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Modelling Cooperation in Biomass Supply Chains: a Conflict Analysis Approach

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Biomass supply chains play an important role in providing feedstock for the production of renewable energy and fuels. However, biomass supply chains frequently face a challenge in large-scale uptake due to the lack of cooperation and coordination among supply chain players. This work presents a conflict analysis approach to analyse the effect of relationships among supply chain players within an optimal biomass supply chain. Conflict analysis was previously introduced to analyse the degree of conflict among nations based on several geopolitical issues systematically. In the context of biomass supply chains, conflict analysis can be adapted to model the relationships between supply chain players based on their preferences towards specific issues or policies. A biofuel supply chain case study is solved to demonstrate the applicability of the proposed conflict analysis. In the presented case study, a hypothetical government policy for biofuel supply chains is introduced. Conflict analysis is used to evaluate the preferences of the supply chain players towards the proposed policy and convert these opinions into quantifiable relationships known as the degree of conflict. Results from the conflict analysis are compared with a case where conflict analysis is not considered.

1. Introduction

Carbon emissions from the energy generation sector have reached alarming levels in recent times. There has been an increase in investment in sustainable energy sources for energy generation. Countries such as The United States (Schmidt, 2020) and Japan (Boyd, 2020) utilise agricultural biomass as an alternative for the replacement of fossil fuel in energy generation. However, the biomass industry has several challenges to overcome before it reaches its full potential. For example, there is still room for further carbon emission reduction from biomass-generated energy. Many works have been developed to investigate this opportunity. Razak et al. (2021) developed an optimisation model for palm oil biomass supply chains aiming to minimise carbon gas emissions. To optimise the supply chain, many environmental policies have also been introduced around the world. Various decision-making tools were developed and incorporated in mathematical models to evaluate the effectiveness of policies towards supply chains. For example, Leong et al. (2019) developed an optimisation model considering output-driven energy policy and emission-driven policy. However, these policies were hypothesised to alter the cost elements involved in the model directly. Following this, the model developed by Saghaei et al. (2020) incorporated the downside risk associated with carbon tax policy and carbon offset policy. The risk is reflected as a penalty cost in the supply chain. Haji Esmaeili et al. (2020) also developed a model which considers the effect of monetary incentives and carbon taxes on the supply chain. Although mentioned works incorporate the impact of policy within their models, the related policies were directly linked to the cost of the supply chain. However, it is more practical if policies can be linked directly to the behaviour of supply chain players. For example, some policies might benefit from certain players more than others. This imbalance might spark disputes and influence the relationship among players. The imbalance then affects the supply chain interaction and indirectly affects the overall cost associated with the supply chain.

Based on the literature review, most previous works do not explicitly study the direct impact of a policy on a biomass supply chain. Therefore, to address the gaps, this work aims to develop an approach to quantify the

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implications of a policy on biomass supply chains. Close focus is given to investigating the effect of relationships among supply chain players based on the degree of agreement among supply chain players.

2. Methodology

A mathematical model is developed to determine the optimal biofuel supply chain in this work. The model breaks the biofuel supply chain problem into multiple periods to represent monthly supply chain operations. The multiperiod consideration is essential for modelling storage behaviour, where the storage inventory at an earlier period is needed to compute the inventory at a later period. Furthermore, the developed model accounts for the mass and energy flow between supply chain players (i.e., biomass producers, biomass storage operators, biomass processing plants) using mathematical equations. The model is solved to determine the optimal biofuel supply chain with minimum total cost by considering material losses across storing periods. This optimal supply chain provides optimal mass distribution across the supply chain. Based on the optimised result, an ideal supply chain can be formulated in which policymakers would like to happen in reality. However, supply chain players may not agree with these proposals in reality due to various reasons. Thus, conflict analysis was used to investigate the effect of these changes on the relationship between supply chain players. Detailed steps are described in the following sub-section.

