

**Renewable Fuel Standard: Implications for land use changes in Malaysia and
Indonesia**

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1. Background

1.1. Literature review and major contributions

The land use change effects of biofuel production and policy has been examined frequently during the past decades. The early projections of these effects raised major concerns regarding the large magnitude of the land use change emissions that biofuel production may generate [1-3]. In the absence of actual observations, the early projections were basically obtained from hypothetical ex ante analyses [4]. The results of more recent studies that take into account actual observations and used more advanced tools show that induced land use changes due to biofuels have not been very large and hence land use emissions induced by biofuels could be much smaller than their early estimates [5-8].

Regardless of these findings, still public media and environmental groups express concerns regarding the US Renewable Fuel Standard and its global land use effects. In particular, more recently it has been argued that the US RFS is responsible for the land use changes in Malaysia and Indonesia (M&I) [9-10]. In response to these concerns, this paper offers the first comprehensive analysis of the link between the US RFS and land use change in M&I. We used a well-known advanced Computable General Equilibrium (CGE) model, dubbed GTAP-BIO, to evaluate the extent to which production of biofuels in US alters land use in M&I. Two recent publications presented the latest version of this model its background [6-7]

We show that interactions among markets for vegetable oil are the main market-mediated drivers of these changes. We show the extent to which substitution among vegetable oils affects these results. Finally, we show that while production of biofuels induces relatively small land use changes in M&I, the share of M&I in induced land use change emissions of biofuels is large. We used the land use emissions model (dubbed AEZ-EF) developed by the California Air Resources Board to calculate these emissions [11]. This model assumes 33% of the expansion of oil palm in M&I falls on peat land. Recent evidence does not support this assumption and suggests lower

shares for oil palm on peat. We show that adopting lower rates for oil palm on peat drops the estimated induced land emissions of biofuels significantly.

1.2. Evolution in markets for vegetable oils

Global production of vegetable oils has increased rapidly over time, from about 61 Million Metric Tons (MMT) in 1990 to about 197 MMT in 2017, with an annual growth rate of 8.2%. An aggressive increase in supply of palm oil made this rapid expansion possible. In this time period, supply of palm oil (including palm kernel oil) has increased from 13 MMT to 77 MMT, with an annual growth rate of 18%. Due to this extraordinary growth rate, the share of palm oil in the global supply of major vegetable oils has increased from about 21% in 1990 to 40% in 2017. Most of the expansion in supply of palm oil occurred in Malaysia and Indonesia (M&I). This region is the main producer and exporter of this product and has the most carbon-rich biomes on the earth. Several papers have examined the environmental consequences of this rapid change [12-16]. The main focus of this literature was the environmental damage done when peat land was converted to palm plantation. This literature also has recognized that palm plantation is not the only driver of deforestation in M&I (17-19).

Palm oil is mainly used as a food product (about 70%) and partly used in the production processes of cosmetic products (about 25%). Only a small fraction of palm oil (about 5%) was used as an energy source (including heating, electricity, and biodiesel). The share of biodiesel in global production of palm oil was less than 3% in 2016. While only a small fraction of palm oil is used for biodiesel production (mainly in the EU region), biodiesel production has been blamed for deforestation in M-I. Even more recently, it has been claimed that the US biofuel policy is responsible for deforestation in M-I (10), while the US does not use palm oil for biodiesel production and only imports a small share of the global supply of this product (e.g. about 2.2% in 2017) for food uses.

2. Method

2.1. Theoretical background

The existing literature has shown that market mediated responses and resource constraints transfer impacts of producing a particular biofuel in one region (e.g. soy biodiesel in US) to the rest of the world, and that affects global markets for agricultural products and generates land use changes across the world [5]. Among all factors that shape market mediated responses, demand and supply

elasticities play important roles. For the link between the US biofuel policy and land use change in M&I, interactions among vegetable oil markets and substitution among vegetable oils plays a critical role. That is because M&I is the main producer and exporter of palm oil, and the US is one of the largest producers and exporters of soybeans at the global scale. In this case, an increase in the production of soy biodiesel generates an additional demand for soy oil and that leads to increases in the prices of soybeans and soy oil in the US and also at the global scale, of course at different rates. Assuming some degree of substitution between palm oil and soy oil, that extends the US demand for palm oil (and perhaps elsewhere). This could generate an expansion in palm plantation in M&I and lead to deforestation in this region¹.

