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Uncertainties in the Bidirectional Biodiesel Supply Chain

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ABSTRACT

For remote areas, small-scale local biodiesel production is particularly attractive if producers and consumers are the same. Such supply chains are labeled as bidirectional. However, little is known on how raw material supply, transportation, logistics, production and operations uncertainties impact the operational performance of such Bidirectional Biodiesel Supply Chains. This paper contributes by exploring these uncertainties in a multiple case study, directed at mobile processing of rubber seeds, in a remote area. Scientifically, the paper contributes by identifying several novel sources of uncertainty: a short-term perspective, lack of knowledge and the previously unrecognized influence of the local government. Additionally, based on these findings, an extended theoretical framework is proposed which links sources of uncertainty to operational performance. The study provides also insights for stakeholders aiming to increase local biofuel production and provides a stepping-stone to investigate adequate measures to manage the identified uncertainties.

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1. Introduction

Uncertainties in biodiesel value chains have been studied extensively (Escobar et al., 2014; Lakovou et al., 2010) as they might constrain rational decision-making and influence performance (Persson et al., 2009). However, these studies investigate mainly the production of biodiesel on a large or medium scale (Skarlis et al., 2012; Ramadhas et al., 2005) assuming farmers grow biodiesel crops at a large scale and transport them to a central processing unit (Uslu et al., 2008). Increasingly it is acknowledged that cultivation of biofuel crops by smallholder farmers is a viable alternative (Woods, 2006). Specifically, local, small-scale biodiesel production is believed to be beneficial for the economic development of rural areas (Ewing and Msangi, 2009) as it reduces the dependence on imported fossil fuels and provides a continuous availability of energy at a known cost (Francis et al., 2005). Such a development implies the establishment of a circular, bidirectional process in which the supplied inputs are transformed into biodiesel and transferred back to the original input suppliers. However, despite the proclaimed importance of localized production for

regional development (Ewing and Msangi, 2009; Poku, 2002), little is known on how to operate such supply chains and what the impact of uncertainties is on these Bidirectional Biodiesel Supply Chains (further abbreviated as BBSC).

The aim of this paper is to investigate the impact of supply chain uncertainties on the implementation and operational performance of a biodiesel supply chain characterized by supplier-buyer duality. Additionally, the possible effects of specific local conditions are considered. With the focus on supplier-buyer duality, the authors hope to add new arguments to the existing discussion on introducing biofuel (e.g. Chin et al., 2014). As this is a novel subject, the empirical part of this paper relies upon an exploratory case study. Given the above mentioned criteria and because the researchers had access to this region, Kalimantan, Indonesia was chosen as a specific area that is relatively remote, not fully developed, has many smallholders and faces typical conditions and uncertainties. Moreover, local biodiesel production is stimulated in this area. The researchers are well aware that an explanatory case study approach is subject to several limitations, including personal bias and data validity. Therefore, a very strict and structured method has been applied in order to minimize the potential impact of these risks.

The paper contributes through identifying and better understanding of sources of supply chain uncertainty in a real life context, which enables us to extend our initial theoretical framework. While the study is academically motivated, insights derived from this

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study are relevant for other parties involved as well, such as local governments and communities, smallholders, and industrial partners willing to invest in the establishment of novel biodiesel production and supply chains. Practitioners can become well informed about different types of uncertainties and ideas to deal with undesired situations.

The remainder of this paper is structured as follows. In the next section the theoretical background together with the conceptual framework of this study are developed. The third section discusses the research method used. In the subsequent section, the findings are presented, followed by a discussion of the results in the fifth section. In the final section, the conclusions of this study as well as suggestions for future research are summarized.

2. Theoretical background

This section elaborates on bidirectional-biodiesel supply chains, and different types of supply chain uncertainty, in order to develop the research framework that integrates both streams of research.

2.1. Bidirectional biodiesel supply chains

Traditional biofuel chains rely on models where farmers deliver their crops to a facility, decoupled from further steps in the process (Gold and Seuring, 2011; Lakovou et al., 2010). In contrast, Sampson (2000) developed – in the context of services – the idea of customer-supplier duality, where: “customers are suppliers of significant inputs to the service production process” (Sampson, 2000, p. 351). In other words, bidirectionality refers to the circular shape of the supply chain, where the suppliers of core inputs in the production process are also the designated consumers of the process’ output. In Bidirectional Biodiesel Supply Chains (BBSC), which are primarily found in remote rural areas (Fredriks et al., 2014; Skarlis et al., 2012) the inputs are locally harvested crops. Supplier-buyer duality occurs in these supply chains when the produced biodiesel remains with, or is redistributed to; the local farmers (Fredriks et al., 2014; Dufey et al., 2007).

