Higher income and higher prices: the role of demand specifications and elasticities of livestock products for global land use

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Abstract

Global land use change is influenced by changes in diets towards more livestock products as well as additional demand for biomass from a growing biofuels industry. Global simulation models trying to quantify future food demand and subsequent land use change often differ in their results due to different demand specifications and elasticities. In order to isolate the impact of the latter on food demand and subsequent land use change we calibrate the global CGE model DART-BIO to different demand specifications and test the effect of changing income elasticities for livestock products. Our findings confirm the importance of demand specifications and income elasticities in influencing final models results, as the size of fixed subsistence quantities in the linear expenditure system (LES) determines the overall flexibility of demand. Large subsistence quantities dampen the responsiveness of private demand to income and price changes and lead to unrealistic reductions in global land use. As income elasticities of livestock demand in China and India become less elastic with growing income, the subsequent decrease in demand for livestock products and fodder crops affects land use worldwide. In general, there is some land use change at the expense of either soybeans or wheat in favor of oilseeds in all regions although the percentages remain very small. In addition, our results imply that the positive impact of biofuel production on livestock output as found by other studies is not reciprocal.

1. Introduction

Large shifts in dietary patterns as they are happening in many emerging economies are an important driver of global land use change. While population growth is increasing total food demand, income growth and urbanization lead to higher value diets with an increasing share of livestock products and processed food (e.g. Bennett, 1941; Valin et al., 2014). Although the demand for pasture land has been declining steadily through the industrialization of animal husbandry, potential land savings are more than offset by the growing demand for land for feed crops (Naylor et al., 2005). Another sector that has been growing rapidly over the last years is the biofuel industry, which exhibits strong linkages to the livestock industry via the use of biofuel byproducts as fodder (Calzadilla et al., 2016). As a consequence of trade liberalization, livestock and biofuel production are geographically decoupled from their resource base and increased demand for animal products in emerging economies influences the composition of land use as well as emissions from agriculture worldwide (Popp et al., 2010; Schmitz et al., 2012).

Studies trying to quantify future food demand and subsequent land use change with global simulation models differ in their results regarding composition and magnitude due to general uncertainty about global drivers (i.e. economic and population growth, climate change) but also due to different model assumptions mainly in terms of demand specifications (Schmitz et al., 2014; Valin et al., 2014). Apart from the nature of the assumed utility function shifts in diets are largely dependent on the choice of income and price elasticities of demand and on the way that these elasticities enter demand specifications. As a consequence of the complexity of global simulation models, the prevalent demand specifications usually only capture elasticities of demand through the calibration of utility function parameters and are very sensitive to the underlying calibration process, which is likely to result in an increased sensitivity of the final model results regarding food demand and land use. Yet, reliable projections of land use change are essential to identify future hot spots of high pressure on land for food, feed and bioenergy production.

Our study therefore aims at quantifying and decomposing how the choice of demand specifications and demand elasticities affect land use change projections in different regions and agro-ecological zones (AEZ) using the global computable general equilibrium (CGE) model DART-BIO. Keeping all other influences constant, we analyze the sensitivity of land use change to different demand systems calibrated to elasticity estimates from different sources (Yu et al., 2003; Hertel and van der Mensbrugghe, 2016). We then apply this framework to measure the influence of income elasticities for livestock in Asian countries on land use in other developing and emerging regions. As livestock production is geographically decoupled from feedstock production, local land use is not only dependent on local demand elasticities, but also on elasticities of fast growing economies especially in Asia. We therefore simulate changes in Asian income elasticities using estimates by Yu et al. (2003) under the different demand specifications.

The third aim of our study is to explore the links between the livestock and biofuel industries. Both Taheripour et al. (2011) and Calzadilla et al. (2016) find a positive impact of biofuel production on livestock output as byproducts such as DDGS can serve as valuable fodder. Even though an increase in demand for livestock products and fodder might lead to tradeoffs for other land uses, there might thus also be a large scope for synergies. As DART-BIO explicitly accounts for byproducts of biofuel production, we make use of our income elasticity scenarios to examine whether the link between biofuels and livestock is reciprocal and quantify potential synergies between demand for livestock products and biofuel production.

The next section gives a brief background of demand specifications in global simulations models, followed by a description of DART-BIO and our scenarios in section 3. Section 4 discusses the results of our sensitivity analysis and simulations, while section 5 concludes.