However, soy oil and palm oil are not the only vegetable oils produced and consumed across the world. The share of other vegetable oils in the global production of all major vegetable oils was about 33% in 2017, which is not a small share. Furthermore, M&I and US are not the only players in this game. Other countries are involved in markets for oil crops and vegetable oils and produce, consume, and trade these products. Hence, in analyzing the link between the US RFS and land use changes in M&I, we should take into account the substitution among all vegetable oils at the global scale. Figure 1 depicts interactions among these markets.

<Figure 1 here>

The top panel of this figure represents the global market for soy oil. In this panel the status quo equilibrium with no biodiesel production in US is shown at point *A*. At this equilibrium, the global consumption/production of soy oil would be Q_0^{SW} at the initial price of P_0^{SW} . When the US begins converting soy oil to biodiesel, say due to RFS, demand for soy oil at the global scale shifts up and right from D_0^{SW} to D_1^{SW} . Assuming no shift in the supply of soy oil, the equilibrium in this market could move to Point *B*. However, over time supply of soy oil may also shift right and down from S_0^{SW} to S_1^{SW} . With these shifts in demand and supply of soy oil, market equilibrium will move to Point *C*. At this equilibrium, the price of soy oil will be P_1^{SW} and its production will be Q_1^{SW} . At this equilibrium, the global consumption of soy oil for non-biodiesel uses will be $Q_1^{SW'}$ and the difference between $Q_1^{SW'}$ and Q_1^{SW} shows soy oil feedstock for biodiesel production.

¹ Production of corn ethanol also affects land use changes in M&I through the markets for vegetable oils as corn and soy are two major crops in the US. Producing more corn for ethanol could reduce production of soybeans and that could alter the markets for vegetable oils as well.

Changes in the soy oil market will affect the market for palm oil as well, as presented in the bottom and left panel of Figure 1. In this panel the status quo equilibrium with no biodiesel production in US is shown at point A' . With the shift in the demand for soy oil and higher price for this product, demand for palm oil will shift to right and up from D_0^{PW} and D_1^{PW} . Over time, the supply of palm oil will also shift to bottom and right from S_0^{PW} and S_1^{PW} . The equilibrium point of market for palm oil will move to C' due to these changes. Due to the movement from A' to C' , price of palm oil will increase from P_0^{PW} to P_1^{PW} and production/consumption of palm oil will increase from Q_0^{PW} to Q_1^{PW} at the global scale. In a CGE model, similar to our model, one can trace these changes and measure interactions between these markets. For example, one can calculate the general equilibrium cross-price elasticity of changes in the global production of palm oil (in moving from point A' to point C' in the bottom and left panel of Figure 1) with respect to changes in the global price of soy oil (in moving from point A to point C in the top panel of Figure 1) using the following formula: $e_{Palm,Soy}^W = \frac{Q_1^{PW}/Q_0^{PW}-1}{P_1^{PW}/P_0^{PW}-1}$.

Similarly, it is possible to calculate this measure between these markets at regional levels. For instance one can calculate the general equilibrium cross-price elasticity of palm oil production in M&I with respect to changes in the global price of soy oil.

Finally, consider the implications of changes in the global markets for soy and palm oils for the US imports of palm oil in the bottom and right panel of Figure 1. The US status quo demand curve for imported palm oil is shown with D_0^{PU} . With this demand curve, at the status quo price of palm oil (i.e. P_0^{PW}), US imports palm oil by Q_0^{PU} . After biodiesel production, the US demand curve for imported palm oil will shift to D_1^{PU} , assuming some degrees of substitution between palm oil and soy oil. With this shift the US will import palm oil of Q_1^{PU} . The general equilibrium cross-price elasticity of changes in US palm imports with respect to its global price can be calculated using the following formula: $e_{Palm,Soy}^{US} = \frac{Q_1^{PU}/Q_0^{PU}-1}{P_1^{PW}/P_0^{PW}-1}$.

