into the monitoring of the BE in order to use this specific information as a supplement to the data from environmental footprints and certification.

Alternative methods alongside remote sensing techniques, such as land use statistics and surveys, are not considered in this paper, because the databases are not as comprehensive as the data pools available for remote sensing. Such alternative methods often provide unreliable data with high uncertainties and data gaps. For a detailed, credible, and resilient analysis of land use changes and environmental impacts in a defined area, regular and uninterrupted data collection is essential. The freely available satellite imagery used with remote sensing is a big advantage in comparison to other analysis methodologies. For statistics and surveys the data collection process becomes expensive when looking at larger areas because the necessary level of detail that is necessary to obtain meaningful results relies on a huge amount of regularly collected data. As a result, this data is not available for every year, area, and administrative level (region, country). For example, the Ministry for Agriculture and Agri-Food Canada proofs the implementation of no-tillage activities on farm level every five years [18].

Therefore, we have decided to focus on remote sensing technology as the most suitable and reliable method to include in our approach of an Integrated Sustainability Risk Analysis.

2.4. Sustainability Certification

The concept of sustainability certification originates from the management of forestry resources [19]. It was first applied with the aim of ensuring that the extraction of timber resources does not surpass the regenerative capacity of forest ecosystems so that future generations can equally benefit from forests [4]. After the initial certification of forest management, additional initiatives could be observed in the early 1990s for the certification of agricultural production systems cultivating crops e.g., for the food production. To prevent the conversion of areas with high ecological value to agricultural areas dedicated to the cultivation of biofuel crops, legally binding sustainability criteria for biofuels were developed and are defined in the EUs RED (2009/28/EC). In recent years, the certification of supply chains for products for food, feed, bioplastics, biochemicals, textiles, cosmetics, paints, and more has become possible under certification systems originally developed to ensure sustainability of biofuels. The sustainability requirements from the RED have thus been extended to other sectors and countries and are already being applied on a much broader basis than for just biofuels used in the EU.

Contrary to environmental footprints, the monitoring of environmental risks based on sustainability certification takes place on a much smaller scale for individual farmers, producers and processing sites. Surveys or interviews with producers or processors are a potential method for evaluating local conditions and gaining insights on the practical relevance of certification inquiries and the implementation of agricultural best practice inquiries. Starting with the certification of just the raw material, the concept of certification was further developed over time to address the sustainability of the whole supply chain of products. The so-called "chain of custody approach" monitors the whole supply chain of a product from its origin or cultivation to the final product ready for distribution. It enables complete traceability across the value chain because each supply chain element is subject to certification. By now, many sectors are monitored and controlled through sustainability certification systems with the aim of ensuring that no bio-based feedstocks or products which enter the markets violate the respective set of environmental, social, and economic sustainability requirements. The European Commission (EC) recognized a number of voluntary systems [2] which differ regarding applicability (e.g., geographic and feedstock scope, coverage of the supply chain element). The geographical scope may vary from national certification to multi- or international levels. Furthermore, either single or multiple feedstocks can be assessed. In addition, certification systems differ widely with respect to their required sustainability level, their stakeholder involvement and governance structure and thus also with respect to their integrity and credibility. Certification systems for bio-based products now exist for sectors such as energy, forestry, construction, food and feed, textiles, chemicals and plastics, pharmacy, and other materials and products.

Available sustainability certification systems verify a range of criteria and indicators to ensure a sustainable supply chain. These include criteria for e.g., deforestation free supply chains, the protection of high carbon stock (HCS) land and biodiversity, environmentally responsible production, good agricultural practices, human, labor and land (-use) rights, good governance, and emission reduction. Ideally, sustainability criteria are verified by external and independent audits to ensure compliance with the requirements of the certification system and the credibility and reliability of the data. In addition to audits, upfront risk analysis and assessment are an important part of the sustainability certification of supply chains, e.g., to determine LUC or to identify designated protected areas in the vicinity of cultivation areas. This represents the interface to results from footprint models and in particular remote sensing analyses which as a result need to be taken into account.

2.5. Production and Use of Palm Oil

As an operationalization of the conceptual approach developed for this paper, a study on palm oil has been conducted. This vegetable oil is significant due its wide range of uses. Demand for palm oil, and therefore the size of cultivation areas, is continuously increasing. Furthermore, the oil fruits are characterized by high yields per hectare. Palm oil is used in the food and feed sector, in the chemical industry, for the production of cosmetics, and for biofuel production [2]. At the same time, the cultivation of oil palm is often associated with fire clearance of large forested areas, carbon release, monocultures, and habitat loss of endangered species. Despite this, the demand for palm oil is expected to continue to increase [20].

The main producing countries of palm oil are Indonesia, Malaysia, and Thailand (see Table 1) but the oil produced is exported all over the globe and is part of various economic sectors in importing countries such as the food and feed industry, the energy sector and the chemical industry. The German Environmental Aid Association (DUH) stated in its document on a market dialogue for sustainable palm oil that "the palm oil industry is the livelihood of over 3 million smallholders worldwide" [21]. Global Forest Watch (GFW) has launched a new version of the Universal Mill List (UML) of 1875 verified palm oil mills located in 27 countries which are currently in operation worldwide [22]. According to the GFW Universal Mill List, 1095 palm oil mills have been verified in Indonesia, 489 in Malaysia, and 51 in Thailand [23]. The total number of all existing palm oil mills on a global scale could not be found.

Table 1. Global production and export quantities of palm oil as of November 2019 [24,25].

Country	Production Quantity (1000 t)	Export Quantity (1000 t)
Indonesia	43,000	30,300
Malaysia	21,000	18,350
Thailand	3000	–
Colombia	1680	770
Nigeria	1015	–
Honduras	580	–
Other	5539	4913
Total	75,814	54,333

As shown in Table 1, the majority of palm oil produced is exported. However, the environmental and social impacts of the production remain in the countries of origin. For the reference year 2019, there are no export values for Thailand and Nigeria given by the United States Department of Agriculture (USDA). The category "Other" for export quantities includes Guatemala, Papua New Guinea, and other smaller exporting countries.