2. Background

Despite enormous increases in agricultural productivity in the previous decades the demand for global agricultural land has been growing steadily due to a growing world population that is becoming richer and demanding more land intensive food. In the last couple of years the industrial demand for agricultural products has been increasing through biofuel production. These demand developments are likely to change the composition of land use worldwide no matter where demand increases are happening. The latest OECD-FAO Agricultural Outlook (OECD-FAO, 2016) for example projects an increase in agricultural land expansion in Brazil and Argentina for soybean production used as feed for livestock, while most of this livestock is consumed (and produced) in Asia. The latter finding is based on results from a partial equilibrium (PE) model of world agricultural markets (Aglink-Cosimo) that - unlike most CGE models - does not explicitly model consumer demand behavior (OECD, 2016).

Modeling of consumer behavior is essential for projecting food demand. Several different approaches are used by global simulation models applied to demand projections. As part of the Agricultural Model Intercomparison and Improvement Project (AgMIP), Valin et al. (2014) are the first to comprehensively compare demand specifications in different CGE and PE models and the role of population growth, income and price changes for world food demand. In general, CGE models explicitly model consumer behavior based on utility functions and include income and price elasticities, while the PE models covered in the intercomparison project model demand in reduced form (Valin et al., 2014). The MagPIE model for example does not even include a market mechanism and is therefore unable to capture land use changes following demand responses (Valin et al., 2014). While Valin et al. (2014) provide a thorough assessment of models and demand specifications in influencing food demand projections, they do not cover the use of crops for fodder or bioenergy and therefore miss important feedback links that might affect land use apart from food demand. Conversely, Schmitz et al. (2014) compare the same models as Valin et al. (2014) with a focus on land use change, but do not explicitly take the role of demand specifications in the different models into account.

Overall, Valin et al. (2014) show that most of the deviations in the food projections of the different models originate from a combination of general model features, different demand specifications, and different demand elasticities. One goal of this study is to isolate the impact that demand specifications and elasticities have on food demand and subsequent land use change by using only a single CGE model, DART-BIO. Before explaining our method for isolating this effect, the following section discusses the prevalent demand specifications in CGE models.

2.1 Demand systems in CGE models

Four different demand systems are commonly applied in CGE models, each with certain advantages and disadvantages. Yu et al. (2003) analyze the performance of the homothetic Cobb-Douglas (HCD) system, the linear expenditure system (LES), the Constant Difference of Elasticities (CDE) approach and the Implicitly Direct Additive Demand System (AIDADS) for projecting world food demand. AIDADS is usually found to perform best in reproducing actual demand behavior allowing for non-homothetic preferences and the Engel flexibility in a sense that it can be calibrated to empirical income elasticities of demand which decrease with increasing income. The disadvantage of AIDADS lies in its complex functional form and in the small number of commodity groups that can be modelled (a maximum of 10), which makes it difficult to depict the rich nature of sectors and economic structure of the world economy (Yu et al., 2003).

The linear expenditure system (LES) on the other hand has a relative simple functional form and can be applied to any number of commodities (Dervis et al., 1982). But as the LES excludes inferior goods by definition, the system is also better suited to relatively broad commodity groups (Lluch et al., 1977). An advantage is that the LES contains an explicit calculation of price elasticities through the Frisch parameter, implying own-price inelastic demand and all goods to be net substitutes. It also allows for non-homothetic preferences and calibration to empirical income elasticities, but income elasticities will approach unity when income grows, so that the system becomes the homothetic Cobb Douglas eventually, which violates Engel’s law. The LES is a practical and easy to implement system but the calibration process is very sensitive to income elasticities and the choice of the so-called Frisch parameter, the elasticity of the marginal utility of income as will be explained in the next section.

The CDE approach exhibits non-homothetic preferences as well and some Engel flexibility, since the parameters can be calibrated to empirical income elasticities (Hanoch, 1975). The latter remain constant even as income rises, so that the approach does not entirely conform to Engel’s law either. Unlike AIDADS, HCD and LES, however the CDE approach allows for an explicit calibration of its substitution and income parameters to both income and price elasticities of demand.