In short Figure 1 shows how changes in the global market for soy oil, induced by biodiesel production in US, leads to change in the global market for palm oil and that affects US demand for palm oil. These changes depend on the rate of substitution between soy and palm oils at the demand side. When there is no substitution between soy and palm oils, demand for palm oil will not increase when price of soy oil goes up due to producing soy biodiesel in the US, or the US

demand for imports of palm would not increase. To discuss the above analyses we focused on the interactions between palm and soy oil. However, in the real world, in addition to these two products, other vegetable oils such as corn oil, canola oil, cotton seed oil, sunflower oil, and many more types of vegetable oils are produced and consumed across the world and their markets interact.

The CGE mode that we used in this paper, aggregates all types of vegetable oils into four groups including: soy oil, palm oil, canola oil, and other vegetable oils and fats, and traces their changes at the global scale by country. We will use this model to examine the extent to which these markets interact at the country and global levels. The model takes into account substitution among vegetable oils by country. We examine the extent to which the substations among vegetable oils affect the interaction among vegetable oils and how that affects land use changes in M&I and their corresponding land use emissions. Using this model, we calculate the general equilibrium cross-price elasticity of changes in palm oil production in M&I with respect to changes in the price of soy oil. We show how this elasticity responds to the changes in the substitution elasticities among vegetable oils.

2.2. Improvements in GTAP-BIO model

The latest version of the GTAP-BIO model and its background are presented in Taheripour et al. [6] and Taheripour et al. [7]. We use and improve this model to reflect the impacts of biofuel production in the US on land use changes in M&I. The improvement addresses an important aspect of the links between livestock, vegetable oil, and biofuel industries and their land use implications. Taheripour et al. [20] have shown that over time the rapid expansion in supplies of soybeans and corn have increased availability of feed products and that helped the livestock industry to produce more animal based food products per unit of land and extend production of these food products much faster than population growth, while area of pasture land declined in recent years. This suggests that the livestock industry substituted feed with land in its production process. We modified our model to take into account this important fact into account.

The modification alters the nesting structure the production functions of the GTAP-BIO model. Figure 2 represents the current nesting structure of substitutions among inputs in the GTAP-BIO production functions. As shown at the top of this figure, currently this model divides all inputs into two major branches of primary (including labor, land, capital and energy) and intermediate inputs

(e.g. feed items for livestock). There is no substitution at the top of this production structure. This means no substitution between feed and land. However, this structure captures some degree of substitution between land, labor, and capital, which implies some degree of land intensification in response to higher land prices (more output per unit of land) for land using sectors, including livestock.

<Figure 2 in Here>

On the other hand, on the branch for intermediate inputs, the current model allows substitution among feed items for the livestock industry, as shown Figure 3. This nesting structure allows the livestock industry to move away for more expensive feed items toward lower priced items according to the observed trends in real world (e.g. substitution between corn and DDGS or soybean meal with other protein sources).

<Figure 3 in here>

In this research we keep the feed structure of the model as it is. However, we move the whole feed structure of the model to the first branch (the primary branch) at the top of nesting structure as shown in Figure 4. This figure shows that in the revised model, labor, capital, and resources are bundled together, and then their mix mingled with land (land from different agro ecological zones (AEZs)). This mix then combined with the feed mix in one nest. Finally, the mix of primary inputs and feed is combined with other primary intermediate inputs. This arrangement takes care of the substitution between feed and land and allows the livestock industry to use more feed when the price of land goes up, and vice versa.

<Figure 4 in here>

We introduced the substitution between land and feed demonstrated in Figure 4 into the GTAP-BIO model reported by Taheripour et al. [6]. This model uses the latest version of the GTAP-BIO database which represents the global economy in 2011. Then with this model and its database, we developed a set of simulations to tune the model to observed trends in the ratio of feed over land in recent years in the US livestock industry. We find that the implemented substitution between land and other primary inputs in the old model is also a good candidate for the substitution between the mix of primary inputs and feed.

2.3. Examined experiment

To examine the extent to which biofuel production in the US affects land use changes in M&I we developed two different sets of simulations. In the first set we allow all types of vegetable oils and oil crops to respond to the expansion in biofuels, as happens in real world. We refer to this set of simulations as *Base Cases*. In the second set, we alter the model closure to only take into account palm oil and soy oil and drop all other vegetable oils. We refer to this set of simulations as *Restricted Cases*. The second set follows the literature that only takes into account interactions between palm oil and soy oil and ignores other vegetable oils [10]. For the *baseline* and *restricted* sets we examine the impact of corn ethanol and soy biodiesel, separately. In both sets of simulation, for corn ethanol we shocked the model to increase its production from 2011 level to 15 Billion Gallons (BGs). This shock is about 1.1 BGs of ethanol. For the case of soy biodiesel we shock the model to increase its production by 0.5 BGs.

