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Bio-diesel production using mobile processing units: A case in Indonesia

Joeri ten Kate^a, Ruud Teunter^{a,*}, Ratih Dyah Kusumastuti^b, Dirk Pieter van Donk^a

^aUniversity of Groningen, Dept. Operations, PO Box 800, Groningen 9700 AV, The Netherlands

^bUniversitas Indonesia, Dept. Management, Faculty of Economics and Business, Kampus UI Depok 16424, West Java, Indonesia

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ABSTRACT

Bio-diesel is a sustainable alternative to fossil fuel, in particular if the input materials are not edible. This paper considers the production of bio-diesel from rubber seeds, which are currently viewed as a waste product and discarded by farmers. We investigate whether technological innovations in local pre-processing at individual farms and oil production via mobile processing units (MPUs) visiting villages, makes bio-diesel production profitable for groups of farmers. A mixed integer programming model optimizing supply chain decisions is developed and applied to a specific case in Indonesia. We find that operating the relatively expensive MPUs at maximum capacity is essential for economic sustainability. Furthermore, variations in the price of bio-diesel affect the profitability and governments may consider offering minimum price guarantees.

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1. Introduction

In 2015 the first global agreement was reached in a UN framework to combat climate change. A key part of the program is to switch from fossil fuel to renewable energy sources in order to satisfy the increasing global energy demand in a sustainable way. Bio-diesel is one form of renewable energy. It is produced out of vegetable oil or animal fat and is an attractive substitute for the conventional petroleum diesel. Bio-diesel can be produced out of many different kinds of raw materials. Edible oils, such as soybean, sunflower, palm, rapeseed, and canola are most commonly used (Singh and Singh, 2010). However the demand of edible oils increases constantly due to an increasing world population. Moreover, the resulting price inflation makes alternative usage of edible oils for bio-diesel production less economically viable (Yusuf et al., 2011). The use of non-edible oil, as considered in this research, is therefore preferable. Rubber seed oil (RSO) is one of the non-edible oils suitable for the production of bio-diesel. Rubber seeds that are produced by the rubber tree, *Hevea brasiliensis*, are now seen as a waste product. Furthermore rubber plantations are mostly located in rural areas of developing countries, and RSO may be an additional source of income for farmers in those areas. It can also make them less dependent on petroleum diesel, which has a high and volatile price and varying availability in rural areas of developing countries. So RSO production is sustainable from both a green (planet) and social

(people) perspective. Thus, bio-diesel production from rubber seeds can be seen as a way to combine renewable energy production with rural poverty reduction (Leite et al., 2014).

The oil yield from rubber seeds ranges from 40% to 50% (Reshad et al., 2015). According to Ahmad et al. (2014), all the properties of bio-diesel produced from RSO are within the range of standards including the viscosity, flash point, iodine value, ester content and higher heating value. This highlights the fact that rubber seeds are a suitable source for bio-diesel.

However, there are some characteristics that make it hard to develop an efficient supply chain. Like most agricultural crops, rubber seeds are subject to seasonality and perishability. Furthermore there are some uncertainties in the supply chain that can have a large influence on the supply chain performance as uncertainties associated with crop production cannot be neglected (Osaki and Batalha, 2014). For example, weather conditions influence the quality and quantity of the raw material supply. The rubber tree performs well with a day temperature between 26 and 28 °C. According to Yeang (2007), the synchronous flowering is induced by high solar radiation intensity, particularly by bright sunshine. This explains why rubber trees only flower once or twice per year. To maintain a high quality of the seeds it is important that seeds are collected and dried as soon as possible after they fall from the tree, because the oil content of rubber seeds decreases and acid values increase when they are wet. Also the storage time of RSO should be minimized, since the acid value of RSO increases over time (Zhu et al., 2011).

Due to the low energy content per kg of rubber seeds and the fact that rubber plantations are mostly located in rural areas with a low level of infrastructure, transportation costs are substantial. Local processing is essential to avoid farmers traveling long distances,

* Corresponding author.

E-mail addresses: joeritenkate@gmail.com (J. Kate), r.h.teunter@rug.nl (R. Teunter), ratih.dyah@ui.ac.id (R. Kusumastuti), d.p.van.donk@rug.nl (D. Donk).

Fig. 1. The harvesting and production process.

which would reduce the economic and environmental benefits. Two technological developments are encouraging in this respect. First, low cost pre-processing facilities have been developed that can be installed at and used by individual farmers or shared by neighboring farmers. This allows quick drying and pre-processing after collection, which is important to avoid decay of collected fresh seeds. The second innovation is the design of mobile processing units (MPUs) that can travel from one village to the next, so that the final processing steps can also be performed locally for each farmer. Recent development in bio-diesel production technology has enabled the construction of such mobile, automated and environmentally friendly bio-diesel processing systems (Löffler et al., 2014; Mowry, 2011). Lokesh et al. (2015) discuss the benefit of mobile processing without explicitly considering transportation and utilization planning. Combined, these technological developments allow for transport cost-efficient solutions.

Such solutions do require careful supply chain planning, as the routes of the MPUs and the allocation of MPU capacity to the different farmers have to be jointly determined. In this paper, we develop a mixed integer programming (MIP) formulation to this end. We apply this model to a specific case of bio-diesel production from rubber seeds in the Central Kalimantan province of Indonesia. Indeed, a joint Dutch-Indonesian project on bio-diesel production

focusing on both the technological and supply chain challenges motivated this research. The results will show that optimal, coordinated transport decisions are essential to ensure economically sustainable production.

The remainder of the paper is organized as follows. The relevant literature is presented in Section 2. In Section 3 the modeling and solution approach is explained, then in Section 4 the case study is used to validate the model. Section 5 concludes and points to further research avenues.

2. Literature review

In Sections 2.1 and 2.2 we discuss two related streams of literature on agri-chain planning and vehicle routing, respectively. Then, in Section 2.3, we review previous studies on MPUs and point out our contribution.

2.1. Agri-chain planning

Many authors (e.g. Ahumada and Villalobos, 2009; Kusumastuti et al., 2016; Glen, 1987; Shukla and Jharkharia, 2013; Tsolakis et al., 2014) indicate the need for an integrated approach to solve agri-chain problems that consider real-life features such as time

Fig. 2. Location of the case study (Maphill Map Gallery, 2016).

window constraint, seasonality, yield perishability, inventory control and uncertainty. These features will next be discussed shortly (see Kusumastuti et al., 2016 for a complete review).

2.1.1. Time window constraint

Harvesting time windows have been considered in different ways. Some authors (Ahumada and Villalobos, 2011a,b; Ahumada et al., 2012; Grunow et al., 2007; Van Berlo, 1993) assume that harvesting can only be done within a given harvesting window. Others (Arnaout and Maatouk, 2010; Ferrer et al., 2008; Higgins, 1999) consider the consequence of harvesting at different times within the maturation period by incorporating a cost due to quality loss of yield crops. Nagasawa et al. (2009) and Widodo et al. (2006) propose a maturing curve specifying the amount of yield crops in certain point of the maturity time, while Miller et al. (1997) and Ortuno and Vitoriano (2011) incorporate penalty costs for not performing the activity at the optimal time.