Due to the disadvantages of AIDADS in terms of number of commodities, this system is rarely applied in CGE models, but has been used for estimating the income elasticities for the GTAP model (Hertel and van der Mensbrugghe, 2016). In addition, these estimated income elasticities are used to calculate price elasticities following Zeitsch et al. (1991) to calibrate the CDE demand system which is used in GTAP model. Thus, there is no specific calibration to empirical price elasticities and all price elasticities are explicitly defined through the income elasticities. Since we are interested in keeping a fairly disaggregated commodity structure in our model to capture the impact of different food groups on land use, we refrain from implementing the AIDADS system in DART-BIO. Rather we test the sensitivity land use change to different LES specifications and the CDE approach as explained in the next section.

3. Conceptual framework

3.1 DART-BIO

The Dynamic Applied Regional Trade (DART) model is a multi-sectoral, multi-regional recursive dynamic Computable General Equilibrium (CGE) model of the world economy based on data from the Global Trade Analysis Project (GTAP) (e.g. Springer 1998; Klepper and Peterson 2006a). The economy in each region is modelled as a competitive economy with flexible prices and market clearing conditions. The version DART-BIO is calibrated based on the GTAP8.1 database (Narayanan et al. 2012) and has 23 regions, 38 sectors, 45 products and 21 factors of production. DART-BIO incorporates 18 GTAP-AEZs covering six different lengths of growing period and three different climatic zones to account for different land uses (i.e. cropland, pasture and forest) and land heterogeneity within each AEZ and region.

3.1.1 Regional and sectors aggregation of DART-BIO

Unlike the original GTAP database, the DART-BIO database features a detailed representation of biofuel feedstock production, biofuel processing as well as biofuel byproduct sectors. These include bioethanol production from sugar cane/beet maize, wheat or other grains, biodiesel production from palm, soybean rapeseed or other oilseeds as well as three different types of dried distillers grains with solubles (DDGS) as by-products of bioethanol processing and four different types of oilseed meals/cakes as by-products of the vegetable oil industry (see Table 1). We deviate from the standard GTAP model by differentiating between production activities and commodities to model the joint production of biofuels and their byproducts. In addition, as biofuel consumption targets in the European Union are set according to the use of renewable energy in the road transport sector, the DART-BIO model includes separate sectors for motor gasoline and motor diesel.The construction of the DART-BIO database can be found in more detail in Calzadilla et al. (2016).

The regional aggregation is carefully chosen to include the main biofuel producing and consuming countries such as the United States of America (USA), Brazil (BRA), and Germany (GER) among others (Table 2). The regional detail also includes countries where there are main land use changes either due to biofuels production or where major changes in population, income and consumption patterns are expected to emerge (e.g. Malaysia, Indonesia and China).

3.1.2 Demand specifications in MPSGE and DART-BIO

DART-BIO is written in the mathematical programming system for general equilibrium (MPSGE) modelling language in GAMS developed by Rutherford (1997), which depicts a CGE model with constant elasticity of substitution (CES) functions and requires some tricks to implement more complex functional forms. The basic MPSGE specification models private consumer demand with Cobb-Douglas demand functions, as the CES substitution elasticity is set to unity. This form of homothetic preferences is usually discarded in most applications in favor of more flexible demand systems.

Private consumption in DART-BIO is calibrated to a LES, which divides demand into subsistence and supernumerary consumption based on a Stone-Geary utility function and is shown in equation 1 in Table 3 (Dervis et al., 1982). Households first spend a fixed part of their income Y_r on a subsistence quantity $\gamma_{r,i}$ for each commodity and allocate their supernumerary income to different commodities according to fixed marginal budget shares $\beta_{r,i}$, which are the product of average budget shares $\alpha_{r,i}$ and income elasticities of demand $\eta_{r,i}$. This division of total consumption into fixed subsistence and flexible supernumerary quantities allows for a calibration to non-unitary income elasticities and non-homothetic preferences. The subsistence quantities are exogenously calibrated and independent of income and prices, so that their sizes influence how total demand reacts to income and price changes. It is important to note that although the supernumerary quantities of consumption are flexible in terms of substitution between different goods, their income elasticities are unity (Dellink, 2005). Therefore, the LES will eventually converge to a Cobb-Douglas system and approach homothetic preferences when income grows, as the fixed subsistence shares diminish. The LES application in DART-BIO however tries to avoid this shortcoming by updating the subsistence quantities with population growth in each period following van der Mensbrugghe (2005). Depending on the development of total consumption in each period for different regions this technique can lead to smaller or larger subsistence shares compared to the base year, but generally keeps with the trend of declining subsistence shares with rising incomes.