The nine palm oil plantation and mill operators contacted for the survey were chosen based on a selection of the main palm oil producing countries and regions (see Table 1). Indonesia and Malaysia are the main producers of palm oil with a joint share of 84%. Colombia and Honduras are among the biggest producers of palm oil in Latin America [26]. Accordingly, the farm operators that have participated in the survey represent a certain proportion and typical activities of the palm oil production in the four mentioned countries. The production volume of the nine palm oil plantations reflects a total production capacity of up to one million tons of palm oil per year. This reflects only a small share of the annual global production. However, the results, especially for Indonesia and Malaysia, are based on information from leading palm oil producing groups and represent common practices.

As a reference, Germany, for example, imported about 821,500 tons of palm oil in 2019 [27].

3. Methodology

The integrated sustainability risk analysis that is presented as an example with a case study on best practice measures for palm oil production requires, firstly, documents from certification schemes that contain standards and assessable indicators. Based on this information, the criteria and indicators most relevant for palm oil production are linked to criteria of environmental footprints developed within the SYMOBIO project [13]. Literature related to environmental risks is also used. Additional data from remote sensing, which is used for environmental risk assessments, may be used to aid the selection of regions which are permitted or not permitted for import activities to the German BE. These different risk assessment scales, from macro-scale (by footprints) to product-scale (by certification), are combined in the conceptual approach illustrated (Figure 1) and exemplified in a case study. In order to test the approach and to give answers to the research objectives addressed in this paper, we have chosen the following working procedure and methods (Figure 2). In this figure, the reduction of the water footprint in oil palm cultivation is illustrated. The same procedure is executed for the land footprint and risk to biodiversity.

3.1. Review of Existing Literature and Data

In order to develop meaningful approaches to potentially increase the sustainability of palm oil production, we have identified practices which could reduce environmental footprints and risks in the different supply chain elements of palm oil production. Based on a comprehensive literature and data review, environmental risks, sustainable production measures, and agricultural practices are identified for the case of oil palm cultivation. Various sources—(1) data from certification and (2) scientific literature—were identified and included in the analysis in order to obtain the most comprehensive picture possible of the current state of knowledge and to compare sources from different research fields.

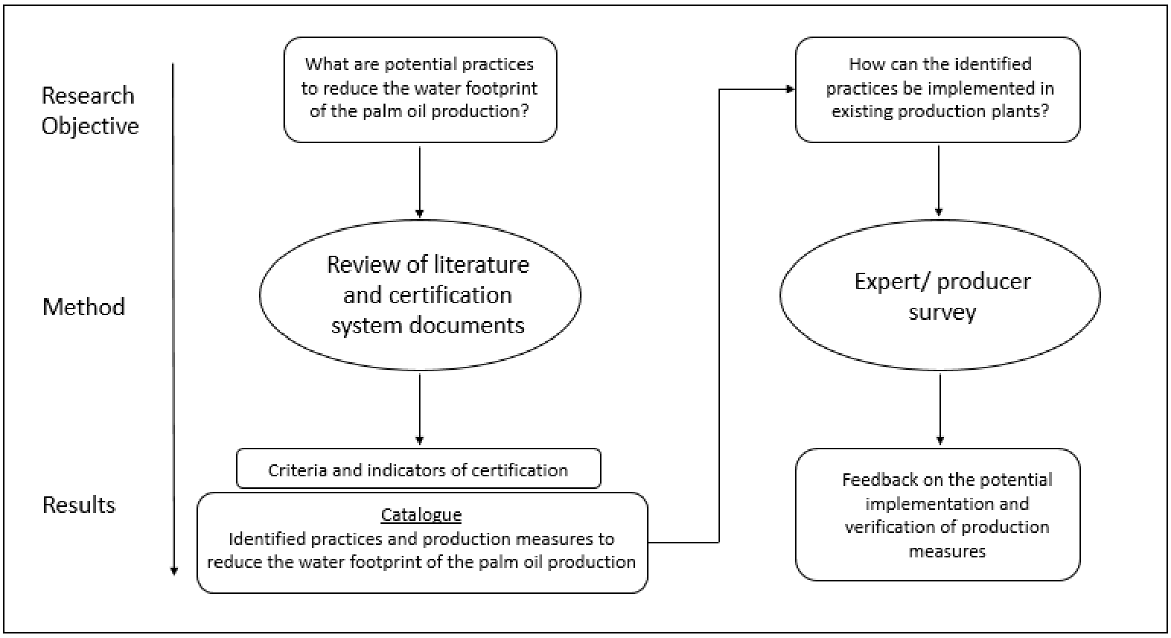

Figure 2. Working procedure and methods (Example: reduction of water footprint in oil palm cultivation).

(1) Initially, system documents of sustainability certification schemes were collected. They serve as the basis for an in-depth study on standards and indicators used for certification to avoid environmental risks related to biomass production. For the analysis of the different certification schemes, a selection of systems has been assessed in more detail as far as the system directly certifies sustainable palm oil or belongs to the major existing certification systems for bio-based goods based on the number of system users and certified volumes. This selection includes International Sustainability and Carbon Certification (ISCC), REDcert EU, UTZ certified (certification programme for sustainable farming of coffee, tea, cocoa and hazelnut), Forest Stewardship Council (FSC), Global Organic Textile Standard (GOTS) and Sustainable Agriculture Network (SAN). These six certification systems and the associated system documents are analyzed in detail within the first report of the SYMOBIO research project [10].

These documents contain standards for certification and associated measurable indicators for agricultural production that give information about production measures. Indicators relevant for oil palm cultivation are retrieved within this methodological step and listed in the results.

(2) After the review of certification system documents, literature on the environmental risks related to the production of biomass and bio-based goods is collected using desktop research on platforms such as Science Direct, Research Gate, Scopus, and Google Scholar. The review emphasizes environmental risks directly related to global biomass production such as water and land use, greenhouse gas (GHG) emissions, and biodiversity. As a basis for the case study, approximately 90 scientific articles were found focusing on palm oil as an import commodity in the German BE. After that, the selection and analysis of existing literature is made based on the relevance to the palm oil production sector and environmental risk assessments. More specifically, key words for the literature review on palm oil were water stress, water consumption, water reuse, land degradation, land use, land use change, deforestation, emissions, and biodiversity maintenance and loss.