2.1 Conflict Analysis

Conflict analysis was proposed by Pawlak (1998). It essentially quantifies the relationship between several $i \in I$ players based on several $y \in Y$ policy issues. Figure 1 summarises the overall methodology for the conflict analysis. Note that the methodology can be extended to multi-players and multi-issues scenarios. For simplicity, this work illustrates the proposed methodology for a three-players (i.e., i=1, i=2 and i=3) and three-issues (i.e., y=1, y=2 and y=3) scenario. All the players can either show agreement, disagreement, or be neutral towards each of the issues y. Each perspective can be assigned values 1, -1 and 0. The value of 1 is set if a player agrees with a policy. Meanwhile, players that disagree or are neutral with a policy are assigned -1 and 0, respectively. Following this scoring criteria, the perspective of the players towards each issue can be summarised in an information system, as shown in upper left of Figure 1. Based on the information system, a relation matrix between players is generated for all issues. The matrix is generated by comparing two players' perspectives, player i and i' based on each issue y. For the current example, the matrix is generated by using player 1's perspective as the basis and comparing it with player 2 and player 3. Then, the comparison proceeds by using player 2 as the basis and compare it with player 1 and player 3. Lastly, the perspective of player 3 is compared with 1 and 2. This procedure is repeated for each issue. Table 1 summarises the possible outcomes of the paired comparison for an issue ($\vartheta_{ii'y}$). As shown in Table 1, it is possible for $\vartheta_{ii'y}$ to be a negative one. As the relationship among players signifies the extent (or score) of them being possible allies, a negative value cannot be used for further calculations directly. Therefore, the values $\vartheta_{ii'y}$ need to be modified. For current work, the modified value ($\vartheta''_{ii'y}$) is obtained from $\vartheta_{ii'y}$ by:

$$\vartheta''_{ii'y} = 1 - \frac{1-\vartheta_{ii'y}}{2} \quad \forall i \quad \forall y \tag{1}$$

The modified values are summarised in Table 1 as well. Based on Table 1, the higher the value of $\vartheta''_{ii'y}$ between two players, the more positive the relationship between those two players Thus, this indicates these players have high potential to be allied with each other. For players with a lower $\vartheta''_{ii'y}$, they are possibly in conflict with each other. For players who have $\vartheta''_{ii'y}$ of 0.5, this indicates at least or both players are neutral towards an issue. When a player holds no opinion towards the issue, that player is considered uninterested in knowing the other player's perspective. Thus, in the case of $\vartheta''_{ii'y}$ having 0.5, they are neutral. As the current example has three issues, three modified relation matrices are generated (Figure 1). Therefore, an average value is taken for each pair using values from all issues to obtain the final relation among players. This average value can be regarded as the likelihood of successful business interaction between two players in the supply chain. For current work, it is termed as the degree of agreement, $\iota_{ii'}$. It is calculated as:

$$\iota_{ii'} = \frac{\sum_{y=1}^{Y} \vartheta''_{ii'y}}{Y} \quad \forall i \tag{2}$$

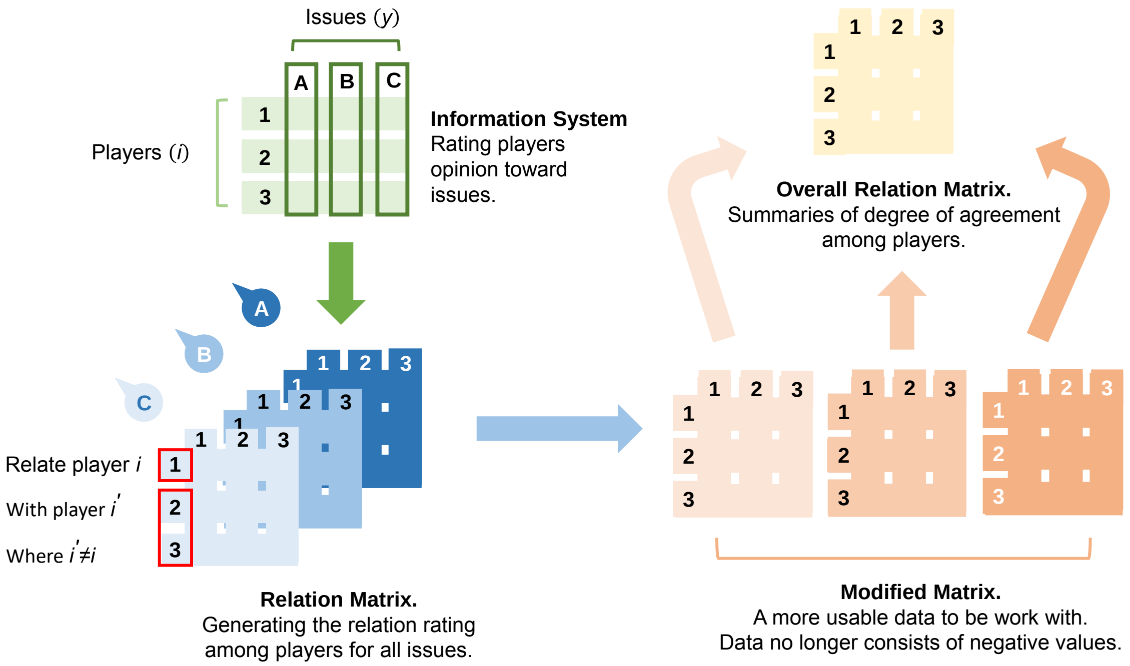

Figure 1: Overview of Conflict Analysis

Table 1: Modified and Unmodified Correlation used for Relation Matrix

player *i* and *i'* on issue y	$\vartheta_{ii'y}$	$\vartheta^{''}_{ii'y}$	Relation of player *i* and *i'*
At least one or both pair values is zero	0	0.5	Neutral towards each other
Both pair values are the same	1	1	Agree with each other
Both pair values are different	-1	0	Disagree with each other