The LES enters into MPSGE only through the subsistence and supernumerary consumption quantities and not through the actual behavioral functions, making it crucial to get the quantities right. While the classical calibration of subsistence quantities requires information on income elasticities, budget shares and the Frisch parameter φ_r as shown in Table 3, there are different ways to calculate and calibrate the subsistence quantities, which will be explained in the following section and all implemented in DART-BIO. We also introduce the

CDE demand system into DART-BIO, which means adding several new equations to the model following Chen (2016) and Rutherford and Lanz (2016).

3.2 Chosen demand specifications

We analyze the sensitivity of demand and land use change to five different demand specifications as shown in Table 4. In the original DART-BIO version, subsistence minima are calculated using a transformation proposed by Dellink (2005) that calibrates the subsistence quantities based on the size of each commodity's income elasticity of demand relative to the highest income elasticity of demand in the consumption bundle:

$$C_{i,r}^{subs} = \left(1 - \frac{\eta_{i,r}}{Max_j\{\eta_{j,r}\}}\right) \cdot C_{i,r} \tag{5}$$

(see Dellink (2005))

With $C_{i,r}^{subs}$ denominating the subsistence quantity ($\gamma_{r,i}$), $\eta_{i,r}$ is the income elasticity of demand for commodity i in region r and $C_{i,r}$ total consumption of commodity i in region r. With this transformation the commodity with the highest income elasticity of demand (usually a luxury good) exhibits zero subsistence consumption and all other goods' subsistence quantities are positive according to the relative size of their income elasticity. Both total consumption quantities and income elasticities are directly derived from the GTAP 8 data (Narayanan et al., 2012). Income elasticities are calculated with the CDE substitution and income parameters provided in the GTAP 8 database (Hertel et al., 2014).

We call this demand specification *STRD* and use it as our baseline to which all other specifications are compared. In general, the calibrated subsistence share of total consumption for all regions is relatively small, making demand relative responsive to income and price changes, even though income elasticities for different commodities vary substantially among the regions. This is firstly because the sector "other goods" has both the largest consumption share in most regions but also the highest income elasticity, resulting in a subsistence share of zero for this sector. This also means that consumers have homothetic preferences for "other goods", which certainly contradicts Engel's law and defeats the object of using a demand system that allows for non-homotheticity. Secondly, for industrial countries those commodities with a low income elasticity such as necessity goods exhibit a high subsistence share, but simultaneously have a small budget share. For emerging and developing countries, necessity goods indeed have a high budget share, but their income elasticities are still relatively high compared to the highest income elasticities, resulting in a relatively low subsistence share. The latter contradicts intuition assuming that subsistence shares are higher in developing than in developed countries. Nevertheless, one must keep in mind that the division of consumption into subsistence and supernumerary quantities remains a model construct that does not necessarily comply with observed consumption patterns. Dellink (2005) proves that his transformation always gives the implicit income elasticities to which the LES is calibrated, as long as there is a strictly positive constant in the denominator. Moreover, price and income responsive private demand may well be needed for certain research questions. The comparison of the different demand specifications in the next section will show the role that the subsistence quantity calibration plays for private demand responses.

The *LES_e* specification is also based on the Dellink (2005) transformation but uses slightly different ("empirical") income elasticities of demand for the calibration than the baseline. Hertel et al. (2014) first estimate income elasticities from empirical data using the AIDADS demand system for all GTAP sectors, which they use in a second step to calibrate the CDE parameters that are used in the GTAP model. The GTAP database itself then provides these calibrated CDE parameters, which were used in the DART-BIO baseline to recalculate income elasticities based on the CDE parameters. The empirical elasticities are only slightly different from the calculated CDE income elasticities, so the results should not be too different from the baseline. Nevertheless we want to avoid the step of first calibrating CDE parameters from these elasticities and then recalculate the elasticities based on the CDE parameters, and therefore use the original estimated income elasticities for this LES specification.