The GTAP-BIO model uses a set of regional parameters to govern substitution among vegetable oils on the demand side including household and industries that use these products for non-industrial uses. The value of this parameter is about 0.5 for the US economy. Since this parameter basically governs the US demand for vegetable oils, we vary the magnitude of this parameter from 0.25 to 10 to examine the sensitivity of land use change in M&I with respect to changes in this parameter. Hence we examine the following experiments:

Baseline experiments including all types of vegetable oils:

- Expansion in US corn ethanol from its 2011 level to 15 BGs under alternative assumption for substitution among vegetable oils,
- Expansion in US soy biodiesel from its 2011 level by 0.5 BGs under alternative assumption for substitution among vegetable oils,

Restricted experiments including only soy and palm oil:

- Expansion in US corn ethanol from its 2011 level to 15 BGs under alternative assumption for substitution among vegetable oils,
- Expansion in US soy biodiesel from its 2011 level by 0.5 BGs under alternative assumption for substitution among vegetable oils.

3. Results (under development)

Here we only present some findings for the case of soy biodiesel. An expansion of US soy biodiesel alters the market for palm oil, and that affects land use changes in M&I. However, the magnitude

of these changes are quite small and vary by case. For, example, an expansion in the US soy biodiesel by 0.5 billion gallons increases the US imports of palm oil by 0.4% and that generates an expansion in palm plantation in M&I by 0.48% with only 6500 hectares expansion in cropland due to deforestation when all vegetable oils are included in the model, and the rate of substitution among vegetable oils in US is about 0.5. In this case, the induced land use change (ILUC) emissions for soy biodiesel produced in US is about 17.5 g CO_{2e} MJ⁻¹. With a substitution elasticity of 2 among vegetable oils, the same expansion in biodiesel increases US imports of palm oil by 2.2% but that does not lead to more production of palm oil in M&I, as there is greater global trade of and substitution between other vegetable oils. Even some countries extend palm plantation on lands with lower carbon content compared to M&I. With a substitution elasticity of 2, ILUC emissions for soy biodiesel drops to 16.6 g CO_{2e} MJ⁻¹.

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21.