In this work, it is desired to investigate the effect of the relationship to the supply chain. This is done by utilising the degree of agreement obtained from conflict analysis. The degree of agreement can provide policymakers with a basis for understanding the effect of biomass supply chain policies rolled out. When the government releases a policy, it contains a specific set of conditions or requirements for each player to meet. However, each player might react differently towards the policy as its requirements may impact their operations. Therefore, some players might not benefit from the policy while others may. This imbalance will create conflict among certain players and affect the overall relationship within the supply chain, as summarised in Figure 2.

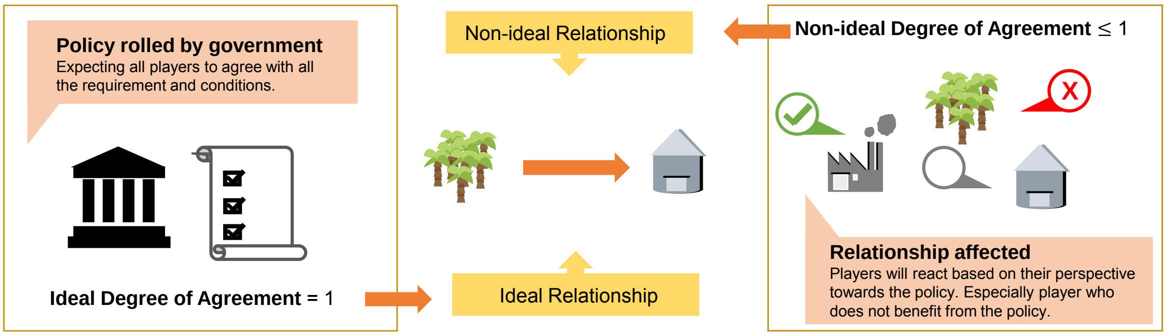

Figure 2: Expected and Real Degree of Agreement

As mentioned, the degree of agreement ($\iota_{ii'}$) can be regarded as the likelihood of successful business interaction between two players in the supply chain. From Figure 2, a biomass source could have a certain amount of $F_{ii'}$ material available for storage. However, the amount of actual material obtained for that storage ($F_{ii'}^{actual}$) will depend on the degree of agreement between the supplier and the storage operator. As mentioned earlier, the degree of agreement is expressed by $\iota_{ii'}$ and is implemented as an analogous term to efficiency for $F_{ii'}$. Therefore, the actual amount of material the storage could obtain is:

$$F_{ii'}^{actual} = F_{ii'} \cdot \iota_{ii'} \quad \forall i \quad \text{where} \quad \iota_{ii'} \leq 1 \tag{3}$$

The above expression explicitly links the relationship among players to the performance of the supply chain. In the case where a successful business transaction occurs, ι_{ab} would have the value of 1. If a conflict exists between two players, $\iota_{ii'}$ would be lower than 1. Eq(3) was added to the initial multiperiod mathematical model to determine the optimal biomass supply chain considering conflict among players. The optimal supply chain obtained here is then compared to the ideal supply chain for further analysis. The methodology described in this section is demonstrated using a case study shown in the following section.

3. Case study

This section presents a case study to demonstrate the proposed methodology. This case study considers a biofuel supply chain in Malaysia with empty fruit bunches (EFB) as feedstock. It consists of thermochemical conversion pathways of oil pyrolysis that are based on the work published by Rubinsin et al. (2020). A superstructure for this supply chain is presented in Figure 3. In Figure 3, the alphabets denote types of facilities, while the indices to the alphabets denote the unit of each type of facilities. Based on Figure 3, a multiperiod model was developed to represent the interactions between players in the supply chain in different periods. In this case study, it is assumed that a government policy is introduced. The policy aims at the operation of a biofuel supply chain with minimum cost. The issues proposed in the policy are:

Issue 1: A transport subsidy divided into three brackets in promoting local biomass development
Issue 2: The requirement for workforce reduction due to COVID-19
Issue 3: The requirement for production fluctuation due to uncertain demand during COVID-19