Unlike the Dellink (2005) formula that uses only information on income elasticities, the classical LES equation for the calculation of subsistence quantities is additionally based on average budget shares and on the expenditure elasticity of the marginal utility of expenditure, the so called Frisch parameter. The latter is also known as the money flexibility and is usually given on a country level (Frisch, 1959). Average budget shares for different commodities can be directly calculated from the GTAP data (equation 2 in Table 1), while the Frisch parameter has to be taken from the literature or ideally be calibrated from the existing data. In the *LES_cal* specification, we take the latter approach, while using a Frisch parameter formula derived from the empirical literature in the *LES_GNI* specification (Lluch et al., 1977).

To calibrate the subsistence quantities and Frisch parameters for the *LES_cal* specification, we use data on consumption quantities and shares from GTAP8 and the estimated income elasticities from Hertel et al. (2014) to calculate total expenditure and marginal budget shares. We solve the system of equations (2)-(4) from Dervis et al. (1982) as shown in Table 1 in GAMS but replace equation (3) with a transformation from Bloningen et al. (1997):

$$\gamma_{r,i} = C_{r,i} + \frac{Y_r \beta_{r,i}}{P_i \varphi_r} \tag{6}$$

All commodity prices P_i are normalized to unity and we set an upper bound of -1 on the Frisch parameter to ensure that the subsistence values do not exceed total consumption quantities. The higher the absolute value of the Frisch parameter, the larger the subsistence quantities, since the second term in equation (6) becomes smaller with a larger absolute Frisch parameter. With the formula $\varphi_r = \frac{Y_r}{Y_r - \sum_i P_i * \gamma_{r,i}}$, the calibrated Frisch parameters approach -1 from below with rising total expenditure (Lluch et al., 1977) as can be seen in the first column Table 5: all industrial countries exhibit a Frisch parameter close to -1, while emerging and developing regions have slightly higher values. The calibrated values are a result of the relative sizes of total expenditure, total consumption for each commodity and marginal budget shares. The formula therefore ensures that our regional aggregation and subsequent sizes of total expenditures do not bias the results in favor of highly aggregated regions, since actual demand patterns determine the Frisch parameter and subsistence quantities as well. For example even though Africa has a larger total expenditure than Scandinavia, it has a larger absolute Frisch parameter value since Africa's marginal budget shares are more evenly divided between different commodity groups compared to Scandinavia, where mostly OTH (other goods) are consumed. Similarly, PAC (Paraguay, Argentina, Uruguay and Chile) has the smallest total expenditure value of all regions but their preference for mostly OTH leads to a relatively low absolute Frisch parameter value. The smaller the absolute value of the Frisch parameter the smaller the calibrated subsistence quantities that enter the CGE model and the more elastic private consumer demand.

Lanz and Rutherford (2016) suggest another option to calibrate the LES, if empirical data on own-price elasticities of demand is available. They calibrate the discretionary expenditure share, which is defined as the negative reciprocal of the Frisch parameter. Given that the own-price elasticities in the GTAP dataset are themselves calculated using the Frisch parameter (Hertel et al., 2014), we refrain from this method and concentrate on the Frisch parameter instead.

Finally, all the previous specifications led to demand systems where some commodity groups had zero subsistence quantities. While this seems intuitively right for luxury goods and for richer countries, it defeats the object of using a more flexible demand system than Cobb-Douglas as it implies homothetic preferences. In the *LES_GNI* specification we therefore use the Frisch parameter formula derived from empirical data by Lluch et al. (1977) to calculate the subsistence quantities. Lluch et al. (1977) first estimate Frisch parameter for 16 countries and different commodity groups, which they regress on the countries' gross national product (GNP) per capita and arrive at the following approximation between the Frisch parameter and GNP:

$$\varphi_r = -\,36 * {GNP_r}^{-0.36} \qquad (7)$$

As GNP is not a common measure of income anymore, we use data on gross national income (GNI) per capita in 2007 for all regions World Bank to calculate GNI-based Frisch parameters as well as subsistence quantities. The Lluch et al. (1977) formula is estimated with data from the 1970s and a maximum GNP per capita of 3,669 USD and leads to a Frisch parameter of -1 at a value of 21,000 USD per capita. This means that the calculated Frisch parameters are larger than -1 for all regions with a higher GNI per capita (between -0.7 and -0.8 for industrial countries) as shown in the fourth column of Table 5. Interestingly, these Frisch parameter values are exactly in line with the original values proposed by Frisch himself, as he assumes a value of -0.7 "for the better-off part of the population" (Frisch, 1959). Similarly, Frisch proposes values of -4 "for the slightly better off but still poor part of the population with a fairly pronounced desire to become better off" and -2 "for the middle income bracket, "the median part" of the population" (Frisch, 1959), which also fits the values calculated with Lluch et al.'s (1979) formula. Since a Frisch parameter value larger than -1.0 leads to negative subsistence quantities, we set the maximum of all Frisch parameters to -1.0 (see last column of Table 5). Nevertheless, even though the GNI formula values are in line with the original theory, the large Frisch parameter and subsequently large subsistence quantities for Africa, India, South East Asia and China will make private demand in these regions less elastic to income and price changes, which can significantly influence modeling results.

Outlook: CDE

3.3 Scenario: Changing income elasticities for livestock products

The previous section has discussed the role of income elasticities in calibrating consumption parameters and in determining consumption under different demand systems. Engel's law states that the share of food in total expenditure decreases with rising income, so that the marginal budget shares for food decrease as people become richer (Chaudri and Timmer, 1986). In general, this means that food products have income elasticities between 0 and 1, but also depends on a country's income level and the disaggregation across food groups when estimating income elasticities. Hertel et al. (2014) for example estimate expenditure elasticities greater than unity for meat and dairy products in low-income countries, while empirical studies usually show that food demand in richer countries is relatively less elastic than in poorer countries (e.g. Lluch et al., 1977). This also implies that income elasticities of food commodities decrease with growing income, especially for food groups with larger than unity elasticities. Yu et al. (2003) estimate expenditure elasticities for several regions over a period of 35 years (1985, 1995 and 2020) and show that income elasticities for animal products are at first larger than unity in emerging and developing countries, but fall below unity with increasing GDP and income until luxury goods eventually become necessities. Engel's finding that increases in income lead to less than proportional increases in food consumption was such an important insight at its time as it alleviated Malthusian fears of running out food (Chai and Moneta, 2010). Likewise, the fact that livestock products are becoming necessities in emerging economies has important implications for future land use and fears of running out of land. Because even though GDP and household income in emerging economies is projected to grow further in the next decades, demand for animal products will not grow at the same pace according to Engel's law.

The two types of demand systems employed in our analysis do not allow for sufficient Engel flexibility and for changes in preferences as income grows (Rimmer and Powell, 1994). Practically, this means that income elasticities and marginal budget shares are fixed. While we avoid the shortcoming of the LES eventually approaching Cobb-Douglas through scaling subsistence demand with population growth, we do not account for changes in income elasticities and subsequent changes in subsistence quantities. Even so, Yu et al. (2003) show that income elasticities of food demand remain quite stable over the period 1985 – 2020 for all developed regions as opposed to the falling income elasticities for livestock products in emerging and developing countries mentioned above. This suggests that the lack of Engel flexibility in our demand systems should be less problematic for capturing demand responses in high-income countries.

In order to nevertheless analyze the impact of changes in income elasticities for livestock products in emerging economies on food consumption and land use, we run a scenario in which we calibrate the different demand specification to the livestock income elasticities changes estimated by Yu et al. (2003) for China and India. Hertel et al.’s (2014) income elasticity estimates for 2007 are unsurprisingly somewhere between Yu et al.’s (2003) estimates for 1995 and 2020. We therefore take the relative reduction in income elasticity between 1995 and 2020 from Yu et al. (2003), which amounts to -32% for China and -21% for India, and impose it on Hertel et al.’s (2014) elasticities. We then recalibrate the different demand specifications with the new elasticities and rerun our model.

4. Results

As already mentioned above the different demand specifications affect only the subsistence quantities entering the benchmark equilibrium. The subsistence quantities then remain fixed and grow exogenously with population, but simultaneously determine the discretionary share of consumption, which is the part that reacts to income and price changes. The higher the subsistence shares, the less elastic is the private demand response. Since the latter is likely to drive model results significantly, we begin this section by comparing the share of subsistence quantity in total private consumption for the different demand specifications to the baseline STRD specification.