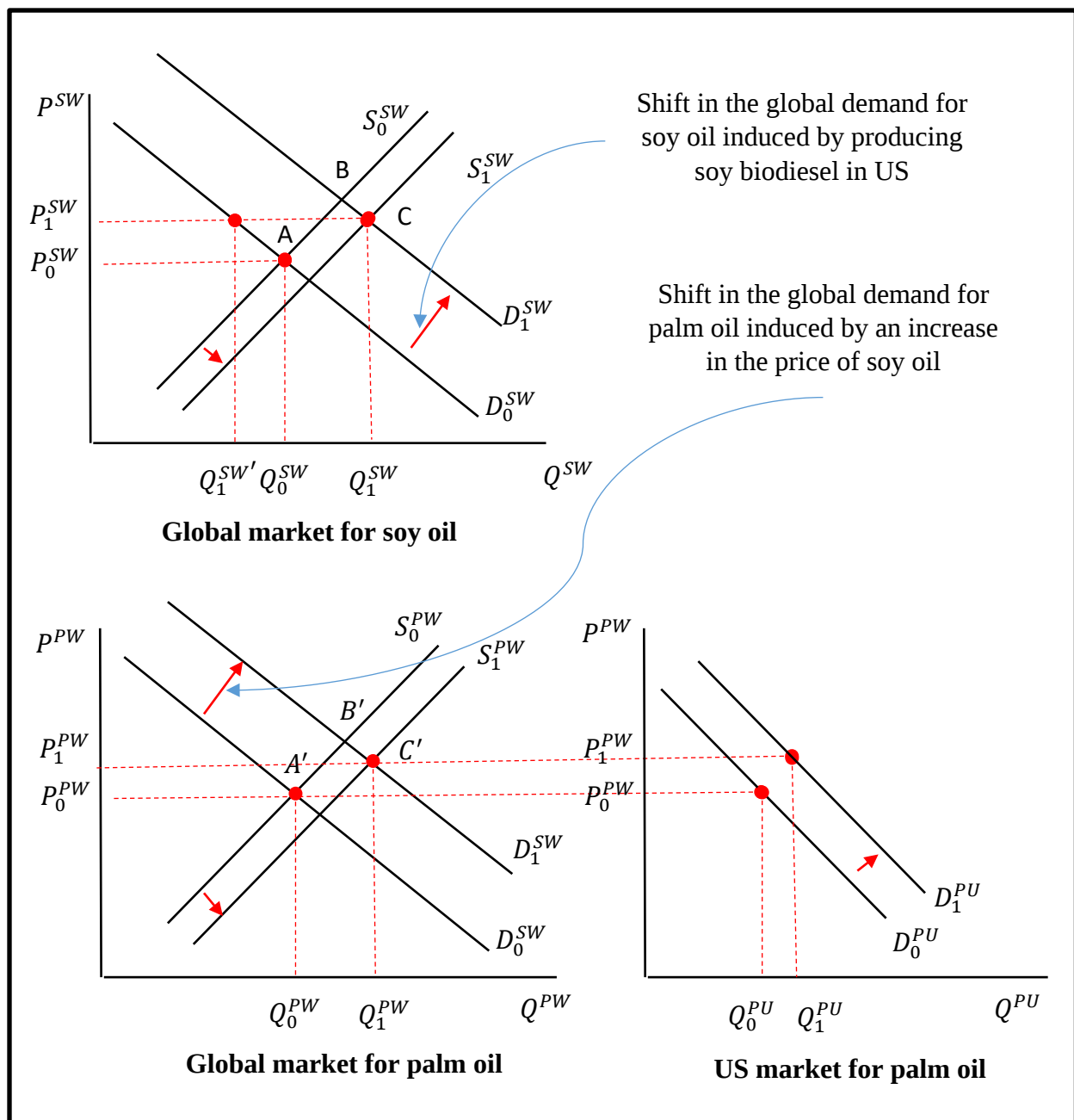


Figure 1. Changes in the global markets for soy and palm oil induced by producing soy biodiesel in US and its impacts on the US imports of palm oil.