2.1.2. Seasonality

Ahumada and Villalobos (2011a,b) and Ahumada et al. (2012) take into account seasonality of the final product price, while Kazaz (2004) and Kazaz and Webster (2011) consider seasonality of the crop price. Ferrer et al. (2008), on the other hand, take into account the dynamic labor availability for manual harvesting. Grado and Strauss (1993, 1995) allow demand seasonality, while seasonality of harvest yield is considered by Qureshi et al. (2007) and Tsubone et al. (1983, 1984, 1986).

2.1.3. Yield perishability

Annetts and Audsley (2002) and Parker et al. (2010) assume that a certain fraction of yield crop will continuously deteriorate due to storage and transportation, while Tsubone et al. (1983) assume that the yield crop will rot after a certain period of time. Ahumada and Villalobos (2011b), Blackburn and Scudder (2009) and Widodo et al. (2006) assume that the deterioration rate follows a continuous function, Ahumada and Villalobos (2011a) on the other hand, categorizing the rate of decay on a scale from 1 to 6.

2.1.4. Inventory control

Grado and Strauss (1993, 1995) develop inventory models to determine the optimal, minimal cost ordering policy for a processing facility. Others consider inventory of raw material at the processing facility (Grunow et al., 2007; Zhang et al., 2012; Zhang and Hu, 2013), final products at the processing facilities (Jones et al., 2003; Miller et al., 1997; Zhang and Hu, 2013) and at distribution channels (Ahumada and Villalobos, 2011a,b) as decision variables. Tsubone et al. (1983, 1984, 1986) develop production planning methods that calculate inventories of semi-processed and final products for a production system.

2.1.5. Uncertainty

Uncertainty related to harvesting and processing is considered in some papers, mainly in terms of harvest yield (Ahumada et al., 2012) and final product demand (Jones et al., 2003). In addition, variability of the final product price is considered by Ahumada et al. (2012), while Miller et al. (1997) also incorporate uncertainty in operating conditions (such as harvesting and processing capacity) in a fuzzy model.

It appears from this overview that many relevant features of harvesting and processing problems have been identified and modeled in different ways. However, we also observe that few authors address the link between harvesting and processing, although coordination is obviously essential for perishable products. Moreover, most authors

assume that processing is done at a fixed central location, e.g. van der Hilst et al. (2010).

2.2. Vehicle routing problems

The vehicle routing problem (VRP) was first introduced by Dantzig and Ramser (1959). It is a generalization of the Traveling Salesman Problem (TSP) that was presented a few years earlier by Flood (1956). Where any route that visits all locations exactly once is a feasible solution for the TSP, additional restrictions can be included in the VRP. The classical VRP only considers a restriction in the travel cost (or distance or time) and aims to find a cost minimizing set of routes for K identical vehicles based at the depot, such that each of the vertices is visited exactly once. Many variants have been studied. We next mention some of the better known ones and refer interested readers to Laporte (2009) for a complete overview. The capacitated VRP (CVRP) includes vehicle capacity restrictions (Toth and Vigo, 2002). Specific time frames for deliveries are considered in the VRP with time windows (VRPTW) (Bräysy and Gendreau, 2005). The Heterogeneous fleet VRP (HVRP) deals with situations where vehicles have different capacities (Koç et al., 2016). Dynamic versions of the VRP have also been studied, where information is updated during the execution of the route, e.g. updating travel times based on traffic conditions (Pillac et al., 2013). More recently, a green perspective has been adopted by focusing on fuel consumption and emissions (Demir et al., 2014).

In most respects, the problem of routing MPUs that we will consider is a classical VRP with identical vehicles and without specific vehicle capacity or time-window restrictions, where the objective is to minimize travel distance (and thereby fuel consumption). However, an important aspect of our problem is that we allow the MPU to visit a village multiple times. Not doing so could imply long stays at (larger) villages in order to process all the rubber seed oil, possibly leading to decay at other villages. For the specific real life case that we consider, it will turn out though that it is optimal to visit each village once.

2.3. MPUs and contribution

Few authors have considered the use of MPUs. Callahan (2008) considers the potential use of mobile processing units in Vermont (US) to obtain vegetable oil and possibly biodiesel from oilseed crops such as sunflower, canola and soybeans. He finds that this can indeed be profitable for individual farmers, although he does not discuss any routing or logistics aspects. Oliveira and Nunes (2009) discuss the potential use of truck-mounted MPUs to stimulate oil production by small-scale farmers in Brazil. They design, construct and test such an MPU, showing that it can produce high quality oil. They also provide a small, preliminary economic feasibility study, but again do not include any routing or supply chain planning aspects. Another study that focuses on technical feasibility and not on supply chain management is that by Acevedo et al. (2016). They describe how MPUs can be used to produce bio-diesel from *Jatropha curcas* seeds in Colombian Caribbean regions.

The study most related to ours is that by Sharifzadeh et al. (2015). They compare the cost efficiency of using mobile units compared to centralized or decentralized production at fixed locations. This is part of a very general model that considers the use of various biomass resources and also optimizes production decisions at multiple facilities for a large area (the UK in their case study). Our paper also considers the use of mobile processing units, but at a much smaller scale (local communities of farmers) and restricted to one type of resource (rubber seeds). The specific focus allows us to take the before mentioned characteristics of a limited harvesting

season and perishability into account, different from Sharifzadeh et al. (2015) who consider pyrolysis of wood and other biomass sources that are likely to be available all year round, although supply may still fluctuate. Moreover, we consider the routing of the mobile units, whereas Sharifzadeh et al. (2015) assume that it takes a fixed time and cost for a mobile unit to be sent to a (remote) location. So, we shall simultaneously optimize the routing (location) of MPUs and the allocation of MPU processing capacity to different farmers (suppliers), while taking the harvest schedule into account.

3. Modeling and solution approach

It takes seven main steps to produce bio-diesel from rubber seeds.

1. The fallen seeds are collected.
2. Collected seeds are stored at the pre-processing site.
3. Stored seeds are dried at the pre-processing site.
4. Dried seeds are stored at the pre-processing site.
5. The oil is extracted from the dried seed at the pre-processing site.
6. Press cake that is left after the oil extraction is sold. Produced rubber seed oil (RSO) is stored at the pre-processing site.
7. RSO is transported to mobile processing unit to be processed into bio-diesel.

Fig. 1 visualises the seven steps of the production process in boxes from left to right and indicates where those steps take place. Note that the first step of collection takes place at the different plantations. Steps 2 to 6 are all part of pre-processing wet seeds into RSO and take place at pre-processing sites. In our case study and the model that we will develop, each plantation has its own pre-processing facility, but this can be easily adapted to situations where plantations share such facilities. The seventh and final step is to process the RSO into bio-diesel using MPUs.

Obviously, seeds can only be harvested after they fall from the trees. Since fresh seeds decay rapidly, it is important to collect them regularly. We will assume that this is done on a daily basis. Farmers in developing countries typically operate small plantations and so this is not too labor intensive. In fact, daily collection spreads the workload over the harvesting season so that other farming activities do not suffer.