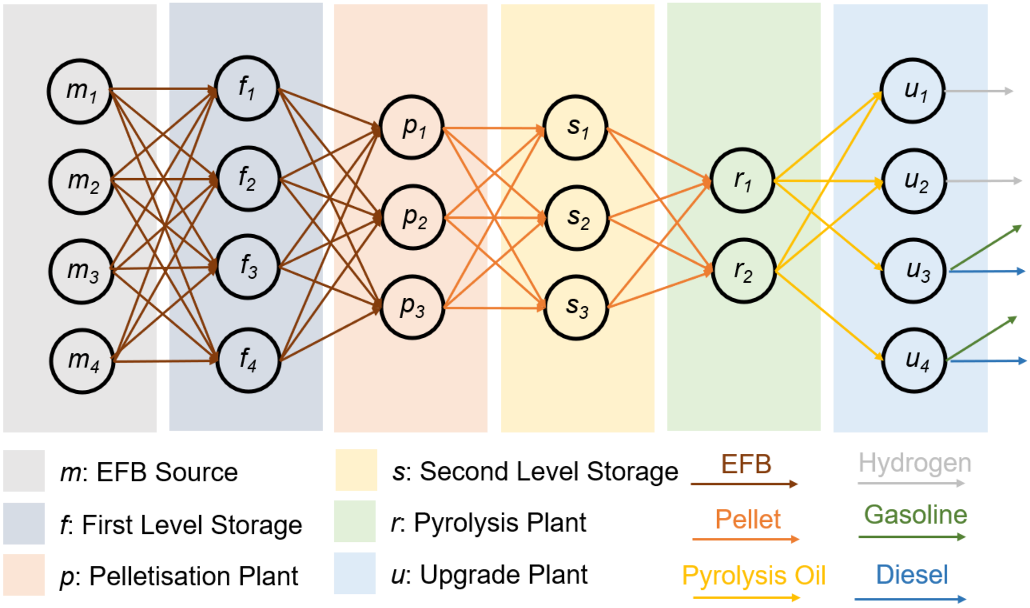

Figure 3: Superstructure of Current Work

The issues may impact the way the supply chain will operate. Therefore, it is essential to determine each player's perspective towards issues proposed in the policy. Several criteria are introduced to classify whether a player disagrees or agrees with an issue proposed in the policy. These criteria are transport subsidies, workforce availability and production fluctuation. Firstly, transport subsidies are provided based on distance travel during transportation of materials. For example, a lower subsidy is given to players who are transporting material over a longer distance. These players may disagree with the outcome. Meanwhile, players who are transporting material over a shorter distance will possibly agree with the subsidy policy since the subsidy provided is much higher. Those that travel on average distance may be neutral towards the subsidy provided. Some predefined values will be set as the limit to categorise the players based on their travel distance. For instance, travelling below 25 km will be considered short, while above 35 km will be regarded as long-distance. Players who travel within the range of 25 to 35 km will be considered as ‘average’. For issue 2, the capability of players to reduce their workforce highly depends on their current available workforce. Supply chain players with workforce shortages are unlikely to reduce their workforce further as they cannot afford to do so while maintaining the acceptable operability of their plants. The opposite applies to players who can reduce their abundant labour. For issue 3, the ability to adjust production depends on the flexibility of a player. A rigid operating plant could not tolerate drastic adjustments in production rate. Thus, these plants will disagree with this proposal. Agile plants would agree with the issue as their operations are responsive to adjust production rates to requirements. The developed mathematical model is solved using Lingo 18.0.

4. Results and discussion

Following the proposed approach, an optimised result of an ideal supply chain is first obtained. Next, conflict analysis is implemented, considering players’ reactions in response to the policies. As shown in Table 2, results obtained from the developed model before and after conflict analysis are presented. These costs are obtained based on the unit of material involved. For example, the production cost is obtained by multiplying the cost of production per tonne of material by the tonnes of material produced. This work uses the cost of production per tonne of material such as pellets and pyrolysis oil from Rubinsin et al. (2020). Note that all cost components from the model with conflict analysis have a higher value compared to those from the model without conflict analysis. This is mainly caused by the increase in overall material flow within the supply chain. As shown in Eq(3), the actual flow with conflict analysis will always be lower than the ideal flow in the case without conflict analysis. To achieve the same demand, the supply chain then requires more flow than before. Therefore, the degree of agreement from conflict analysis yields a practical result that requires more material than the ideal case. For current work, the amount of EFB demanded by the model implemented with conflict analysis is around 3.7 times higher than that required by the model without conflict analysis.