Additional information on production measures are obtained from, among others, the International Union for Conservation of Nature (IUCN) [17], the United States Department of Agriculture [24], the United Nations Environment Programme [28], and the Roundtable of Sustainable Palm Oil (RSPO) [29]. In addition, information has been taken from various papers and publications, in particular

Dara Kospa et al. (2017) on "Strategies to Reduce Water Footprint in Palm Oil Production (. . .)" [30] and "Exploring land use changes and the role of palm oil production in Indonesia and Malaysia" by Wicke et al. (2011) [31].

This literature review enables the development of a catalogue of more sustainable production measures and best practice examples reducing environmental footprints and risks in oil palm cultivation (Figure 2: Catalogue). It is supplemented by further production measures based on the authors experience and knowledge that could help reducing footprints and risks (see Tables 2–4).

3.2. Export and Producer Survey

The empirical part of the research consists of a survey. Selected production measures are listed and palm oil producers from Asia and Latin America were asked if certain measures reducing water and land consumption or enhancing biodiversity are implemented on-site or if an implementation would be possible if specific conditions were given or constraints were lifted.

A questionnaire has been designed based on the review results and the developed catalogue of production measures. The survey aims at proving if the measures listed in the catalogue are or can be implemented on oil palm farms in order to improve agricultural sustainability. In the questionnaire, best practice production measures to reduce resource consumption to mitigate environmental risks and stress in the terms of water, land, and biodiversity are listed to be individually assessed by each palm oil producer (Figure 2: Producer/ expert survey). After providing the geographical location of their plantation sites, operators were asked to state if the listed measures are already implemented on their plantation(s) or if implementing them is feasible. In addition, information about the conditions necessary to implement the suggested measures was requested. The questions about the assessment of listed measures are formulated in dichotomous form so that participants can only answer with either yes or no. An additional open question asks for further information on (potential) implementation measures (unstructured question). Based on our business contacts with oil palm producers and group managers, we have narrowed down the choice of countries and producers relevant for the palm oil market. Accordingly, the questionnaire was sent to oil palm plantation operators in Asia (Malaysia, Indonesia) and Latin America (Columbia, Honduras) that have either one, multiple, or no sustainability certification. On a country level, our local contact persons have selected the respective palm oil plantation operators and mills to participate in the survey. Thus, the questionnaire was not distributed randomly but in a controlled manner so that primary data could be collected from the biggest and leading palm oil producers. A total of nine questionnaires were collected and analyzed and serve as the first operationalization of the conceptual approach of an integrated sustainability risk analysis for certification.

For the assessment of the collected primary data, an empirical analysis with basic descriptive statistic methods was executed. Due to the small number of questionnaires, an evaluation with a statistics software was not applied. Instead, the data from the closed questions was manually examined, evaluated, and converted into percentages to present the frequencies of answers for each measure (see Table 6). The answers from open questions and comment fields were manually evaluated based on the qualitative content analysis according to Mayring (2015). Of the three basic forms of qualitative data interpretation (summary, explication, and structuring), summary was used for this analysis. All comments for one question were generalized and structured into categories into which each comment could be classified. All non-content-bearing texts were paraphrased, and decorative text components deleted to shorten the statements and unify them linguistically. The summarized and categorized comments were then used as a basis for the analysis and comparison with the findings of the literature review [32].

The limited ability to generate data from primary sources in this specific research area and production sector means that the analysis cannot and should not be representative. Instead, it should serve to provide a valuable first impression of the state of affairs. The aim of this approach is to conduct a purely qualitative survey and to ensure the highest possible response rate. By connecting with the local operators, this aim was met. This study is therefore based on an exemplary survey. It was not possible to do more on-the-ground research and collect further primary data in the countries or from the production sites for the time being. Furthermore, due to the specific topical focus, no secondary sources exist. For this reason, we decided to conduct a questionnaire-based primary survey and empirical case study on palm oil as described above. After this first step, it is highly recommended to extend the analysis and to conduct a more extensive survey using the findings from the first exemplary round of questionnaires that we now have available.

The results are presented in Tables 5 and 6, describing the state of sustainability certification in the relevant countries and the probability of implementing certain best practice production measures on a plantation. Both tables are elaborated upon by additional descriptions in the text.

4. Results

The presentation of our results is structured into four sub-chapters. Starting with results obtained from the literature review on indicators used in sustainability certification (Section 4.1) and the basics for an integrated sustainability risk analysis in palm oil production are described (Section 4.2). Afterwards, improved production measures concerning risks connected to water, land and biodiversity in palm oil production are listed in Tables 2–4 (Section 4.3). Based on these agricultural best-practice measures the questionnaire was designed and sent to palm oil producers. The results are presented in Section 4.4, containing the spread of certification systems, the feasibility of implementation of best practices on the producer's site, and additional information for the implementation of the suggested production measures.

4.1. Literature Review on Indicators from Certification

The comprehensive review and analysis of different sustainability certification systems and their associated standards on system documents have shown many overlaps in the core sustainability criteria and indicators within the certification systems analyzed. By applying these standard indicators, direct impacts from the production of goods on the environment can be controlled and requirements for sustainable production and processing in supply chains can be implemented. Some of the indicators found in the review of certification system documents are also used for footprint models and can therefore be linked to indicators used in sustainability certification to combine macro- and product-scales.

The review uncovered three main environmental risks in oil palm cultivation: Water risk due to its high water volume used in farming and potential degradation of water bodies and resources through agricultural impact; land risk because of cultivation in areas of tropical and subtropical forest and therefore competition for land; and biodiversity risk due to conventional planting in monocultures.

The review results of literature and certification systems have formed the basis for the developed catalogue of local best practices and improved production measures in palm oil production listed in Section 4.3, considering separately the reduction of the water footprint, the land footprint, and the enhancement of biodiversity, more specifically the mitigation of risks.