Drying and pre-processing of fresh seeds need to be done as soon as possible after harvesting to avoid decay and is hence done at each separate farm, as was discussed in the introduction. For this first part of the supply chain operations, the optimal strategy is therefore straightforward. The difficulty lies in the scheduling of MPUs, as these need to be moved from one village to the next and because farmers need to share the capacity and therefore coordinate their supply of pre-processed seeds to the MPUs. Given the harvesting and related drying and pre-processing schedule, our objective is to determine the optimal route for MPUs and the allocation of MPU processing capacity. After introducing notation in Section 3.1, this problem is formulated as a mixed-integer programming (MIP) model in Section 3.2.

3.1. Notation

Indices:

$i = \{1, 2, \dots, I\}$	Plantation, I = the total number of plantations
$j, k = \{1, 2, \dots, J\}$	Processing site, J = total number of feasible locations
$t = \{1, 2, \dots, T\}$	Time, T = total number of periods included in the model

Decision variables:

$X_{i,t}$	Weight of seeds dried at plantation i at time t , in kg
$Y_{i,t}$	Weight of dry seeds from plantation i used for oil extraction at time t , in kg
$Z_{i,j,t}$	Weight of RSO from plantation i processed in an MPU at location j at time t , in kg
$M_{j,k,t}$	Number of mobile processing units moving from j to k at time t
$I_{i,t}$	Inventory of harvested (undried) seeds at plantation i at time t , in kg

Parameters:

H	Number of trees per hectare
S	Number of seeds per tree
A	Size of an average plantation, in hectare
W	Weight of one wet seed, in kg
α	Weight yield of dried seeds, in kg per kg undried seeds
β	RSO yield in kg per kg dry seeds
γ	Press cake yield in kg per kg dried seeds
δ	Bio-diesel yield in kg per kg RSO
C^C	Collection costs per kg wet seeds
C^D	Drying costs per kg wet seeds
C^E	Extraction costs per kg dry seeds
C^P	Processing costs per kg RSO
C^T	Transportation costs of RSO per kg per km
C^{TM}	Transportation costs of the MPU per km
$D_{i,j}$	Distance from plantation i to processing site j in km
$D_{j,k}^M$	Distance (for the MPU) from processing site j to k in km
F^{B^C}	Fixed costs of a pre-processing site per season
F^{M^C}	Fixed costs of an MPU per day
N^{PC}	Number of plantations per village
N^P	Number of pre-processing sites
N^M	Number of mobile processing units
CAP^D	Drying capacity of one pre-processing site, in kg seeds
CAP^E	Extraction capacity of one pre-processing site, in kg dry seeds
CAP^P	Processing capacity of an MPU, in kg RSO
P^B	Price of bio-diesel, per kg
P^C	Price of press cake, per kg
ζ_t	Percentage of wet seeds that fell on the ground at time t
$C_{i,t}$	Total weight of seeds collected at plantation i at time t
Q	Maximum number of storage days for wet seeds

3.2. Model formulation

There are two sources of revenue. The main source is from bio-diesel. The plantation owners can use this bio-diesel as substitute for petroleum diesel or sell it at the local market price. The second source of revenue is from press cake, which is the residual of dry seeds after the oil is extracted. Press cake can be sold and used as fertilizer and feed for cattle and poultry. Cost are incurred for collection, drying, oil extraction, processing (converting RSO into bio-diesel), transportation, and (annuity streams of) owning/hiring MPU and pre-processing equipment. For compatibility, all revenues and costs are needed per season. So the pre-processing and equipment costs must also be transformed to a cost per season. In the next section, we will explain how this is done for the specific case that we consider.

Table 1

Number of plantations per village (Representative From Division of Plantation and City of Palangkaraya Forestry, 2015).

Tangkiling village	12 plantations
Banturung village	20 plantations
Sei Gohong village	8 plantations
Kanarakan village	10 plantations

This results in the following objective, where the type of revenue or cost is indicated per line.

$$\begin{aligned}
 & \text{Maximize} \\
 & P^B * \delta * \sum_{i=1}^I \sum_{j=1}^J \sum_{t=1}^T Z_{ij,t} \quad \text{Value of produced bio-diesel} \\
 & + P^C * \gamma * \sum_{i=1}^I \sum_{t=1}^T Y_{i,t} \quad \text{Value of produced press cake} \\
 & - C^C * \sum_{i=1}^I \sum_{t=1}^T C_{i,t} \quad \text{Collection costs} \\
 & - C^D * \sum_{i=1}^I \sum_{t=1}^T X_{i,t} \quad \text{Drying costs} \\
 & - C^E * \sum_{i=1}^I \sum_{t=1}^T Y_{i,t} \quad \text{Extraction costs} \\
 & - C^P * \sum_{i=1}^I \sum_{j=1}^J \sum_{t=1}^T Z_{ij,t} \quad \text{Processing costs} \\
 & - C^T * \sum_{i=1}^I \sum_{j=1}^J \left(D_{ij} * \sum_{t=1}^T Z_{ij,t} \right) \quad \text{Transportation costs RSO} \\
 & - C^{TM} * \sum_{j=1}^J \sum_{k=1}^J \left(D_{j,k}^M * \sum_{t=1}^T M_{j,k,t} \right) \quad \text{Transportation costs MPU} \\
 & - F^M * N^M * T \quad \text{Fixed costs MPU} \\
 & - F^P * N^P \quad \text{Fixed costs pre-processing site}
 \end{aligned}$$

We next list and then explain the constraints that a feasible solution must satisfy. In doing so, we denote the total weight of seeds collected at plantation i at time t by $C_{i,t}$. It easily follows that this total weight is equal to the size of an average plantation times the number of trees per hectare times the number of seeds per tree times the average weight of one seed times the percentage of wet seeds that fell on the ground at time t , i.e. $C_{i,t} = H * S * A * W * \zeta_t$.

$$X_{i,t} \leq I_{i,t} \quad \forall i, t \quad (1)$$

$$X_{i,t} \leq CAP^D \quad \forall i, t \quad (2)$$

$$I_{i,t+1} \leq I_{i,t} + C_{i,t} - X_{i,t} \quad \forall i, t \quad (3)$$

$$I_{i,t} \leq CAP^D * Q \quad \forall i, t \quad (4)$$

$$\sum_{x=1}^t Y_{i,x} \leq \alpha * \sum_{x=1}^{t-1} X_{i,x} \quad \forall i, t \quad (5)$$

$$Y_{i,t} \leq CAP^E \quad \forall i, t \quad (6)$$

$$\sum_{x=1}^t \sum_{j=1}^J Z_{ij,x} \leq \beta * \sum_{x=1}^{t-1} Y_{i,x} \quad \forall i, t \quad (7)$$

$$\sum_{i=1}^I \sum_{j=1}^J Z_{ij,t} \leq \sum_{k=1}^J M_{j,k,t} * CAP^P \quad \forall j, t \quad (8)$$

$$\sum_{k=1}^J M_{k,j,t} = \sum_{k=1}^J M_{j,k,(t+1)} \quad \forall j, t \quad (9)$$

$$\sum_{j=1}^J \sum_{k=1}^J M_{j,k,t} = N \quad \forall j, t \quad (10)$$

$$M_{j,k,t} \in \mathbb{N} \quad \forall j, k, t \quad (11)$$

$$X_{i,t}, Y_{i,t}, Z_{ij,t}, I_{i,t} \geq 0 \quad \forall i, j, t \quad (12)$$

The logic is as follows:

1. Weight of seeds drying during period t at plantation i does not exceed inventory of wet seeds at the beginning of period t at plantation i . It takes one period to dry seeds.
2. Weight of seeds drying during period t at plantation i does not exceed the drying capacity.
3. Inventory of wet seeds at the beginning of period $t+1$ at plantation i does not exceed inventory at the beginning of period t plus seeds collected minus seeds dried during period t at plantation i .
4. Inventory of wet seeds of plantation i at the beginning of period t does not exceed drying capacity times the number of days wet seeds satisfy the quality requirement. There is no point in storing more wet seeds, as those additional seeds would have to be discarded at some point. So this constraint is *necessary* to avoid decay of stored wet seeds. Moreover, as we next argue, this constraint is also *sufficient* to avoid decay of stored seeds. Since the timing of drying does not affect the costs, it is clearly optimal to dry as many wet seeds as possible, i.e. to dry at full capacity CAP^D if enough wet seeds are available in storage and dry all available wet seeds otherwise. Therefore, under first-in-first-out (FIFO) sequencing, constraint (4) is sufficient as well as necessary to avoid decay. This observation allows us to avoid the introduction of inventory variables that contain information on what fractions of stored wet seeds have been stored for how long, along with the constraints that would be needed to update such inventory variables from one period to the next.
5. Total weight of dry seeds used in the extraction process until period t at plantation i does not exceed total weight of dry seeds produced until period $t-1$ at plantation i .
6. Weight of dry seeds used in the extraction process during period t at plantation i does not exceed extraction capacity.
7. Total weight of RSO processed until period t at plantation i does not exceed RSO produced until period $t-1$ at plantation i .
8. Weight RSO processed at processing site j during period t does not exceed processing capacity of available MPUs at processing site j .
9. Number of MPUs going to processing site j at period t is equal to leaving processing site j at period $t+1$.
10. Number of MPUs at period t is equal to N .
11. All movement variables are natural numbers (positive integers).
12. Drying, extraction, processing and inventory amounts are non-negative.

Note that we do not include the standard VRP constraint that the MPU should visit each processing site exactly once. As discussed in [Section 2.2](#), it may be optimal to visit sites multiple times since a single, long stay at some site could lead to RSO decay for farmers situated close to other sites.

4. Case study application

The case study is about bio-diesel production from RSO in Bukit Batu, Palangka Raya, a sub-district of Central Kalimantan (see [Fig. 2](#)), an Indonesian province on Borneo. Most of the data that will be presented is collected by field research, while some is obtained from

sources in the literature such as [Abduh \(2015\)](#). Central Kalimantan covers an area of 153,565 km² and has a population of around 2.4 million ([BPS Kalimantan Tengah, 2014](#)). In this relatively rural area, agriculture is the principal occupation. The bulk of the province's GRDP (gross regional domestic product) is generated by plantations, most notably palm oil and rubber. The area of rubber plantations in Central Kalimantan province is 271.84 thousand hectares, which is 7.65% of the total rubber plantation area in Indonesia ([BPS Kalimantan Tengah, 2014](#)). A substantial portion of around 38% of the provincial roads, is still unpaved. In some areas rivers can be used for transportation, but even river-based transportation needs facilities, which remain insufficient ([Giap et al., 2015](#)).

This case study includes rubber plantations of four different villages in Central Kalimantan. The village names and numbers of plantations are listed in [Table 1](#). These plantations are all small (around 2 ha) and privately owned ([Bot, 2013](#)), since the size of the plantations are very similar, the model can use an average plantation size (A) of 2 ha. The number of trees per hectare (H) at these plantations is 555 ([Representative From PT. Inhutani III \(state owned rubber plantation company in Central Kalimantan\), 2015](#)), with 400 seeds per tree (S) which have an average weight (W) of 0.005 kg ([Bot, 2013](#)). Rubber trees produce seeds twice a year ([Representative From PT. Inhutani III \(state owned rubber plantation company in Central Kalimantan\), 2015](#)).

The harvesting season starts when the first seeds drop down on the ground. It is hard to assess a realistic fall-pattern. Most plantation owners never paid careful attention to the fall-pattern, since the seeds are now seen as a waste product ([Representative From Rubber Farmer Groups in Palangkaraya, 2015](#)). However, based on their rough estimates, in the base model the fall-pattern (ζ_t) is assessed at; a drop of 5% of the total seeds of the tree per day for the first four days, after that a drop of 10% for the next six days, and finally a drop of 5% for the following four days. Thus the time-span of the seeds dropping down on the ground in the base model is assessed at 14 days.

The collected seeds are stored at the pre-processing site. It is assumed that every plantation has its own pre-processing site to minimize transportation costs and decay, hence the number of pre-processing sites (N^p) is 50. The fixed costs of one pre-processing site are €10,800 for its whole lifetime ([Abduh, 2015](#)). The pre-processing site is written off after approximately 20 years, this results into fixed costs (F^p) of €270 per pre-processing site per season. Note that we apply the average cost approach to estimate the fixed costs, rather than the more sophisticated but also more complex net present value approach that would involve estimating interest rates over the next 20 years. To reduce the rate of decay, the seeds are stored in crates in a well ventilated room. In this way the seeds meet the quality requirements (Q) for 10 days ([Zhu et al., 2011](#)).

After the seeds are collected and stored at the pre-processing site, the seeds need to be dried. The drying cost of 1 kg undried seeds (C^D) is €0.025 (estimated based on [Abduh, 2015](#)). The drying capacity (CAP^D) of one pre-processing site is 480 kg of undried seeds per day ([Abduh, 2015](#)). After the seeds are dried, they weigh 96.7% of their original weight ($\alpha = 0.967$) ([Abduh, 2015](#)). The dried seeds are stored at the pre-processing site. They stay in good condition for 8 months, since the planning horizon of the model is only a fraction of these 8 months ([Abduh, 2014](#)), the quality of dry seeds is not affected during the planning horizon of one season.

The cost of extracting oil from 1 kg dried seeds (C^E) is €0.029 (estimated based on [Abduh, 2015](#)), and the maximum amount of dried seeds that can be used for oil extraction (CAP^E) is 464 kg per day. Out of 1 kg dried seeds, (β) 0.259 kg RSO and (γ) 0.707 kg press cake can be produced ([Abduh, 2015](#)). This press cake can be sold and used as fertilizer or feed for cattle and poultry, it has a value (P^C) of €0.17 per kg ([Abduh, 2015](#)). The RSO is stored at the pre-processing

Table 2

Distances between plantations and processing sites, in km.