Two types of BBSC can be distinguished: those applying a fixed, and those applying a mobile processing unit. This study focuses on the second production type. Mobile processing is argued to have great potential for future small-scale biodiesel production (Oliveira et al., 2009). Moreover, its mobile and inherently small-scale nature reverses the traditional supply chain process: rather than transporting the input to the processing unit’s location, the processing unit itself is moved (Oliveira et al., 2009). While there might be sustainability related advantages, it also results in extensive exposure to operational uncertainties. Therefore, studying cases of mobile biodiesel production provides an interesting and valuable insight into the effect of uncertainties on the BBSC.

2.2. Uncertainties in biodiesel production

In this study, the authors follow the comprehensive definition of supply chain uncertainty by Van der Vorst and Beulens (2002), “supply chain uncertainty refers to decision making situations in the supply chain in which the decision maker does not know definitely what to decide as he is indistinct about the objectives; lacks information about its environment or the supply chain; lacks information processing capacity; is unable to accurately predict the impact of possible control actions on supply chain behavior; or, lacks effective control actions”. Uncertainty arises from the lack of information of a certain supply chain actor about the activities performed in other stages of the supply chain, and his influence on these activities (Wilding, 1998). Building on this, Awudu and Zhang (2011) noted that in regard to biodiesel supply chains, five generic

sources of uncertainty can be distinguished, which would be discussed in the sequel.

Biomass Supply Uncertainty is primarily the result of variability in yield and quality of the supplied inputs (Awudu and Zhang, 2011). A variety of external factors, among which weather conditions, can result in the delivery of raw material in a smaller amount or of inferior quality as compared to forecasted or expected (Zhang and Wilhelm, 2011; Bassok and Akella, 1991). The effect of supply uncertainty is expected to be exaggerated under decentralized bidirectional production due to the reliance on inputs from a relatively small number of farmers, which increases the dependence on the output of each farmer and enhances the variability in supply (Lakovou et al., 2010). Moreover, supplier-buyer duality itself potentially increases supply variability since production in these chains is in the first place performed to fulfill the direct need of the buyer-supplier. The low need for biodiesel therefore, could potentially reduce the quantity of biomass delivered.

Transportation and Logistics Uncertainty is defined as the “inability to deliver both biomass raw materials and finished products in a timely and cost effective manner” (Awudu and Zhang, 2011, p. 1363). Adequate transportation in biodiesel supply chains is complicated as the low energy density of the biomass makes transportation a difficult and costly process (Eranksi and Dale, 2011). Furthermore, high perishability (Blackburn and Scudder, 2009) implies that uncertainty in the transportation of raw materials has a multiplying effect on supply uncertainty. Moreover, Fredriks et al. (2014) highlight the impact of regional conditions by showing that in remote areas the infrastructural quality and density differences can be substantial. Finally, the use of a mobile processing unit could yield unexpected transportation costs and delays. Through the impairment of production during such delays, lower performance of the entire value chain can be expected.

Production and Operation Uncertainty arises when a firm is unable to meet its planned quantity of production due to unanticipated events (Awudu and Zhang, 2011). The causes of production and operation uncertainty lay in the internal processes of the production facility. Nevertheless, it might also be due to actions of other supply chain actors, e.g. through the delivery of poor quality inputs (Ochoa et al., 2010) or poor infrastructural quality (Richard, 2010). Finally, the resolution of machine failure as well as the overall operation of the production unit requires a certain educational level of the users and actors in the supply chain, which might relate to the overall educational level in a region (Aikman and Pridmore, 2001). Remote regions usually have lower educational levels and lower infrastructural quality, thereby potentially yielding higher production uncertainty.

Demand for biodiesel is largely dependent on the price of the alternative, fossil fuels, which is uncertain in the long-term (Azam et al., 2005). Additionally, price uncertainty addresses the uncertainties in the price of biomass and other inputs (Awudu and Zhang, 2011).