The results of the literature review and evaluation of indicators used in addition to information from certification in connection to footprint analysis substantiate the conceptual approach of integrated sustainability risk analysis illustrated and tested in this paper (see Figure 1).

4.2. Integrated Sustainability Risk Analysis

Environmental footprints can form the basis for monitoring impacts related to BE activities and provide an overview of the situation and potential sustainability risks in a region or country. The information gap at the local level can be filled by certification systems delivering specific spatial data on an agricultural level to analyze potential risks for each location. It can be demonstrated that there are positive examples of sustainable production where the required sustainability criteria and indicators are verifiably implemented, even in countries that show high risks regarding their environmental footprints. As a result, such countries do not get "blacklisted" (i.e., the import of biomass produced in these regions could be restricted due to concerns about the sustainability of their production) and sustainable materials and products can be delivered. Furthermore, best practice production measures could spread across a whole region to promote a decrease of the overall risk potential of the region if these best practices are identified using the approach presented in this paper and further disseminated. New technologies such as remote sensing can effectively support this development by providing high-resolution data for specific areas or parts of a country. The monitoring can be done for a defined cultivation area, which increases the quality of the analysis and "blacklisting" a whole country could be avoided. Remote sensing technologies also ensure a functioning and efficient certification process in some cases.

Both environmental footprint models and remote sensing technologies can be integrated into the upfront risk analysis for sustainability certification. This combination of data delivers elementary information for reliable sample-based and focused audits based on clearly identified risk areas and core sustainability topics. This creates the possibility for improvements and changes on the agricultural level, especially in countries which would be "blacklisted" due to the use of footprint assessment results only.

The questionnaire about production measures in the palm oil production industry that has been developed is an example of how the integration of the different concepts of environmental footprints and sustainability certification can be applied. Palm oil production as part of the primary economic sector has been selected because it is classified as a high-risk agricultural good due to its large impact on the environment and high sustainability risks identified e.g., by footprint models. Sustainability certification has led to improvements in the production of palm oil through "no deforestation" requirements and demands for good agricultural practices and required GHG emission reductions on cultivation and oil mill level. Remote sensing is integrated into the upfront risk analysis and the verification of no deforestation in the cultivation of palm plantations.

The fields of environmental footprint modelling, sustainability certification, and remote sensing analysis are closely interconnected. Their common reference is the risk analysis and identification of risk factors. At present, they are not yet well connected. However, the integration of these three approaches is promising to better monitor the sustainability of the BE. The three approaches can be brought into a hierarchical order forming an integrated sustainability risk analysis for certification. Data collection from all three concepts provides respective information on each hierarchical level in order to enable an integrated risk analysis.

The first level is made up of the developed environmental footprint models used to show material flows on a global scale. These models consider broad environmental impacts on water, land, and air (carbon emissions) of a produced good or supply chain. Through the identified material flows and interconnections within and outside a country or region, such footprints can reveal potential environmental risks and risk areas on a global scale. For the case of palm oil, environmental risks could potentially be soil degradation, erosion, biodiversity loss, deforestation, or water scarcity in areas with biodiversity hotspots, water stress or contamination, land conflicts (resulting in illegal deforestation) etc.

The second level of the approach is the method of certification. Sustainability certification systems impose concrete requirements on the cultivation and production of raw materials and goods and verify these at the local level. At the same time, sustainability certification systems enable traceable supply chains to be set up, from cultivation or the origin of a feedstock and processing to the final market. It was shown that, on the process and product level, existing BE certification systems do include numerous criteria and indicators related to different environmental footprints (land, water, carbon), however, monitoring and verification are executed on a local scale. The certification process can be used to check the areas previously identified as risk areas by the footprint models at the local level with the help of the criteria catalogue. Certification helps to support producers in sustainable production to identify and verify sustainable production methods, which could help to promote use of these methods, even in high-risk areas. This allows the differentiation between individual producers within a risk area, the identification of best practices, and the establishment of sustainable supply chains from these producers. A reliable certification system requires a solid risk analysis and assessment as part of the certification process to verify core sustainability requirements like no deforestation, protection of HCS and biodiversity areas, protection of designated areas, etc. This is where the remote sensing analysis can be used to connect the results from sustainability certification and environmental footprints as a third instance.

Remote sensing technology based on satellite imagery makes it possible to detect specific risk areas, any type of LUC, and different kinds of protected areas like natural forests, national parks, or peatlands on broad and local scales. This additional information and data can thus be included in the risk assessment of a region or a specific production area. Remote sensing should supplement a global risk assessment with environmental footprints and be used to analyze the identified potential risk areas of raw material production on a local scale and provide further data for evaluation and sustainability certification.

4.3. Improved Production Measures for Environmental Risk Reduction

Based on the literature review described in the method section we derived production measures and efficiency measures for the three stages of oil palm nursery, plantation, and the palm oil mill where the processing to palm oil or palm kernel oil takes place. The main objective of the implementation of these measures is to reduce the potential risks and impacts on water and land consumption and biodiversity risks, as examples of the risk areas addressed by the footprint analysis in the SYMOBIO project. The left column in Tables 2–4 indicates the process of the palm oil supply chain in which the identified measure can be implemented. The measures for the oil palm plantation or palm oil producer are described on the right side.

Table 2. Measures to reduce water footprint on oil palm plantations.

Stage of Palm Oil Production	Measure for Producers
Nursery	• Reduce the amount of water used for irrigating germinated seeds in poly bags (with sprinklers) • Replace polybags with bags which require lower water consumption in production • Use bags made of biodegradable material to avoid contamination of water sources • Place nursery and plantation as close to each other as possible to reduce fuel consumption
Plantation	• Reduce the quantity of water used during pesticide production and application • Switch to organic pesticides (to maintain good groundwater quality) • Recycle water for watering young palm oil plants • Build catchments for rainwater in water-stressed regions • Adequate wastewater treatment in the plantation process
Palm Oil Mill	• Reduce distance from plantation to mill to minimize fuel used for transportation • Technical improvements in oil press station to reduce the amount of electricity used • Optimize boiler processes for fresh fruit bunch sterilization to reduce energy demand • Avoid discharge of water to the environment during the milling process • Remove or break down pollutants during wastewater treatment (no discharge of effluents into streams, it may affect people and biodiversity downstream) [30] • Reuse wastewater produced, i.e., recycling of cooling water coming from turbines [30]

Table 3. Measures to reduce land footprint on oil palm plantations.