		Processing site			
		Tangkiling	Banturung	Sei Gohong	Kanarakan
Plantation	Tangkiling	8	16	15	26
	Banturung	16	9	20	27
	Sei Gohong	15	20	10	21
	Kanarakan	26	27	21	6

site. RSO can be stored for up to 1 year, hence it will not decay during the planning horizon of one season.

The final stage of the production process is transporting the stored RSO to a processing site where it will be converted into bio-diesel by an MPU. The transportation costs of 1 kg RSO (C^T) is estimated at €0.0003 per km ([Representative From PT. Inhutani III \(state owned rubber plantation company in Central Kalimantan\), 2015](#)). The roads between villages are mostly paved, while the roads between plantations and the villages are mostly unpaved. Therefore the MPU can only reach the villages. As a result, it is possible to group the plantations per village. This means that all plantations in the neighborhood of one village are combined and treated as one big plantation. Thus the drying and oil extracting capacity per village is CAP^D and CAP^E times the number of plantations in that village. The same applies for the amount of collected seeds, the total per village is calculated. The average distance (D_{ij}) in km between plantations in the neighborhood of village i and the processing site j is given in [Table 2](#). Please note the positive values on the diagonal, indicating the average distance from a plantation to the central village location.

On the first day of the season the MPU has to be transported from a depot to a processing site, and after the last day of the season the MPU has to be transported back to a depot. To make use of the full potential of the MPU, it is best to place the depot in a central and easily accessible location for a large area. In this case the city center of Palangkaraya, the capital of the province Central Kalimantan, is the best option. During the season the MPU is transported from village to village. In this way the transportation costs of RSO are kept at a minimum. The transportation costs of the MPU (C^{TM}) is estimated at €0.30 per km ([Abduh, 2015](#)). The distance between processing sites and depot ($D_{j+1,k+1}^M$) are given in [Table 3](#).

When the RSO is at the right location it can be processed. The processing costs (C^P) are €0.131 per kg RSO (estimated based on [Abduh, 2015](#)). Since the data of this case study consists out of only four villages, the number of MPUs (N^M) is set to one in order to keep fixed cost from MPUs as low as possible. The amount of RSO that can be processed at the processing site (CAP^P) is set to 1000 kg RSO per day in the base model. We note that the MPUs are still in the design phase, The (construction) costs of one MPU are assessed at €40,000 ([Abduh, 2015](#)) with a lifetime of 16 years. Since the MPU can be used in other areas as well, plantation owners have to rent the MPU per day. The number of days an MPU can be used per year is assessed at 100, hence the fixed costs (F^M) are €25 per day, again based on average cost considerations. RSO is converted into bio-diesel at a ratio of 1:1 ($\delta = 1$) ([Abduh, 2015](#)). The produced bio-diesel can be used as a substitute for petroleum diesel, hence the price of petroleum diesel can be used to value the bio-diesel. However, the price of

Table 3

Distances (for MPUs) between processing sites and from depot, in km.

	Tangkiling	Banturung	Sei Gohong	Kanarakan	Depot
Tangkiling	0	8	6	19	47
Banturung	8	0	10	19	39
Sei Gohong	6	10	0	13	56
Kanarakan	19	19	13	0	50
Depot	47	39	56	50	0

petroleum diesel is very volatile in this rural area, it can vary between €0.656 and €0.922 (Representative From Rubber Farmer Groups in Palangkaraya, 2015). Our *base case* scenario is to take the average value of €0.789 as the price of bio-diesel (P^B), but we will also vary this in a sensitivity study.

The planning horizon is the final parameter that has to be determined before the model can be solved. Since plantation owners have to rent the MPU per day, the planning horizon should be as short as possible, as long as all RSO can be processed. With a processing capacity of 1000 kg per day and a 27,800 kg of RSO that can be produced, the MPU has to be available for at least 28 days. For the first two days there is no RSO available for processing (one day of drying and one day of oil extracting), hence the planning horizon is set to 30 days in the base case.

An overview of the (base case) parameter values for all model parameters and the sources from which they are obtained is given in Table 4. For readability, we also include parameter descriptions and notations. Finally, we refer interested readers to Bot et al. (2015) for more case study background regarding supply chain uncertainties with respect to material supply, transportation and production.

5. Results

We first present and discuss the results for the base case scenario in Section 5.1 and then perform a sensitivity study on key parameters in Section 5.2. The model was programmed in RStudio (Version 0.99.903; R version 3.2.2; Package: lpSolveAPI 5.5.2.0-17) and run on an HP Pavilion dv6 Notebook PC (Intel(R) Core(TM) processor i7-2630QM CPU @ 2.00 GHz 2.00 GHz; RAM: 6.00 GB; Software: Windows 10 64-bits).

5.1. Base case results

The base case model has 1320 decision variables and 990 constraints. The exact optimal base case solution is determined after 22 min. In the next subsection, we will shortly discuss as part of our sensitivity study how the computation time is affected by the specific parameter settings.

As discussed before, freshly harvested seeds are dried and pre-processed as quickly as possible in a first-in-first-out sequence to minimize decay. It turns out that all seeds can be dried and processed in time. Although this is obviously a positive result, we do note that there is considerable excess capacity since the capacity usage is not more than 46% on any day and so a smaller unit per farmer would suffice or two farmers could share the capacity of a single unit.

Our main interest is in the scheduling of MPUs as these are shared by the farmers and thus require coordinated movement and capacity allocation plans. Fig. 3 shows the optimal routing of the MPU and Fig. 4 shows the corresponding capacity allocation (i.e. seed supply). Note from Fig. 3 that the MPU first moves from the depot to Banturung. This has two advantages. First, it is the village closest to the depot. Second, it is the village with the largest number of farmers. The latter is beneficial as local supply from any single village during the first few days of the harvest season is not enough to fully utilize the capacity of the MPU. By first moving to the village with the largest number of farmers, the 'shortfall' is minimized and thereby the amount of seeds that need to be supplied from nearby villages (see Fig. 4) is minimized. Not using such additional supply from other villages would imply that the MPU needs to be hired for one or more extra days, but a sensitivity study will show in what follows that this is much more costly.

At the end of day 15, all supply from Banturung has been processed and the MPU moves to the nearby village of Tangkiling. For

Table 4

List of model parameters, ordered by the process to which they relate, with descriptions, notations, estimated (base) case parameter values, and sources from which those values are obtained.