The final source of supply chain uncertainty consists of *environmental uncertainties* arising through unexpected governmental actions with regard to taxes (Rozakis and Sourie, 2005), sustainability (Hammond et al., 2008), and other regulations and policies (Yeh et al., 2008).

2.3. Research framework

From the above discussion of the literature, a comprehensive framework can be derived which links the types of uncertainty identified in previous research to the main issue of interest of the present study: operational supply chain performance. Operational performance is defined here as the degree to which a Bidirectional Biodiesel Supply Chain is able to meet its expected biodiesel output

quantity and quality within a given time period (De Toni and Tonchia, 2001; Maskell, 1991). As Fig. 1 shows, based upon previous knowledge, the sources or drivers of the distinguished uncertainties can have either a direct or an indirect impact on operational supply chain performance. Additionally, it has been argued that some of these sources can be context dependent i.e. influenced by regional conditions or the – local – government.

3. Research method

In the above sections, it has become evident that BBSCs have hardly been investigated. Following Karlsson (2008) and Poku (2002), an inductive approach is taken in this study to build theory on the specific context of this relatively novel topic. As such, an exploratory case study has been applied, using multiple, contrasting cases.

3.1. Measures

The following operational definitions are used in order to measure the main constructs in the research framework.

Raw Material Supply Uncertainty: The inability of field research interviewees to provide coherent information about rubber seed harvesting period and quantity, and a lack of previous experience with rubber seed collection. The inability to provide positive responses to these points represents a lack of knowledge of the core input to the production process (Lakovou et al., 2010). Thereby, a lack of positive responses to this definition indicates raw material supply uncertainty.

Transportation Uncertainty: Following Bappeda (2013) and Richard (2010) transportation uncertainty is higher if fewer infrastructural modes are available and if the available infrastructure is not continuously (year-round) accessible.

Production Uncertainty: Operationalized through the level of education received by the actors in the supply chain. Education is shown by Aikman and Pridmore (2001) to be an important factor leading to externally caused machine failures, either through improper machine usage or by affecting the quality of inputs delivered (Ochoa et al., 2010).

Demand and Price Uncertainty: Following Azam et al. (2005) and Awudu and Zhang (2011), this uncertainty can be operationalized as the variability in price of the inputs as well as the price of diesel, the competing substitute product, on the local market.

Governmental Uncertainty: Comprises the variation in current fuel and biofuel legislation and current local economic development programs in the case study regions. As BBSCs are argued to be beneficial to Local Economic Development (Dufey et al., 2007), the continuity of these programs, together with variability in current fuel legislation and policies (Hammond et al., 2008), can be used as a measurement for governmental uncertainty.

3.2. Case selection

The remote rural area of Central-Kalimantan has been selected as the main region for this study. Central-Kalimantan is well known as a relatively undeveloped region. Moreover, it is the target area for a cross-cultural collaborative project of six Dutch and Indonesian universities that aims to contribute to the sustainable development and reduction of poverty by developing a mobile biodiesel installation and its operation (see for details: Agriculture Beyond Food, 2008).

As this paper focuses on theory building, it is appropriate to select multiple distinctly different cases (so-called theoretical sampling, Yin (1994)). Theoretical sampling enables the generalization of case study findings. Central-Kalimantan is well suited for doing this, as the size of the region and the diversity of the communities therein offer the opportunity for choosing different cases, a case being a supply chain consisting of multiple villages. In selecting contrasting cases and thus to guarantee theoretically different cases, the drivers of uncertainty from the research framework in Fig. 1 have been applied:

- Quality of the existing infrastructure, as driving uncertainties of transportation times and potential for breakdowns.
- Educational Facilities (as a proxy for educational level), as driving the knowledge and capabilities of the supply chain actors and thus raw material supply and production uncertainty.
- Region Population Density (as a proxy for price and demand uncertainties): supply chain regions with a higher population

Fig. 1. The research framework: relating operational performance to types of uncertainties and sources of uncertainty.

density are more likely to have a developed local market (Fredriks et al., 2014) and have a larger supply base, which both drive supply and price uncertainty.

- **Primary Occupation:** Preliminary research has established that farmers in different areas of Central-Kalimantan have different sources of primary income. A subsequent directed literature study indeed supported the proposition that this might influence people's opinion about, as well as incentives to participate in a Bidirectional Biodiesel Supply Chain project (Oke and Gopalakrishnan, 2009).