Table 2: Associated Cost with and without Conflict Analysis

Cost Component	Without Conflict Analysis (MYR)	With Conflict Analysis (MYR)
Penalty	8.1×10^5	3.8×10^6
Production	3.6×10^6	4.1×10^6
Storage	1.2×10^3	3.1×10^4
Transport	8.4×10^3	2.0×10^4
Total	4.5×10^6	8.0×10^6

After conflict analysis is implemented, the optimal supply chain yields route as shown in Figure 4. Here, the supply chain shows preference on transferring material between players with a higher degree of agreement ($\iota_{ii'}$). Table 3 summarises the main suppliers of storage f_3 before and after conflict analysis. Before conflict analysis, the model decided m_3 and m_4 was the main supplier to f_3 due to their shortest distance. This is to minimise the transportation cost thus the total cost associated with the model. After conflict analysis is implemented, the model decided to switch the main supplier of f_3 to m_1 and m_2. Table 3 shows that these suppliers have a longer travel distance to f_3; however, they both have a higher degree of agreement when compared to m_3 and m_4. Thus, conflict analysis causes the model to transfer material among players with a higher degree of agreement. Following the above discussion, these contribute to a heavily underestimated cost associated within the supply chain if the relationship among players were not considered. When the relationship is considered, the overall cost has increased by 77 % as shown in Table 2. With this, both models yield results that greatly differ from each other. This suggests that the optimal solution obtained from the model without considering relationship among player is deemed to be too optimistic. Therefore, any decision derived from the model without considering relationship might backfire in practical.

Table 3: Suppliers of Storage f_3 before and after Conflict Analysis is implemented

From	To	Distance (km)	ι_{ab}	Material Transferred (t)	
				Before Conflict Analysis	After Conflict Analysis
m_1	f_3	73.2	0.83	0	10.1×10^3
m_2		40.3	0.83	0	8.8×10^3
m_3		22.5	0.33	4.4×10^3	0
m_4		13.4	0.17	5.2×10^3	0

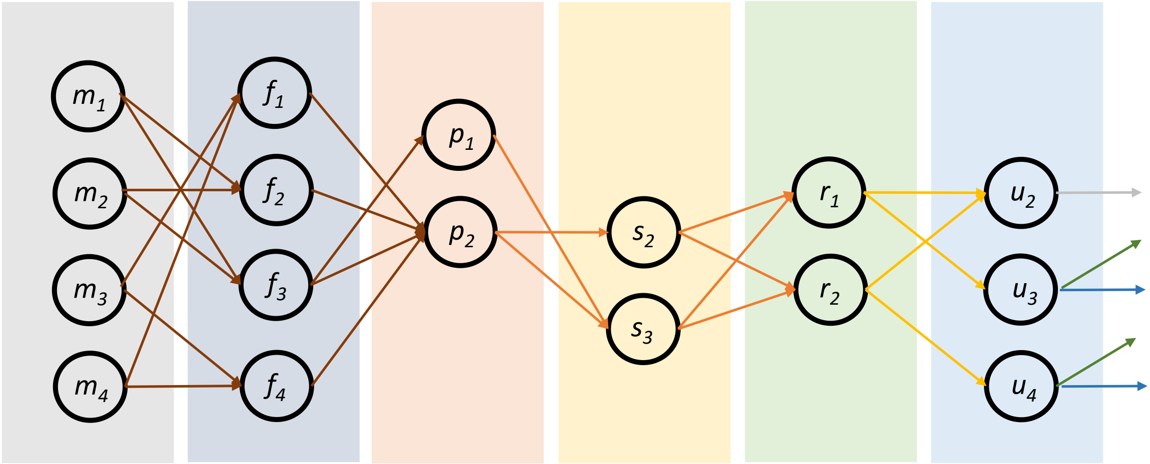

Figure 4: Optimal Biomass Supply Chain after Conflict Analysis

5. Conclusions

The work aims to investigate the effect of the relationship among players in a supply chain. A multiperiod mathematical model is developed to determine optimal supply chain routes for supply chain players. Conflict analysis is implemented to generate the degree of agreement, which quantifies the relationship among supply chain players. A hypothetical scenario where government releases a particular policy with requirements is introduced as a case study in providing insight on how relationships among players will affect the supply chain. The case study has shown that all the cost components associated with the supply chain increase after implementing conflict analysis (total cost increased by 77.7 %). Besides, the model chose a pathway with a higher degree of agreement (~1.5 to 3.9 times higher) rather than the shortest distance. Thus, the degree of agreement signifying the relationship among players causes an impact by changing the behaviour of the supply chain. For future recommendations, the effect of different storage on deterioration could be considered.

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