Stage of Palm Oil Production	Measure for Producers
Nursery	• Avoid seedling cultivation on land not previously used for agriculture so unused land is not converted • Minimize energy/fuel demand in the nursery to reduce negative impacts on land

Plantation	• Reduce the flow of nitrate emissions to soil (after fertilizer application)
	• Leave residues and waste on-site in order to avoid erosion or soil degradation
	  ○ At the same time avoid eutrophication of soils
	  ○ Leaving crop residues in place and increasing external input of organic matter can contribute to carbon stock improvement [33]
	• Demarcate forest land and protection of land that still has forest cover to avoid land use change (LUC) [31]
	• Use single falling parts of fruits for oil production as well
	• No further clearance of peatlands to maintain carbon storage
	• Maintenance of sufficient fronds to support high palm productivity [34]
	• Monitoring and managing of pests and diseases
	• Keep records of pH values of soil before and after fertilization
	• Combined plantation rubber tree and oil palm (break-up of monocultures also bring social benefit due to year-round employment)
	• Apply best management practices to increase yield and reduce land use [34]
	  ○ Crop recovery
	    ■ Harvest interval (HI) of seven days,
	    ■ Minimum ripeness standard (MRS) = one loose fruit (LF) before harvest,
	    ■ Same day transport of harvested crop to palm oil mill,
	    ■ Harvest audits to monitor completeness of crop recovery and quality (i.e., ripeness) of the harvested crop,
	    ■ Good in-field accessibility (clear paths, bridges wherever needed)
	    ■ Clean weeded circles,
	    ■ Palm platforms constructed and maintained wherever needed, and
	    ■ Minimum under-pruning in tall palms to ensure crop visibility
	  ○ Canopy management
	    ■ Maintenance of sufficient fronds to support high palm productivity,
	    ■ Removing abnormal, unproductive palms,
	    ■ Filling in unplanted areas,
	    ■ Selective thinning in dense areas, and
	    ■ Monitoring and management of pests (leaf eaters) and disease (Ganoderma)
	  ○ Nutrient management
	    ■ Spreading pruned fronds widely in inter-row area and between palms within rows,
	    ■ Eradication of woody perennial weeds,
	    ■ Mulching with empty fruit bunches (EFB),
	    ■ Management of applied fertilizers (i.e., type, dosage, timing and placement), and
	    ■ Monitoring of plant nutrient status and growth
	  ○ Fertilizer input [35]
	    ■ Mineral fertilizer type: ammonium sulphate for nitrogen supply, triple super phosphate for phosphorus supply, and kieserite for magnesium supply,
	    ■ Fertilizer placement for phosphorus, potassium, magnesium on frond heaps, and
	    ■ Application of empty fruit bunches at the inter-row areas for blocks close to oil palm mills
	  ○ Harvesting (mean interval of seven to eight days)
	  ○ Drainage (drainage for blocks which were prone to water-logged conditions)
	  ○ Spreading of pruned palm fronds (pruned fronds were spread widely between palms within rows and in the inter-row area)
	• Improved chain integration of by- and co-products
	  ○ Oil palm trunks (OPT) used as an alternative to softwood timber from pulpwood plantation [28]
	• Increased production chain efficiency
	  ○ Increasing the oil extraction rate (OER)
	    ■ Capacity building for plantation management, particularly for smallholdings, and
	    ■ Harvesting FFBs at an optimal ripeness [36]
	• Use of underutilized lands
	  ○ Identification with the method Responsible Cultivation Areas (RCA) [37]
	    ■ Suitable land
	      • Biophysical (climate, terrain, soil)
	      • Environmental (avoiding high carbon stock areas and biodiversity areas)
	    ■ Available land
	      • Land is not used for agriculture
	Land is not traditionally or legal owned

Table 3. *Cont.*

Stage of Palm Oil Production	Measure for Producers
Palm Oil Mill	• Use of co- and by-products (empty fruit bunches, palm oil effluent, palm kernel shells and fiber) • Increased production chain efficiency ○ Increase oil extraction rate by delivering FFB to mill in 24 h and avoid poor plantation management and suboptimal harvesting [38] ○ Depending on the energy source used: if renewable energy from wooden origin, reduce renewable energy demand to minimize resource consumption (wood, pellets, wood chips) Use plantation residues in biogas production (for mill operation)

Table 4. Measures to mitigate risk for biodiversity on oil palm plantations.

Stage of Palm Oil Production	Measure for Producers
Nursery	• Use fertilizers with limited level of toxicity • No prophylactic use of pesticides, unless in exceptional circumstances (if identified in national best practice guidelines) [29] • Maintain ecosystem services (regulatory services) • Water applied during pesticides application should have good water quality (no pollution with chemicals, feces or fertilizers)
Plantation	• Plant only in areas that were already oil plantation to avoid further LUC • Minimize impact on forestry resources on-site where new land is cultivated • Farmers supply water also for retaining level of ditch [39] - Growing fish population as side effects: avoid decrease in endangered species • Implement bee stocks at planting area (pollination) • Use agricultural machines not exceeding a certain depth in soil (protection of living organisms) • Monitor indicator for biodiversity loss: Mean Species Abundance (MSA; mean original species in a disturbed situation relative to their abundance in undisturbed ecosystems; express how intact the ecosystem is) [28,40] • LUC leads to loss of biodiversity (see land footprint) therefore avoid conversion of natural rain forest, peat swamp forest, cropland and others [31] • Indicator: % of forest (reference year 1989) that is now used for plantations - Vulnerable mammal and bird species' habitats in danger of extinction (mainly in South America and Africa) [41] • Implement protection areas (no-plant-areas) to maintain habitats of IUCN Red List species, i.e., [20] - Orangutan (critically endangered) - Gibbon (critically endangered to vulnerable) - Sumatran tiger (critically endangered) • Systematic ecological restoration measures - Tree islands in a conventional oil–palm plantation
Palm Oil Mill	• Distribute organic waste and residues from mill process adequately to avoid negative influence on living organisms in or on ground • Avoid excessive soil sealing • Use agricultural and forestry residues for energy production