Two cases, comprising two supply chains, consisting in total of 7 villages have been chosen in applying the above criteria for selection. The first case comprises a relatively developed area that scores highly on the first three criteria and furthermore, the main occupation in this region is rubber farming. In contrast, the second case comprises a region that is relatively difficult to access and its inhabitants regularly shift occupation between gold mining and rubber farming. Subsequently, this case is characterized as the less developed chain. The details of both cases are given in Table 1, indicating the characteristics of each village in the various case study areas according to the criteria described above as well as additional information. The selection procedure applied assures that different regional conditions and characteristics are covered, thereby providing the ability to generalize the findings of this study.

3.3. Research instrument and interview protocol

As a hypothetical situation has been studied, it is even more important to ensure the minimization of personal bias in communicating the main message to the interviewees, and to ensure information symmetry between the researcher and interviewee. Therefore, a booklet was developed to introduce the subject to the interviewees (Voss et al., 2002). An adapted version of the tested and verified booklet of Fredriks (2012) was used to communicate the core message of the Mobile Biodiesel project. The application of this standardized booklet ensures reliability of the data collection. Appendix 1 provides an illustration of a typical page of the standardized booklet used during the interviews.

Additionally, an interview protocol has been developed in order to guide the semi-structured interviews. Questions were based upon the research framework and the operational definitions as given above (see Appendix 2 for a typical version of the interview protocol). Accordingly, questions focused on personal experiences of the interviewees regarding among others, rubber (seed) harvesting, sources of income, education and educational facilities, governmental influence and the infrastructure in the region. Both the brochure and the interview protocol have been discussed with experts for clarity and completeness and have been pretested through interviews with smallholder farmers and institutions in a pilot study on Central-Java. A minor revision of figures and additional description were added based on the pilot study.

3.4. Data collection

As a general preparation and background for the actual field-work and to prepare the above instruments, 13 expert interviews were conducted in April and May 2013 with 4 professors from Bandung Institute of Technology Bandung and the University of Palangkaraya, 7 regional experts from local Non-Governmental Organizations and 2 representatives from the regional governmental body for planning and development of the Central-Kalimantan region. The interviews lasted between one and two hours and aimed to develop a further qualitative as well as

quantitative understanding of the Central-Kalimantan region. Topics discussed were the geographic and socio-economic division of the region as well as the local and regional leadership structure and the infrastructural modes applied in the region. Furthermore, government documents and databases have been accessed in order to support the case selection and provide objective, supportive information. These documents and expert interviews also provide an additional information source to enable triangulation of the data that helps to establish validity and reliability.

The information gathered in semi-structured interviews and observations during site visits comprises the primary source of data for this study. In total 24 interviews took place in Central-Kalimantan: 9 rubber farmers, 8 rubber traders and 7 local government representatives such as the village leader and secretary of the 7 selected villages. All of the interviews were conducted by two researchers. In order to minimize the language barrier a professional translator, assigned to this research by the University of Palangkaraya, was present during each interview. Interviews were held in May and June 2013 and generally lasted between one and two hours. Several visits to rubber plantations and storage locations also took place. In total, this paper relies on 45 interviews with a total of 80 h of interviews.

3.5. Data analysis

Following the data gathering, the information obtained through in-depth interviews was transcribed and coded in order to condense the information, discern patterns and to increase the validity (Saunders et al., 2012; Voss et al., 2002). Subsequently, within- and between case analyses have been performed to observe unique patterns within, and compare results between the contrasting cases. In addition, to improve the reliability of the data gathering process, information obtained through interviews and personal observation has been triangulated through the use of other data sources, such as government databases (Gibbert et al., 2008). Triangulation allows for the adoption of various perspectives to assure validity (Voss et al., 2002; Yin, 1994). Theoretical replication has been assured as indicated, through the selection of multiple distinctly different cases, which also increases external validity (Eisenhardt and Graebner, 2007; Stuart et al., 2002). Finally, data were further condensed by focusing on the main results around the sources of uncertainty: firstly focusing (following the coding) on the sources and drivers identified from literature, while keeping an open mind for possible new, not yet identified sources and drivers.

4. Results

Following the structure of the research framework, the findings are presented below.