Related process	Parameter description	Notation	Value	Source
General	Trees per hectare	H	555	Representative From PT. Inhutani III (state owned rubber plantation company in Central Kalimantan) (2015)
General	Seeds per tree	S	400	Bot (2013)
General	Plantation size (ha)	A	2	Bot (2013)
General	Weight of one wet seed, in kg	W	0.005	Bot (2013)
General	Number of plantations	N	50	Field study
Collection	Collection cost per kg	C^C	0.098	Farmers
Storage wet seeds	Maximum days in storage	Q	10	Zhu et al. (2011)
Drying	Drying yield fraction	α	0.967	Abduh (2015)
Drying	Drying costs per kg	C^D	0.025	Abduh (2015)
Drying	Capacity per day (kg wet seeds)	CA^{PD}	480	Abduh (2015)
Oil Extraction	RSO yield fraction	β	0.259	Abduh (2015)
Oil Extraction	Press cake yield fraction	γ	0.707	Abduh (2015)
Oil Extraction	Cost pre-processing site per season	F^P	270	Abduh (2015)
Oil Extraction	Capacity per day (kg dry seeds)	CA^{PE}	464	Abduh (2015)
Oil Extraction	Extraction cost per kg dry seeds	C^E	0.029	Abduh (2015)
Oil Extraction	Price per kg press cake	P^C	0.17	Abduh (2015)
Bio-diesel processing	Bio-diesel yield	δ	1	Abduh (2015)
Bio-diesel processing	Bio-diesel processing cost per kg RSO	C^P	0.131	Abduh (2015)
Bio-diesel processing	Transportation cost per kg RSO per km	C^T	0.0003	Representative From PT. Inhutani III (state owned rubber plantation company in Central Kalimantan) (2015)
Bio-diesel processing	Transportation cost of MPU per km	C^{TM}	0.30	Abduh (2015)
Bio-diesel processing	Distance plantation i to processing site j	D_{ij}	Table 2	Field study
Bio-diesel processing	Distance between processing sites j and k	D_{jk}^M	Table 3	Field study
Bio-diesel processing	Cost of an MPU per day	F^M	25	Abduh (2015)
Bio-diesel processing	Number of MPUs	N^M	1	Set at 1
Bio-diesel processing	Capacity per day, kg RSO	CA^{PP}	1000	Abduh (2015)
Bio-diesel processing	Price of bio-diesel, per kg	P^B	0.789	Representative From Rubber Farmer Groups in Palangkaraya (2015)

Fig. 3. Optimal route of the MPU.

this and also for the last two villages to be visited, the MPU stays until all seeds have been processed. During the last day of a stay at some village, additional supply from other villages may be needed (see Fig. 4) to operate the MPU at full capacity. During other days, only local seeds are processed, thereby minimizing transportation costs from farmers to the MPU.

As it turns out, the optimal route (Depot, Banturung, Tangkiling, Sei Gohong, Kanarakan, Depot) is also the shortest possible route. We remark that this is not a trivial outcome, since MPU transportation costs are only a part of the total costs that are minimized. So, in other situations it is possible that the optimal solutions deviates from the shortest route, for instance to ensure that the village to be visited first is a large one so that it has high local RSO supply during the start of the season. As mentioned before, in our specific setting the first village on the shortest route is also the largest one.

The total profit per season for producing 27,800 kg bio-diesel in the base case scenario is €65.17 per season, and so a meager €1.30 for each of the fifty farmers. It is very close to break even, implying a negligible return on investment. So for these settings, some form of subsidy or further technological development is needed. However, as the next subsection will show, the profit (margin) is very sensitive with respect to especially the price of bio-diesel, which is expected to go up in the future given the increasing global energy demand and depleting fossil fuel sources.

5.2. A sensitivity analysis

As mentioned in the case study description, there is a lot of volatility in the price of bio-diesel, which closely follows the price of petroleum diesel. It varies between €0.656 and €0.922 per kg. In the base case the value in the middle of this price range was selected, but given the high volatility it is important to study the effects of deviating from that base value. An important observation is that the bio-diesel price does not alter the optimal solution, as the same solution obviously remains the most cost-effective. However,

the price does affect the profitability of bio-diesel production for the optimal solution. Recalling the total production of 27,800 kg bio-diesel per season, this implies that each one cent increase in the price of bio-diesel implies an additional profit of €278. At the highest likely price of €0.922 per kg, the total profit per season will be €3762.61. Since the total costs per season are €34,770, this translates to a considerable return on investment of 10.82%.

It is also important to consider different values for the capacity of the MPU, as they are still in the design phase. The base case capacity is 1000 kg RSO per day. Since the MPU can only process for 28 days in the base case (total period minus one day of drying and one day of oil extracting) and it has to process 27,800 kg per season, the capacity is utilized for 99.3%. Increasing the capacity increases flexibility and makes room for production delay (e.g. when the MPU breaks down for a few days). A larger capacity also slightly reduces the transportation costs of RSO, since plantation owners can wait until the MPU is in the closest village to process their RSO. However these savings are barely noticeable. To set an example, when the MPU's production capacity is increased from 1000 to 1500 kg RSO per day the total profit per season is only €8.09 higher. So, if it is possible to increase the production capacity with 50% for an additional 10% of the construction cost of the MPU, it will still have a negative influence on the total profit, hence it can be concluded that having a large excess capacity should be avoided. When the capacity decreases, such that not all available RSO can be processed, the total profit also decreases rapidly. If the MPU has a capacity of 900 kg RSO, leaving all other parameters unchanged, the total profit is €1699.49 lower, which results in a negative ROI. Hence it is very important to ensure that the capacity of the MPU is large enough to process all available RSO.

Finally, we consider the option of creating more scheduling flexibility by increasing the planning horizon from 30 to 35 days, i.e. by hiring the MPU for 5 more days. It turns out that this does not affect the route of the MPU. The MPU stays somewhat longer at each of the villages, so that it is no longer needed to (sometimes) supply seeds from other villages. This reduces the transportation costs of RSO, but the increase in MPU rental costs is much higher. So, in line with an overall negative effect of increasing the capacity per day, increasing the total available production capacity has a negative effect on the total profit.

Table 5 confirms the significance of the bio-diesel price for all settings: base, increased or decreased MPU capacity and increased planning horizon.

The computation times are also affected by the specific settings. They vary between 1.5 and 32 min for the cases considered. Capacity usage turns out to be a key factor. Recall that the computation time was 22 min for the base case, where capacity ($CAP^p = 1000$ for $T = 30$ periods) is very tight but sufficient, making it difficult to find an optimal solution. Computation times are much smaller if either there is more than enough capacity (8 min for $CAP^p = 1500$ and $T = 30$) or not enough capacity (3 min for $CAP^p = 900$ and $T = 30$; 1.5 min

Fig. 4. Origin of processed RSO for the optimal solution.

Table 5

Profit and return on investment for different scenarios.

		Total profit	Profit per plantation	ROI
Base case	$p^B = 0.789$	€65.17	€1.30	0.19%
$T = 30, CAP^P = 1000$	$p^B = 0.922$	€3762.61	€75.25	10.82%
Increased MPU capacity	$p^B = 0.789$	€73.26	€1.46	0.21%
$T = 30, CAP^P = 1500$	$p^B = 0.922$	€3770.70	€75.41	10.85%
Decreased MPU capacity	$p^B = 0.789$	€−1634.32	€−32.69	−4.75%
$T = 30, CAP^P = 900$	$p^B = 0.922$	€1717.28	€34.345	4.99%
Increased planning horizon	$p^B = 0.789$	€−51.74	€−1.03	−0.15%
$T = 35, CAP^P = 1000$	$p^B = 0.922$	€3645.70	€72.91	10.45%

for $CAP^P = 800$ and $T = 30$). Increasing T from 30 to 35 creates 220 additional decision variables en 165 new constraints, leading to longer solution times (32 min for $CAP^P = 1000$ and $T = 35$).