4.4. Results of Empirical Case Study on Palm Oil

Nine questionnaires returned from oil palm plantation operators in Colombia (five), Honduras (two), Malaysia (one), and Indonesia (one) provide the basis for the evaluation below. The plantations in Colombia are situated in the regions Magdalena (one) and Nariño (one), or are not geographically specified (three). One plantation in Honduras is situated in the north of the country, the second one is not geographically determined. In Malaysia, plantations in Western and Eastern (Sabah) Malaysia are addressed.

4.4.1. Spread of Certification Systems

Plantations are either certified by one, several, or no sustainability certification systems (as indicated in the left column of Table 5).

Table 5. Distribution of sustainability certifications among countries.

Sustainability Certification System	Quantity Certifications	Country of Certification
RSPO (Roundtable of Sustainable Palm Oil)	3	Colombia, Malaysia
MSPO (Malaysian Sustainable Palm Oil)	1	Malaysia
ISCC (International Sustainability and Carbon Certification)	4	Colombia, Honduras, Malaysia, Indonesia
Rainforest Alliance	1	Honduras
Other certifications	6	Colombia, Honduras
None	3	Colombia

Other certifications mentioned are the Safety Certificate for Contractors (SCC), Kosher, ISO 9001:2015 and ISO 17025 in Colombia, and ISO 14000 and ISO 9000 in Honduras.

Among the sample, plantations in Indonesia and Malaysia as the main producing regions of palm oil and palm kernel oil have at least one sustainability certification. In Colombia, most plantations without any certification are found. RSPO and ISCC are the most common sustainability certification systems mentioned in the sample. One national sustainability certification system was mentioned for Malaysia (MSPO).

4.4.2. Feasibility of Implementation of Best Practices

In Table 6, the suggested best practice production measures and participants answers regarding their implementation or potential feasibility are given. First, best practices for a reduced water footprint (A to E) are listed, followed by the measures to minimize the land footprint (F to K). Production measures with regard to biodiversity are described further below (L to R). The most relevant qualitative results from the comment field are included in the text below. Percentages in the columns "already implemented" and "implementation feasible" in Table 6 indicate the probability that a plantation operator answered with 'yes' to a suggested measure.

Table 6. Best practice production measures for palm oil production and probability of implementation.

	Production Measures	Already Implemented	Implementation Feasible
A	Change to biodegradable bags for germinated seeds	11%	44%
B	Change to organic pesticides	56%	22%
C	Reduce quantity of water used during pesticide production	22%	0%
D	Recycle water for irrigation	44%	33%
E	Built catchments for rainwater in water stressed regions	22%	56%
F	Avoid seedling cultivation on unused, pristine land	89%	–
G	Demarcation of forest land and protection of land that still has forest cover	78%	0%
H	Avoid further clearing (especially on peatlands)	89%	–

Table 6. *Cont.*

	Production Measures	Already Implemented	Implementation Feasible
I	No plantation on peatlands	89%	–
J	Leave crop residues on field and increase external input of organic matter	89%	–
K	Minimize energy demand in nursery/plantation	56%	33%
L	No prophylactic use of pesticides	89%	22%
M	Create diverse age structures of oil palms to increase plantation diversity (no total clearing/replanting)	67%	11%
N	Implementation of tree islands on plantations to vary plant diversity	56%	22%
O	Include buffer areas between plantation and forest (hinder human access and minimize anthropogenic influence)	89%	11%
P	Plant polyculture plantations to grow multiple forest products	33%	44%
Q	Maintain epiphyte coverage	44%	11%
R	Include areas of native vegetation cover	67%	22%

(–) no comment stated by plantation operators.

Water Risk

For production measures reducing or mitigating the water risk on oil palm plantations, producers mainly mention monetary constraints that hinder implementation. Some on them could be applied if they were more cost effective, e.g., water recycling for irrigation (33%), changing to biodegradable bags for germinated seeds (44%), or building of water catchments for rainwater (56%). A change to biodegradable bags for germinated seeds is moreover not intended due to minor strength compared to conventional bags. On five out of nine plantations (56%), a switch to organic pesticides has already taken place, i.e., by integrated pest management, promotion of bio-pesticides, or is intended. In most cases there is no pesticide production on plantations and therefore no water is used for this process. Water recycling for irrigation is either applied by using drainage surrounding the plantation, determined in a water management plan, or not relevant because of sufficient precipitation. Due to the use of an initial assessment, land with water stress is excluded from conversion into a plantation, so water catchments are redundant. Nevertheless, water reservoirs could potentially be implemented on plantations that were asked this question (56%). Additional measures to enhance sustainability are water footprint assessments for setting targets and to state best practice measures, the use of mechanical or manual rain water catchment to reduce water use in irrigation periods, daily calculation of water balance to find the adequate irrigation amount, and a pesticide ban in river buffer zones or close to water stress regions to avoid any contamination.

Land Risk

The suggested agricultural measures mentioned in the questionnaire to mitigate land risks are mostly already implemented, i.e., avoidance of seedling cultivation on unused pristine land (89%) and further clearing (89%), demarcation of forest land and protection of land with forest cover (78%), no plantations on peatlands (89%), or leaving crop residues on fields and increase external input of organic matter (89%). Avoided seedling cultivation on unused land can be achieved with previous land analyses or sustainability policies and the establishment of new procedures without cultivation in high conservation value areas (HCVA). Within the scope of the commitment to sustainable business conservation no development on or exploitation of protected areas, such as HCVA, HCSA, or peatland areas, may occur. Illegal cropping and land use could hinder the demarcation of forestland. To avoid further clearing, carbon analysis on land (also if not peatland) helps to prevent any negative effects. Measures applied to increase the use of residues are e.g., use of recycled palm trunks, fronds, and empty fruit bunches to increase the soil's fixing capacity. Residues from cuttings are placed around oil palms to enable nutrient recycling. Strategies for reduced energy demand in nurseries and on plantations are applied in some cases (56%). Reduced energy demand can be linked to demand control or plantation workers' training to save and use energy efficiently or by methane capture facilities on the plantation or at the oil mill that minimize the use of diesel generators.