4.1. Raw material supply uncertainty

The field research conducted for this study shows a direct influence of weather conditions and tree growing conditions on biomass supply uncertainty. An equally uncertain factor is the quantity and quality of the available rubber seeds that are collected. All but one of the interviewed rubber farmers indicate that it is currently considered waste and has consequently been given little attention. As a result, the knowledge about quality measurement techniques for the biomass input is very limited and ensuring a minimum level of input quality can be considered to be hard.

In addition, the input quantity delivered is highly uncertain. A major factor regarding input quality uncertainty is the type of plantation: Hutan Karet or Kebun Karet. Hutan Karet (Rubber Forest) plantations form the traditional plantation type of Kalimantan's

Table 1

The table provides an overview of the summarized data for the case study villages.

Case	Village	Number of inhabitants ^{a,b}	PM2L combined score ^c	Development status PM2L ^c	Main occupation ^b	Total hectare of rubber trees ^b	Available infrastructural modes ^{b,c}	Highest level of education available ^{b,c}	Recent development programs ^b
Developed area (Case 1)	Pilang	1247	42	Developed	1) Rubber farming (75%) 2) Fruits 3) Fishing	1000	- Asphalt road - River	Middle school	Various activities by WWF, REDD+, and CIMTROP.
	Henda	612	38	Developed	1) Rubber farming 2) Fishing 3) Rice cultivation/Logging	100	- Asphalt road - River	Middle school	Training to develop Rattan Wickerwork activities to support income (REDD + Task force & UNDP, 2013)
	Buntoi	2496	45	Developed	1) Rubber farming 2) Rice cultivation Fishing	1000	- Asphalt road - River	Middle school	Development community learning center (Khan, 2013)
Less developed area (Case 2)	Bawan	1005	44	Developed	1) Gold mining 2) Rubber farming	250	- Asphalt road - River	High school	1) Rubber farming training 2) Various health and forestry improvement programs
	Tambak	312	35	Underdeveloped	1) Gold mining 2) Rubber farming	174	- River	Primary school	Yearly rice cultivation training program
	Hurung	335	35	Underdeveloped	1) Gold mining (70%) 2) Rubber farming (30%)	80	- Dirt road - River	Primary school	None
	Manen Kaleka	321	35	Underdeveloped	1) Rubber farming (60%) 2) Gold mining (30%) 3) Fruit farming (10%)	100	- River	Primary school	None

Below, a summary of abbreviations is provided.

- PM2L: Program Mamangun Tuntang Mahaga Lewu – Development program for rural communities in Central-Kalimantan, administered by the regional government.
- WWF – World Wide Fund for Nature.
- REDD+ – Reducing Emissions from Deforestation and forest Degradation, a global program administered by the United Nations.
- CIMTROP – Center for International Cooperation in Sustainable Management of Tropical Peatland, specialized research institute of the University of Palangkaraya
- UNDP – United Nations Development Programme.

^a Source: Indonesian Bureau of Statistics (Badan Pusat Statistik Indonesia, (2010)).

^b Source: Own Field Research (2013).

^c Source: the Provincial Development Planning Agency (Bappeda) (2013).

Dayak inhabitants. The number of rubber trees per hectare is relatively large and the interviewed rubber middlemen state that the rubber harvest per tree is low. Regardless, farmers have been observed to perceive this type of plantation as convenient as these plantations incur little maintenance. They are mainly present in the less developed area. The other plantation type, the Javanese plantation KebunKaret, yields a smaller number of trees and more attention is paid to the maintenance of the land. The more structured KebunKaret type dominates in the developed area. The responses of the interviewees strongly indicate that the lack of maintenance of particularly the Hutankaret plantations implies that even when the amount of seeds is high, the realized biomass input collected will be substantially smaller as the available rubber nuts are hard to find between the other vegetation.

Furthermore, as stated by the representative of a local NGO: “[Farmers] do not think about what they cannot see”. In relation to the limited education of many farmers, this interviewee states that buyer-suppliers are primarily focused on fulfilling their immediate consumption needs, without considering potential future needs. Such a short-term orientation affects supply uncertainty. Moreover, the cross-case comparison shows that occupation switching behavior in regions where rubber farming is not the sole occupation enhances supply uncertainty: the earnings of alternative occupations determine whether a farmer visits his plantation.