6. Conclusion

We studied the planning of bio-diesel production in rural areas using MPUs. A mixed-integer program formulation was developed to find the optimal routing of MPUs and the allocation of MPU capacity to farmers, and was applied to the production of bio-diesel from rubber seeds in a region of Indonesia. This leads to a number of insights that are relevant for policy makers. One important finding is that, given the relatively high cost of building MPUs, they must operate at almost full capacity to make bio-diesel production economically sustainable. Governments should own the MPUs and ideally rent them out to farmers for different types of bio-diesel production in order to maximize the use of MPUs. Zooming in on the supply of raw material (rubber seeds) by farmers to the MPUs, even if the MPU visits all (major) villages, some transportation between villages can be needed at the start of a season to also ensure high capacity usage in that period.

An important sensitivity result is that the price of bio-diesel, which is very volatile, heavily influences the profitability of bio-diesel production. At the midpoint of the price range for the recent past, the profit and related return on investment are very small. At the top end of the price range, however, the return on investment is more than 10%. Ensuring a certain minimum price could be a very effective way of stimulating farmers to take up bio-diesel production. Developing smaller, less costly pre-processing units is another way to boost profitability. In the current (base case) setup, these units account for 38% of the total cost. Our results showed that half of the available capacity would still be sufficient to process all seeds without delay. Alternatively, the units can be shared between farmers, but this implies more coordination and transportation.

There are some limitations to our research. Starting with the MPU, there is uncertainty about the construction price and possibly production capacity of the MPU since only a prototype has been build (Löffler et al., 2014; Mowry, 2011). Information about the fall-pattern is also scarce. Since the rubber seeds are currently seen as a waste product, plantation owners so far did not record the precise fall-pattern. Our results are based on rough estimations by farmers. Moreover, the fall-pattern will vary from one season to the next based on weather conditions. Equipment breakdowns, changes in the available workforce and short term orientated decision making by farmers create additional uncertainties. Future research should be directed towards incorporating these uncertainties, for instance by developing stochastic optimization methods for supply chain planning. More empirical research in different areas and on different types of bio-diesel production is also needed. Finally, computation times could become an issue for much larger instances (with multiple MPUs and/or more villages to be visited over a longer planning horizon), and so it is worthwhile to study alternative

‘tighter’ formulations of the mathematical model that we proposed or develop approximate solution techniques.

References

- Abdud, M., 2014. Personal Communication With One of the Authors.
- Abdud, M., 2015. Biobased Products From Rubber, Jatropha, and Sunflower Oil. University of Groningen. PhD Thesis.
- Acevedoa, P., Cabezaa, I., Puella, J., Benedettib, E., 2016. Mobile plant for biodiesel production from *Jatropha curcas* seeds, in Colombian Caribbean regions. Chem. Eng. Trans. 50, 283–288.
- Ahmad, J., Yusup, S., Bokhari, A., Kamil, R., 2014. Study of fuel properties of rubber seed oil based biodiesel. Energy Convers. Manag. 78 (1), 266–275.
- Ahumada, O., Villalobos, J., 2009. Application of planning models in the agri-food supply chain: a review. Eur. J. Oper. Res. 196 (1), 1–20.
- Ahumada, O., Villalobos, J., 2011. Operational model for planning the harvest and distribution of perishable agricultural products. Int. J. Prod. Econ. 133 (2), 677–687.
- Ahumada, O., Villalobos, J., 2011. A tactical model for planning the production and distribution of fresh produce. Ann. Oper. Res. 190 (1), 339–358.
- Ahumada, O., Villalobos, J., Mason, A., 2012. Tactical planning of the production and distribution of fresh agricultural products under uncertainty. Agric. Syst. 177 (1), 17–26.
- Annetts, J., Audsley, E., 2002. Multiple objective linear programming for environmental planning. J. Oper. Res. Soc. 53 (9), 933–943.
- Arnaout, J., Maatouk, M., 2010. Optimization of quality and operational costs through improved scheduling of harvest operations. Int. Trans. Oper. Res. 17 (5), 595–605.
- Blackburn, J., Scudder, G., 2009. Supply chain strategies for perishable products: the case of fresh produce. Prod. Oper. Manag. 18 (2), 129–137.
- Bot, P., 2013. Uncertainties in the Bidirectional Biodiesel Supply Chain: An Empirical Model Developed in Central Kalimantan Indonesia. University of Groningen. Master Thesis.
- Bot, P., van Donk, D., Pennink, B., Simatupang, T., 2015. Uncertainties in the bidirectional biodiesel supply chain. J. Clean. Prod. 174–183.
- Bräysy, O., Gendreau, M., 2005. Vehicle routing problem with time windows, part I: route construction and local search algorithms. Transp. Sci. 39 (1), 104–118.
- Callahan, C., 2008. A Feasibility Study of a Mobile Unit for Processing Oilseed Crops and Producing Biodiesel in Vermont.
- Dantzig, G., Ramser, J., 1959. The truck dispatching problem. Manag. Sci. 6 (1), 80–91.
- Demir, E., Bektas, T., Laporte, G., 2014. A review of recent research on green road freight transportation. Eur. J. Oper. Res. 237 (3), 775–793.
- Ferrer, J., MacCawley, A., Maturana, S., Toloza, S., Vera, J., 2008. An optimization approach for scheduling wine grape harvest operations. Int. J. Prod. Econ. 112 (2), 985–999.
- Flood, M., 1956. The traveling-salesman problem. Oper. Res. 4 (1), 6175.
- Representative From Division of Plantation and City of Palangkaraya Forestry, 2015. Private Interview With One of the Authors.
- Representative From PT., 2015. Inhutani III (state owned rubber plantation company in Central Kalimantan) Private Interview With One of the Authors.
- Representative From Rubber Farmer Groups in Palangkaraya, 2015. Private Interview With One of the Authors.
- Gallery, Maphill Map, 2016. Accessed: 05-30. <http://www.maphill.com/>.
- Giap, T., Merdikawati, N., Amri, M., Berger, B. (Eds.), 2015. 2014 Annual Competitiveness Analysis and Development Strategies for Indonesian Provinces. Word Scientific Publishing Co. Pte. Ltd., Singapore.
- Glen, J., 1987. Mathematical models in farm planning: a survey. Oper. Res. 35 (5), 641–666.
- Grado, S., C., Strauss, 1993. An inventory control model for supplying biomass to a processing facility. Appl. Biochem. Biotechnol. 39 (1), 5–25.
- Grado, S., Strauss, C., 1995. Using an inventory control model to establish biomass harvesting policies. Sol. Energy 54 (1), 3–11.
- Grunow, M., Gunther, H., Westin, R., 2007. Supply optimization for the production of raw sugar. Int. J. Prod. Econ. 110 (1–2), 224–239.
- Higgins, A., 1999. Optimizing cane supply decisions within a sugar mill region. J. Sched. 2 (5), 229–244.
- Jones, P., Kegler, G., Lowe, T., Traub, R., 2003. Managing the seed-corn supply chain at Syngenta. Interfaces 33 (1), 80–90.