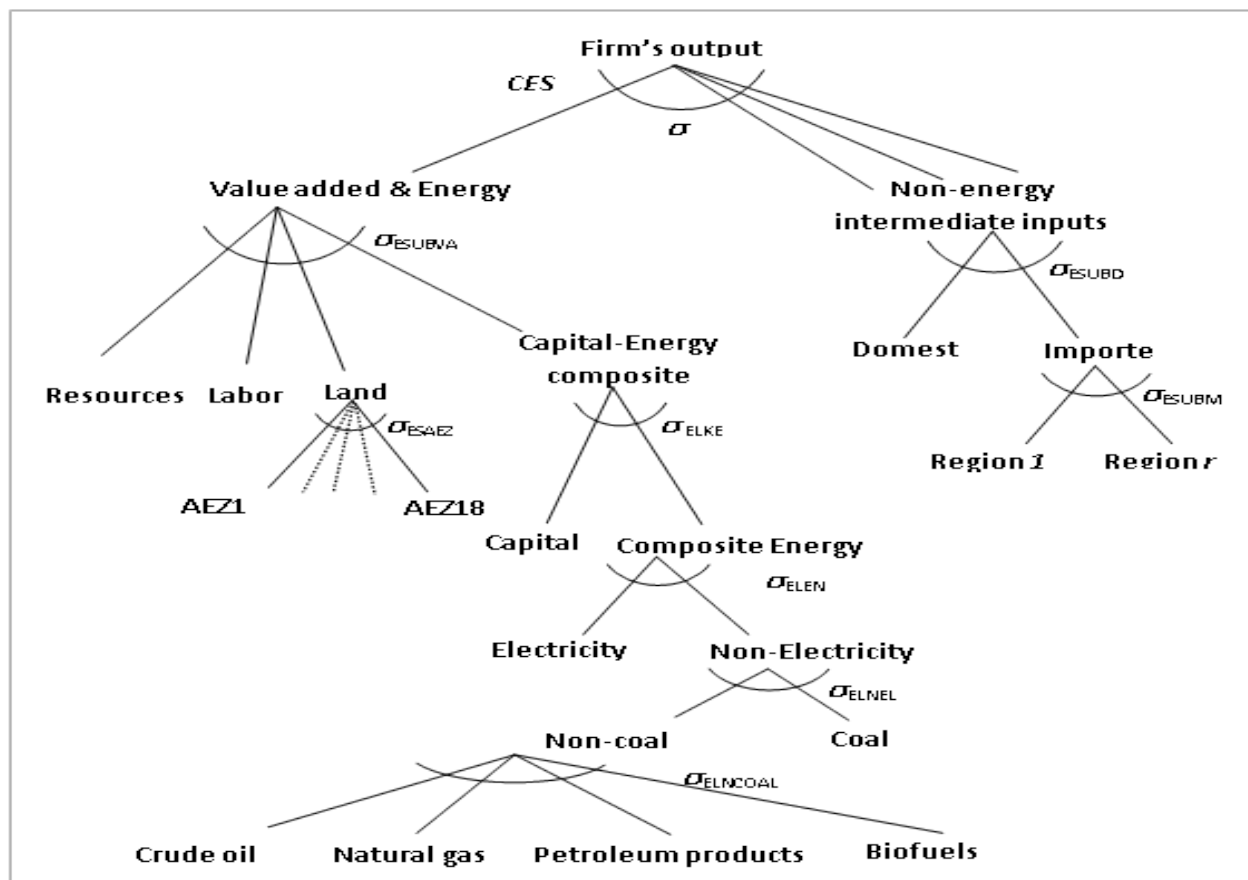


Figure 2. Existing nesting structure in GTAP-BIO production functions

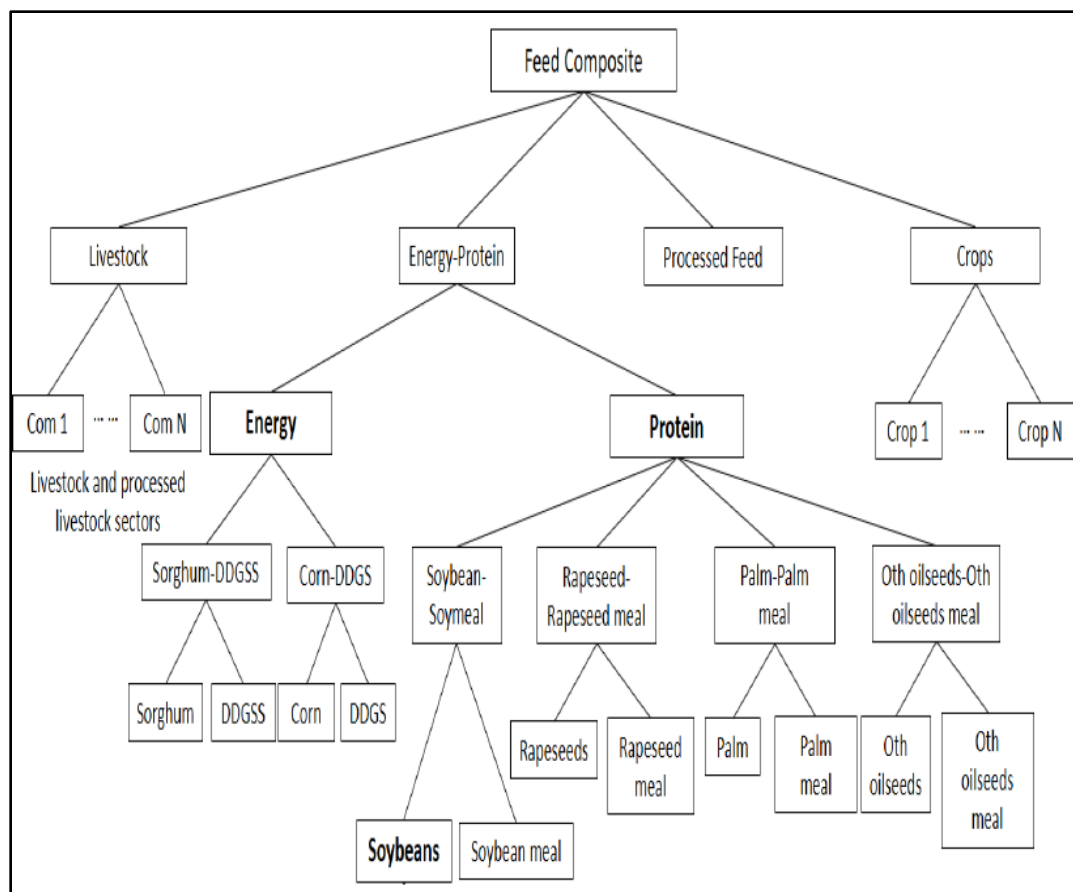