4.2. Transportation and logistics uncertainty

This study shows that the extent of regional development is strongly related to the quality of a region's infrastructure, as has

also been observed by previous researchers (Fredriks et al., 2014; Dufey et al., 2007). One important differentiator is the primary transportation mode in each case. The most reliable and efficient transport mode in the first case is the road, as road infrastructure is well developed and specifically major roads, as is confirmed by representatives from various NGOs. The interviewed inhabitants of the less developed region however, primarily transport themselves by boat, as the roads are subject to weather conditions, and heavy rainfall in the wet season will affect the available roads. Additionally, the rubber middlemen and village leaders have confirmed that the primary mode of transport for goods, including the collected latex harvest, is also by boat.

Whereas nearly all villages in both case regions are located next to a river, data from governmental sources shows that access to road networks in the less developed region is limited to a minor percentage of communities. It can be stated that indeed the quality of the infrastructural network affects the transportation and logistics uncertainty, which are different in different regions. Transportation uncertainty is primarily present in the less developed area, while transportation times in the developed area can be fairly reliably estimated year-round. Specifically, the accessibility of the communities in areas outside the reach of infrastructural development programs is subject to the uncertain weather conditions. Moreover, as interviewees' state, the accessibility of villages is strongly dependent on the distance from a more developed area, such as a city. The Transaction and Logistics Uncertainty is thus dependent on regional conditions. Finally, movement of the mobile processing unit itself is a source of uncertainty as it depends on the road network, which is unreliable, especially in less developed areas.

4.3. Production and Operational Uncertainty

Two prime sources of production uncertainty can be distinguished: internal and external machine failures. The research findings here suggest that internal failures will be limited as source of uncertainty as according to machine engineers: “the machine can be made robust to cope with movement across bad roads.”

In line with the conclusions of [Ochoa et al. \(2010\)](#) and [Aikman and Pridmore \(2001\)](#), it should be stated that lack of buyer-supplier knowledge forms an important source of production uncertainty. The lack of knowledge related to the measurement of biomass quality by the local buyer-suppliers has become evident for instance, as only one of the interviewed rubber farmers was able to describe a quality measurement process. This knowledge gap creates the potential for unrealistic expectations about the quantity and quality of the output delivered.

The second source is the low level of the educational facilities in Central-Kalimantan, as is confirmed by the report of [Sparrow and Vothknecht \(2012\)](#). Not only do many villages in the province lack important educational facilities such as junior high schools within walking distance (6 km – [Sparrow and Vothknecht, 2012](#)), the quality of the available facilities is below average. While a primary school is present in nearly all communities, 25% of the teachers in these schools have not obtained a bachelor's degree ([Sparrow and Vothknecht, 2012](#)). Moreover, teachers in junior secondary schools did not finish university in up to nearly 50% of the cases. Furthermore, even in those districts where qualitative characteristics appear to be positive at first sight, interviews with representatives of local NGOs indicate that the actual performance of the educational system often lags behind: teacher absence is generally high and weather conditions, especially in the wet season, strongly influence the opening times of the schools.

As a result most smallholder rubber farmers lack (technical) education throughout the remote areas and can be considered to be incapable of adequately understanding and/or performing maintenance tasks, something that is acknowledged in multiple interviews in the selected case study regions. Therefore, machine downtimes will be uncertain. Additionally, from the case study interviews it has become evident that local inhabitants possess clear short-term behavior towards equipment maintenance, which fuels uncertainty about machine breakdowns, and preventive maintenance. In relation to the earlier short-term perception with regard to raw material supply uncertainty, preventive maintenance is a matter that is discarded as irrelevant by several interviewees.

4.4. Demand and price uncertainty

As the primary input product, biomass, is considered to be waste in both case regions, it does not possess any explicit value and indeed, institutes little price uncertainty. With regard to uncertainty of the end product, biofuel, uncertainty exists, as the price of fossil fuel is highly variable. Additionally, local NGO representatives with extensive knowledge of the area highlight that the price fluctuations tend to magnify when the accessibility of a region declines. Despite the low price of fossil fuels in Indonesia compared to the world market price, increased private usage and mobility and misuse of the subsidized fuel for industrial purposes render the amount of subsidized fuel available to be insufficient ([Fadillah, 2012](#)). Moreover, the availability of official gas stations in Central-Kalimantan is limited to the main city, which makes citizens of the rural areas in the province dependent on the sale of fuel from small, private local roadside shops. Consequently, not only are the fuel prices higher in remote areas due to added transportation cost,

the effects of fuel shortages and price changes in the urban areas are transferred to remote villages in a magnified manner. Moreover, prices are, as an effect of the relative bad accessibility, rather locally settled and interviewee responses indicate that the prices are highly variable, even within each case study area.