- Kalimantan Tengah, B.P.S., 2014. Kalimantan tengah dalam angka 2014 (Central Kalimantan in figures 2014). Statistical Report.
- Kazaz, B., 2004. Production planning under yield and demand uncertainty with yield-dependent cost and price. *Manuf. Serv. Oper. Manag.* 6 (3), 209–224.
- Kazaz, B., Webster, S., 2011. The impact of yield-dependent trading costs on pricing and production planning under supply uncertainty. *Manuf. Serv. Oper. Manag.* 13 (3), 404–417.
- Koç, Ç., Bekta, T., Jabali, O., Laporte, G., 2016. Thirty years of heterogeneous vehicle routing. *Eur. J. Oper. Res.* 249 (1), 1–21.
- Kusumastuti, R., van Donk, D., Teunter, R., 2016. Crop-related harvesting and processing planning: a review. *Int. J. Prod. Econ.* 174, 7692.
- Laporte, G., 2009. Fifty years of vehicle routing. *Transp. Sci.* 43, 408–416.
- Leite, J.G.D.B., Silva, J.V., van Ittersum, M.K., 2014. Integrated assessment of biodiesel policies aimed at family farms in Brazil. *Agric. Syst.* 131, 64–76.
- Löffler, H., Affif, S., Burgers, P., Govers, C., Heeres, H., Karyanto, O., Manurung, R., Vel, J., Visscher, S., Zwaagstra, T., 2014. Agriculture beyond food: experiences from Indonesia. Technical Report NWO/WOTRO, The Hague.
- Lokesh, A., Mahesh, N., Gowda, B., White, P., 2015. Sustainable biofuel strategy in Karnataka state a review. *Manag. Environ. Qual. Int. J.* 26, 288–300.
- Miller, W., Leung, L., Azhar, T., Sargent, S., 1997. Fuzzy production planning model for fresh tomato packing. *Int. J. Prod. Econ.* 53 (3), 227–238.
- Mowry, G., 2011. A portable, automated and environmentally friendly biodiesel processing system. *Int. J. Sust. Energy* 30 (1), S24–S34.
- Nagasawa, H., Kotani, M., Morizawa, K., 2009. Optimal cooperative harvesting patterns of agricultural fresh products in case of multiple farmers and multiple markets under periodical flowering. *J. Oper. Res. Soc. Jpn.* 52 (4), 417–432.
- Oliveira, L., Nunes, D., 2009. Design and operation of a mobile biodiesel processing unit. *Proceedings of the 2009 International Conference on Chemical, Biological and Environmental Engineering (CBEE 2009)*, pp. 29–37.
- Ortuno, M., Vitoriano, B., 2011. A goal programming approach for farm planning with resources dimensionality. *Ann. Oper. Res.* 190 (1), 181–199.
- Osaki, M., Batalha, M., 2014. Optimization model of of agricultural production system in grain farms under risk, in Sorriso, Brazil. *Agric. Syst.* 127, 178–188.
- Parker, N., Fan, Y., Ogden, J., 2010. From waste to hydrogen: an optimal design of energy production and distribution network. *Transp. Res.* 46 (4), 534–545.
- Pillac, V., Gendreau, M., Guéret, C., Medaglia, A., 2013. A review of dynamic vehicle routing problems. *Eur. J. Oper. Res.* 225 (1), 1–11.
- Qureshi, M., Qureshi, S., Wegener, M., 2007. Economic implications of alternative mill mud management options in Australian sugar industry. *Agric. Econ.* 36 (1), 113–122.
- Reshad, A., Tiwari, P., Goud, V., 2015. Extraction of oil from rubber seeds for biodiesel application: optimization of parameters. *Fuel* 150 (1), 636–644.
- Sharifzadeh, M., Garcia, M., Shah, N., 2015. Supply chain network design and operation: systematic decision-making for centralized, distributed, and mobile biofuel production using mixed integer linear programming (MILP) under uncertainty. *Biomass Bioenergy* 81, 401–414.
- Shukla, M., Jharkharia, S., 2013. Agri-fresh produce supply chain management: a state-of-the-art literature review. *Int. J. Oper. Prod. Manag.* 32 (2), 114–158.
- Singh, S., Singh, D., 2010. Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: a review. *Renew. Sust. Energ. Rev.* 14 (1), 200–216.
- Toth, P., Vigo, D., 2002. Models, relaxations and exact approaches for the capacitated vehicle routing problem. *Discret. Appl. Math.* 123 (1–3), 487–512.
- Tsolakis, N., Keramydas, C., Toka, A., Aidonis, D., Iakovou, E., 2014. Agrifood supply chain management: a comprehensive hierarchical decision-making framework and a critical taxonomy. *Biosyst. Eng.* 120 (1), 47–64.
- Tsubone, H., Muramatsu, R., Soshiroda, M., 1983. Designing an effective production system for processing agricultural products. *Int. J. Prod. Res.* 21 (1), 17–30.
- Tsubone, H., Muramatsu, R., Soshiroda, M., 1984. Production system for the agricultural processing industry. *Int. J. Prod. Res.* 22 (6), 1043–1053.
- Tsubone, H., Muramatsu, R., Soshiroda, M., 1986. A production-model for agricultural processing products. *Int. J. Prod. Res.* 24 (4), 799–809.
- Van Berlo, J., 1993. A decision support tool for the vegetable processing industry: an integrative approach of market, industry and agriculture. *Agric. Syst.* 43 (1), 91–109.
- van der Hilst, F., Dornburg, V., Sanders, J., Elbersen, B., Graves, A., Turkenburg, W., Elbersen, H., van Dam, J., Faaij, A., 2010. Potential, spatial distribution and economic performance of regional biomass chains: the north of The Netherlands as example. *Agric. Syst.* 103, 403–417.
- Widodo, K., Nagasawa, H., Morizawa, K., Ota, M., 2006. A periodical flowering-harvesting model for delivering agricultural fresh products. *Eur. J. Oper. Res.* 170 (1), 24–43.
- Yeast, H.-Y., 2007. Synchronous flowering of the rubber tree (*Hevea brasiliensis*) induced by high solar radiation intensity. *New Phytol.* 175, 283–289.
- Yusuf, N.N.A.N., Kamarudin, S.K., Yaakub, Z., 2011. Overview on the current trends in biodiesel production. *Energy Convers. Manag.* 52 (7), 2741–2751.
- Zhang, F., Johnson, D., Johnson, M., 2012. Development of a simulation model of biomass supply chain for biofuel production. *Renew. Energy* 44 (1), 380–391.
- Zhang, L., Hu, G., 2013. Supply chain design and operational planning models for biomass to drop-in fuel production. *Biomass Bioenergy* 58 (1), 238–250.
- Zhu, Y., Xu, J., Mortimer, P., 2011. The influence of seed and oil storage on the acid levels of rubber seed oil, derived from *Hevea brasiliensis* grown in Xishuangbanna, China. *Energy* 36 (8), 5403–5408.