Figure 3. Structure of feed composite in GTAP-BIO model

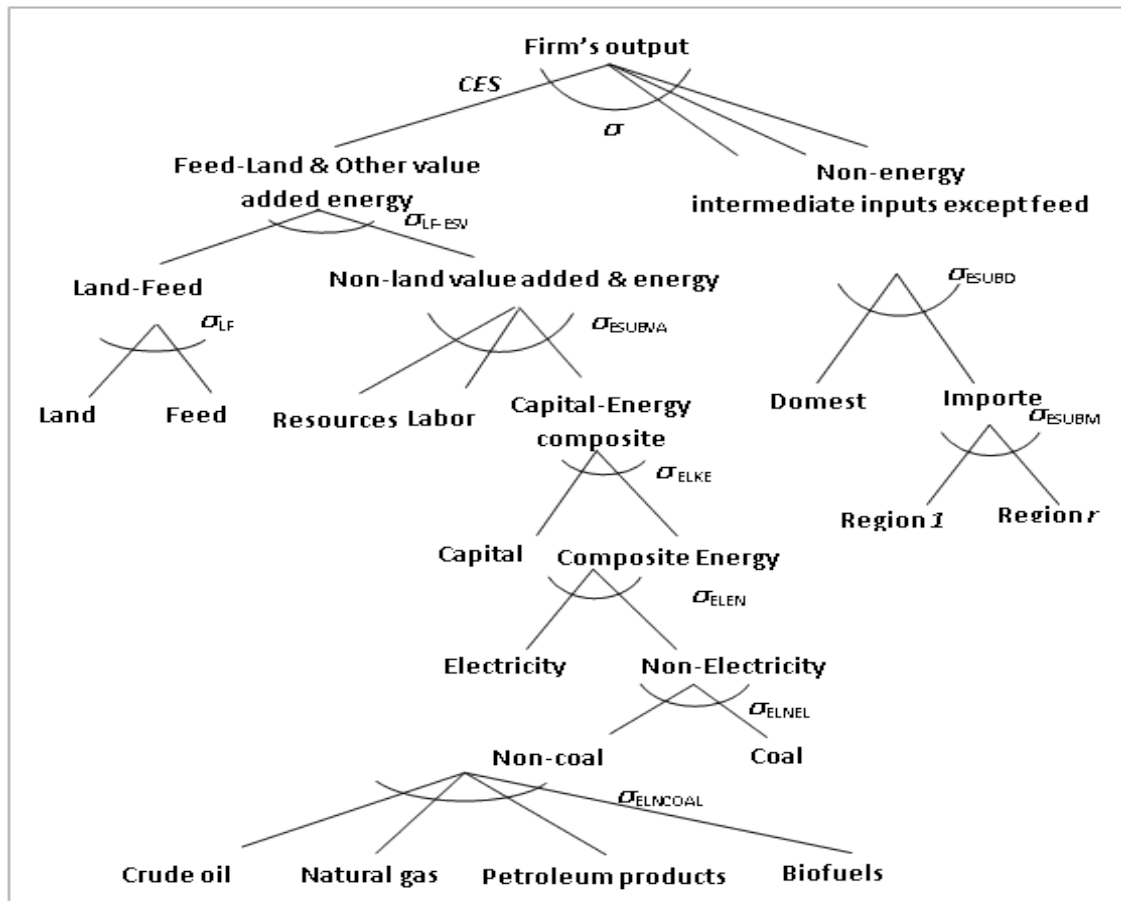


Figure 4. New nesting structure in GTAP-BIO production functions (SHOULD BE FIXED)