Biodiversity Risk

Biodiversity is strongly influenced and at risk on monoculture plantations. Most plantation operators have abandoned prophylactic pesticide use (89%), apply pesticides exclusively in case of palm disease, or focus on minimizing pesticide use throughout all phases, e.g., application is in compliance with national law. Diverse age structures within oil palm plantations are sometimes implemented (67%) and are reached by replanting in phases or a structured management plan that only allows replanting on already cultivated areas. Pest infestation might destroy diverse age structures resulting in replanted homogeneous plantations (in terms of the age of plants). As a measure to increase plant diversity on plantations, tree islands or biodiversity corridors are present on five of nine plantations (56%). These tree islands are protected in case they have a high conservation value. The implementation of buffer zones between forest and plantations in order to hinder human access and minimize their influence already took place on the majority of plantations (89%). This action is determined by national guidelines and regulations, for instance in Malaysia. Biodiversity corridors (buffer zones) help to protect the natural fauna, maintain the ecological value of a region, and enhance biodiversity. Some plantations in the sample grow polyculture plantations (33%) supported by planting programs in all areas, including smallholder supply base or in collaboration with local communities. The collaboration aims at achieving food self-sufficiency, raising awareness about alternative farming methods and generating extra income. Native vegetation within plantations is conserved or planted on 67% of plantations by e.g., a reforestation and water cycle protection program or because it is declared as an HCV area. Management and monitoring plans support the identification of HCV areas.

4.4.3. Additional Conditions for Implementation of Best Practices

Additional information has been provided by producers through the comment field in the survey. These comments have been sorted by footprint or risk. This comment field gives information about additional (potential) measures (implemented or not implemented) to enhance sustainable water or land use or to maintain biodiversity.

To support enhanced water use and footprint production producers added the following measures, among others:

- Water management plan with indicators measuring performance on proper use and disposal of water
- Water management plan at each operational unit to safeguard efficient water use, to ensure water use and management has no negative environmental impacts, to protect and preserve water catchment sites and rivers and avoid contamination of surface and buffer zones
- Water footprint assessment and setting of targets for best practice
- HCV management for rehabilitation of riparian zones
- No application of pesticides close to water stressed regions
- Daily water balance calculation

Additional or potential agricultural measures for land footprint reduction or maintenance of the resource land are:

- Combined approaches to responsible palm oil production underpinned by scientific research, development and use of technological advances, i.e., research on yield improvements and productivity, fertilizers and pesticides
- Mulching
- Reduction of agricultural expansion by using sustainable management models with good environmental practices to enhance land productivity
- For the reduction of biodiversity risks, potential measures stated by plantation operators are:
- Planting of beneficial plants on plantation (plants with flowers providing nectars)
- Implementation of biodiversity reserves and protection of biodiversity strategies
- Planting flowering plants to attract beneficial insects and to maintain good sources of predatory insects to keep population of damaging insects in check
- Avoidance of weeds by clearing between rows of palms; cut down just in case of competition for light
- Prohibition for hunting of RAP species or any kind of cutting or burning of trees (supported by signs) and build awareness on importance of biodiversity conservation among plantation staff as part of a sustainability policy

5. Discussion

Collection of data and information on production processes within the BE for detailed and extensive monitoring on different spatial levels has to take place for all three components: environmental footprint models, sustainability certification, and remote sensing analysis. All data has to be taken into account and included in the risk assessment to extend the monitoring from a regional to a local scale.

The combination of results from risk assessments based on environmental footprints and information on sustainability certification could be beneficial for environmental risk analysis for countries producing commodities that are exported and being traded in high volumes all over the globe.

A broad range of data from all spatial levels is needed to better analyze the sustainability of the BE, to derive and analyze potential sustainability risks and to determine potential agricultural risk areas. Therefore, all available relevant data sources should be integrated into a monitoring process and taken into account for the identification of risk factors.

The evaluation of the questionnaire, including additional information obtained regarding the feasibility of implementation of agricultural best practices, leads to some general observations: Oil palms mostly grow in tropical regions that do not suffer from water stress. Therefore, the provision of water for irrigation is not a risk factor for the plantations and the environment in the region. In these cases, the focus should rather be on environmental risks through the loss of biodiversity and land use changes [41].

The assessment of biodiversity requires different methods to the analysis of a land or water footprint. LUC can be detected by remote sensing data, which can be used in part for the water footprint, i.e., existence of ponds, lakes, drainages. In contrast, measuring biodiversity needs other indicators, e.g., Mean Species Abundance (MSA) [42]. Fuel consumption for transportation between plantation and mill has a minor role because the oil fruits need to be processed within 24 h to avoid palm oil degradation.

The questionnaire contains a short list of best practices selected from the catalogue presented above (Tables 2–4) to achieve a high return rate for the evaluation of this study. Nevertheless, the sample size is relatively small (nine questionnaires) and a follow-up focusing on the main producing countries of palm (kernel) oil, Malaysia and Indonesia, is recommended.

The questionnaires represent a sample of palm oil plantations around the globe. Plantation operators were asked to voluntarily fill out and send back their answers. There are no details about the size of the plantation or the state of development in the context of sustainability. The only indication of the conditions on these plantations is the fact that they have an existing sustainability certification.

The implementation of some production practices from the best practice catalogue might be hard to measure, e.g., 'include use of single falling fruits for oil production'. Specific audit guidelines would be necessary to control this specific practice.

Further research should be conducted on the deviation of low-risk best practices on oil palm plantations and common agricultural practices. Recommendations on how the implementation of best practices could work on plantations would increase the utilization of the conceptual approach of an integrated sustainability risk analysis described here and would count as a follow-up activity.