The uncertainty in fossil fuel prices in remote areas could promote the involvement of supplier-buyers in the BBSC through the offering of a price consistent alternative fuel. This is acknowledged by interviewees in the less developed region, who see a bidirectional supply chain as an opportunity to reduce fossil fuel price uncertainty by reducing their dependence on external oil deliveries and fluctuations in the price of the product. A re-occurring comment is that Bidirectional Biodiesel Supply Chains allow the region “to become less dependent on the city's oil.”

Finally, this case study shows the effect of the existence of a variety of income sources. Specifically, in the Less Developed areas, the prices of latex and gold will drive farmers either to gold mining or to rubber farming. Such switching will make the delivery of the seeds more uncertain as interviewees hesitantly confirm “[latex and rubber seeds harvesting] has to compete with the profits earned by gold mining.” In other words, if latex farming is not the primary income source, the amount of biomass gathered will be subjected to the marginal value of a labor hour for different occupations.

4.5. Governmental uncertainty

Governmental uncertainty is strongly related to policies regarding subsidies for fuel. These subsidies accounted for nearly 18% of the total governmental expenditures in Indonesia in 2012 and are expected to increase in the future. To control the expenses, the government has announced plans to lower subsidies on fuel and restrict fuel quotas ([Ministry of Finance \(2013\)](#)). However, due to upcoming elections and industrial lobbyists the execution of these plans remains uncertain.

Additionally, interviewees highlight the fact that the policies of various institutions and government departments are badly integrated, resulting in uncertainty related to the legality and validity of permits granted or financial support. According to representatives from local NGOs, the lack of interdepartmental communication regularly results in overlapping zoning allocations and concession rights that cause costly lawsuits between opposing parties. Thus, governmental uncertainty at the national and regional level is caused by both insecurity about continuity of policies as well as a lack of integration between governmental agencies.

Interestingly, at a supply-chain region level, governmental uncertainty lies primarily with the local village governments. Interviewees with local rubber farmers clearly indicate that the influence of national and regional governments at village level is limited in the remote areas. Contrarily, the power is consolidated at the local village government and a commonly heard remark by interviewees in the case study areas was that “if the village leader stands behind the project, everyone will follow.” Additionally, the interviewed local government representatives strongly emphasize the strength of the local community while simultaneously indicating the limited impact of regional and national governmental policies on the area. In the investigated case study areas, the past has furthermore shown that this can complicate the success of nongovernmental projects in the developed region. Thus, at a village level the complicated relations between the governmental lines and other lines of authority (like those coming from the religious field) have to be combined. In both case study areas, the past has shown that this can complicate the success of nongovernmental projects in the developed region.

Fig. 2. The extended framework indicates the impact of uncertainties on the operational performance of the bidirectional supply chain.

The above discussion shows that BBSC are prone to several specific uncertainties in addition to those highlighted by previous research. In order to gain a more accurate view of the sources of uncertainty impacting the operational performance of BBSC, an extended framework is proposed. The extended framework, presented in Fig. 2, combines the knowledge of previous research with the BBSC specific uncertainties identified in this study.

6. Conclusions

This study contributes to the relatively limited academic knowledge on uncertainties in the Bidirectional Biodiesel Supply Chain (BBSC) by identifying several specific sources of uncertainty affecting the performance of BBSCs. It finds, as the main sources of uncertainty in the BBSC the short-term perspective of local supplier-buyers; the lack of product and technical knowledge of the local stakeholders; price and demand uncertainty in the fossil fuel supply chain and supply chains of alternative income sources; and local government and regional conditions. This study contributes through its extension of the conceptual framework, which was based on current literature, with the main empirical findings of this study. The extended empirical framework helps to understand the sources of uncertainty and can be applied to mitigate the effects of operational uncertainties on the performance of Bidirectional Biodiesel Supply Chains. Additionally, the extended framework provides a starting point to investigate Bidirectional Biodiesel Supply Chains further.