With this approach, different scales of sustainability assessment are brought together in order to ensure reliable certification, e.g., via local best-practice examples, an extension of monitoring etc. Due to the extension of a generic risk assessment based on environmental footprints, sustainable producers even in geographical proximity to high-risk areas can be identified as low-risk providers of import commodities. An exclusion of high-risk regions and therefore, a denial of certification, is not an appropriate solution because low-risk areas might also be located in high-risk regions (addressed by footprints). Marginalization of these regions and rejection of producers will not occur with the conceptual approach developed in this study (i.e., through more complexity and spatial detail).

The combined methodology and connection of scales between economy (footprints) and company/product (certification) contributes to more transparent and more sustainable supply chains. Statements regarding the intensity of certain risks in specified areas are possible due to the combination of footprint modelling, remote sensing analyses, and product and company certification.

In that sense, sustainability certification provides and uses indicators to determine risks to sustainability in order to enable more transparency and reduce the impact of the risks detected. The databases maintained by certification systems can be used and extended for monitoring the BE and serve as source to gather information for a sustainability risk analysis. Certification guarantees zero deforestation, sustainability, traceability, feedstock identity, the use of actual conversion factors and volumes, and can provide certain data that is necessary for sustainability monitoring and risk assessments. At present there is no alternative to certification for verifying and guaranteeing the implementation of sustainability requirements for certain feedstocks and product volumes. The use of certification systems and data gathering from them will increase in the future.

Within a sustainability certification process, collected satellite data can be used to identify and verify environmental risks in the area of cultivation and production and assists in the establishment and monitoring of sustainable and deforestation-free supply chains.

Current barriers still exist in the form of incomplete or non-existent databases from certification systems. The quality and quantity of the data gathered, documented, and provided by the certification systems is diverse. The most relevant information for monitoring, but which is not yet sufficiently collected, is information about certified quantities of feedstock or final products on the market. This is the case for both certified agricultural and forested areas. This data is crucial for a detailed analysis or risk assessment of sustainable markets and trade flows and would show the impact of certification.

Several sustainability certification systems do have a large database of certified biomass producers and processors, their supply chains and certified products at their disposal (see for example ISCC, RSPO, and FSC) [43–45]. There are diverse certification systems that are collecting data through their work which cover various geographical areas and sectors, and which vary in the depth of detail of the data collected.

With regard to monitoring activities, usable and nearly complete data from certification systems appropriate for monitoring the BE is currently limited to a number of certification systems which provide data about covered feedstocks, final markets and sectors, the number of countries covered, and certified quantities and areas (see the exemplary 2018 annual impact report by ISCC [46]). These data categories are indispensable for identifying information that are required for regular monitoring. The absence of this information implies gaps in monitoring and leads to a lack of policy guidance for data collection.

To overcome these difficulties, governmental regulations on uniform certification processes, criteria and their implementation can help, e.g., via guidelines on mandatory data collection for certification systems. These databases should be publicly available. In the new RED II for the biofuel market in the EU coming into force in 2021, the European Commission has already stated that "[a] Union database should be put in place to ensure transparency and traceability of renewable fuels" and has provided article 28 with further guidance on a union database and exchange of data between national systems, voluntary schemes, and verifiers [7].

The method of remote sensing is seen as support for a BE monitoring system linking broad scale environmental footprint data and country or regional scale certification data and contributes to transparent and trustworthy monitoring. With the help of this data on different complementary levels of monitoring, the systemic modelling of the BE can be strengthened, and the degree of detail can be greatly increased.

The combined approach of these three concepts could lead to more sustainable production and certification and a chance for previously excluded companies in high-risk areas to get certified.

6. Conclusions

This study is of importance as it points out the relevance of integrated sustainability risk analyses for reducing environmental impacts on the ground and at the beginning of the supply chain. It contributes to existing literature through results obtained from an analysis of various sustainability certification systems in the shape of a catalogue of production measures for imported goods used in the German BE. In addition, this paper extends existing literature by shedding light on the process of blacklisting farmers as a side effect of generic and superficial environmental impact analysis. Through such environmental impact and footprint analyses producers are excluded from import market activities if the results show high environmental risks, which leads to the blacklisting of entire regions or countries. Improved production measures focusing on resource and biodiversity protection, as suggested in this paper, and smaller regional scales, help to avoid the blacklisting of local farmers if sustainability (in water, land use and biodiversity conservation) is guaranteed in all production steps. Best practices for oil palm plantations which reduce significant risks, such as risks to water, land, and loss of biodiversity, can be made accessible for producers.

Author Contributions: Conceptualization, J.H. (Josephin Helka), J.O; S.M., J.H. (Jan Henke), P.H. and D.T.; Methodology, J.H. (Josephin Helka), J.O; S.M. and J.H. (Jan Henke); Validation, J.H. (Josephin Helka), J.O., J.H. (Jan Henke) and S.M.; Formal Analysis, J.H. (Josephin Helka) and J.O.; Investigation, J.H. (Josephin Helka), J.O. and J.H. (Jan Henke); Resources, J.H. (Josephin Helka), J.O., Ja.H, M.A., P.H, S.M. and D.T.; Data Curation, J.H. (Josephin Helka); Writing-Original Draft Preparation, J.H. (Josephin Helka), J.O., M.A., J.H. (Jan Henke) and S.M.; Writing-Review & Editing, J.H. (Josephin Helka), J.O., M.A., J.H. (Jan Henke); Visualization, J.H., J.O. and S.M..; Supervision, S.M., J.H. (Jan Henke), P.H. and D.T.; Project Administration, S.M, J.H. (Jan Henke), P.H. and D.T.; Funding Acquisition, S.M. and D.T. All authors have read and agreed to the published version of the manuscript.

Funding: This work was conducted within the scope of the project SYMOBIO (SYstemic MOnitoring and modelling of the German BIOeconomy), funded by the Federal Ministry of Education and Research (BMBF).

Conflicts of Interest: The authors declare no conflict of interest.

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