The present paper is also relevant for managers and policy makers. While the sources of uncertainty developed here cannot be regarded as exhaustive, they allow managers of BBSCs to define more accurately the core sources of uncertainty in their supply chain. In doing so, these decision-makers are offered a mainstay,

Local Economic Development program, these factors therefore effectively limit the development of remote rural areas. Policy makers from both regional and national governments can thus benefit from the results of this study by designing policies that reduce such uncertainty-enhancing factors.

This research is subject to several limitations. First of all, this study is one of the first to study empirically the impact of supply chain uncertainties on the operational performance of the Bidirectional Biodiesel Supply Chain, based on an exploratory case study. While such an exploratory endeavor fits the current state of the knowledge, the results cannot be regarded as comprehensive. Future researchers are strongly urged to build upon this study and elaborate and extend the presented framework. One possible and promising direction for future research would be to further enhance the generalizability of the framework by investigating and comparing the impact of uncertainties in other types of bidirectional production supply chains e.g. in other areas and for other raw materials. Further, the present study did not include any uncertainties such as availability, related to additional inputs for the biodiesel process, such as catalysts, which is another limitation of the study. This needs to be taken up in further research. Finally, this study highlights the impact of supply chain uncertainties and provides several practical suggestions to minimize the negative influence. However, this study has not yet addressed the in-depth, structural analysis of uncertainty controlling mechanisms. Future researchers are highly encouraged to take up that important issue and investigate how the 'bidirectionality uncertainties' identified can be effectively managed.

Appendix 1. An illustration of a typical page of the standardized booklet

Uncertainties affect the success and profitability of the MBP

Raw Material Supply Uncertainty can be measured by unexpected variability in:

- **Quantity** of seeds delivered (due to farmer participation willingness and weather conditions which affect seed availability)
- **Quality** of seeds delivered
- **Type** of seeds delivered (rubber & palm seeds require different machine modifications and yield a slightly different biodiesel output)

Main questions to be answered:

- What is the volume of seeds (rubber and/or palm) that can be harvested in a certain region
- What is the quality of the harvested seeds (rubber and/or palm)
- How willing are smallholder farmers to collect and process these seeds
- How susceptible is the raw material supply to changing conditions (for instance changes in weather, alternative fuel prices)

which enables them to develop supply chain strategies that minimize the impact of uncertainties and maximize supply chain performance. For policy makers, this study shows that regional factors such as lack of education and poor quality of infrastructure are associated with higher uncertainties and thus likely lower performance of a BBSC. As BBSCs are regularly implemented as part of a

Appendix 2. Interview Guide

Smallholder farmers (Main Topics):
General Situation Assessment:

1. What do you do on the land every day as a farmer?
2. Are you a member of a cooperation, work for a company/government or do you work independently?
3. If you work for a company, how do they help you (training or money for example)?
4. If you work alone, do other farmers in your village work for a cooperation?
5. Where do you sell your harvest and how far is that from your land?
6. What is the average income of people in this village?
7. What is the price of diesel in this area?
8. What do you use the fuel for and how much do you need?

Raw Material Supply Uncertainty:

Inform interviewee about the project; go through brochure page 1–6.

1. How many (hectares of) rubber trees are you working on?
2. Are you harvesting rubber seeds already, and what do you do with them now?
3. How often per year can you harvest rubber seeds?
4. How many rubber seeds would you be able to collect per harvest and how variable is this?
5. What does the output primarily depend on?
6. What do you think of the MBP project (and the value it gives to your waste products)?
7. Given the explanation of the project, would you be willing to take the effort to collect and deliver the rubber seeds to the machine?
8. How long do you believe you will need to collect 1 kg of rubber seeds?
9. Does the quality of the seeds go down rapidly?
10. What other plants than rubber do you harvest (e.g. palm)?

Transportation Uncertainty.

Go through brochure page 7.

1. What is the largest size vehicle that could travel through the MBP project area and reach your village?
2. Would it be capable of travelling through the entire region year round?
3. Does the quality of the roads vary a lot over the year (for example due to rainfall)?
4. Are their plans for the future development of the infrastructure in the region?

Production and Operations Uncertainty.

Go through brochure page 8.

1. What is the highest level of schooling that you received?
2. Have you ever received technical training (for example to repair engines)?
3. Is there a technician in this village?
4. Do you think you will benefit from receiving additional technical training?

Demand and Price Uncertainty.

1. If you could use your rubber seeds to produce biodiesel, would you do so?

Would you produce solely for your own needs or would you also produce extra to sell it on the market?

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