4.1 Change in share of subsistence quantity in total private consumption

On global average, the share of subsistence quantities in total private consumption in the benchmark year 2007 remains unchanged under both LES_e and LES_cal compared to the STRD specification. This is not surprising considering that the LES_e specification differs only a little from STRD and LES_cal exhibits low absolute Frisch parameters. As expected the global subsistence share is higher under the LES_GNI specification (due to the much higher Frisch parameters for some regions) and increases from 4.6 to 12.9%. How the different parametrizations affect the subsistence quantities in the benchmark year becomes apparent on the regional scale as shown in Figure 1. To better compare the changes in subsistence shares among the demand specifications, we concentrate on the most important emerging and developing regions and choose the USA as representative for all industrial regions in our model, as the differences are very similar across developed countries.

Figure 1 confirms the global average results concerning the LES_GNI specification, as all developing and emerging regions exhibit subsistence shares more than three times higher than under STRD: in South East Asia for example, the share amounts to 12% under the STRD specification and 66% under the LES_gni specification. With an increase of 52 percentage points compared to STRD, the subsistence share of Sub-Saharan Africa is the highest among all regions under LES_GNI (about 70%), which is in line with Africa having the largest absolute Frisch parameter (see Table 3). In industrialized regions such as Germany and the USA, shares of subsistence quantities in total private consumption are relatively small and similar in all specifications. As all developed countries' Frisch parameters are close to -1, subsistence quantities under LES_cal and the LES_gni are primarily determined by income elasticities (see equation (6)) and are therefore close to STRD and LES_e, where subsistence quantities are only dependent on the relative size of income elasticities.

Some regional differences can also be found under both the LES_e and LES_cal specifications, even though both specifications show similar values. This is likely due to the fact that both specifications were calibrated with the same income elasticity values. The share of subsistence quantity in total consumption is slightly lower in Middle and South America (PAC) except for Brazil. A similar trend can be seen in China and India (-1.7 percentage points). Interestingly, the share is almost double in Malaysia/Indonesia compared to STRD. The specifications have a reverse impact on the subsistence level in Sub-Saharan Africa: Under the LES_e specification the share rises (6.7 percentage points), but is close to STRD under the LES_cal specification. As the Frisch parameter for Africa under LES_cal is relatively small, there is no increase in subsistence quantities compared to STRD. In general, the differences between STRD and LES_e can be explained with a slight change in the order of magnitude of income elasticities. The commodity group "OTH" exhibits the largest income elasticity in the STRD specification so that its subsistence quantity is always zero after the Dellink et al. (2005) formula. In the LES_e specification some commodities in some regions have higher income elasticities then OTH so that the Dellink formula assigns a subsistence share to OTH. As OTH has the largest average budget share, even a small subsistence share of other drives up the total subsistence quantity. This effect is most pronounced for the LES_e subsistence share of Sub-Saharan Africa as well as Malaysia. The latter region also has the highest absolute Frisch under LES_cal and therefore shows a similar subsistence share as LES_e.

Figure 2 breaks up the subsistence quantities according to five sectors including vegetarian food ("veg", this includes all staples and vegetarian processed food), meat and dairy products ("MDP"), rest of agriculture and forest ("RestAgriFor"), energy and industry. On the global level, LES_e and LES_cal are very similar to STRD but show higher shares of energy goods (+5 percentage points) and industry goods (+3 pp) compared to STRD, while the food consumption share is slightly lower (-6PP vegetarian food, -1% meat products). The LES_GNI specification on the other hand has a much higher share of industry goods. This is because a lot of regions have a relatively large subsistence quantity of OTH due to the high Frisch parameters under LES_GNI, which drives up the share of industry goods by 47 percentage points (4% under STRD) mainly at the cost of vegetarian food (-40PP) and meat products (-10PP). This trend can also be observed across the representative regions shown in Figure 2. The Latin American and Asian regions show a much larger share of industry goods (more than 50%) und lower share of food commodities in their subsistence consumption under LES_GNI compared to STRD. Even in Sub-Saharan Africa, food amounts to only half to the subsistence consumption while it was 95% in STRD. In most industrialized regions, subsistence quantity shares by sector are relatively stable across all demand system specifications due to the similarities in subsistence quantity calculations as mentioned above. The meat subsistence share remains at around 17% in all specifications, while new specification exhibit higher shares of industry and energy goods compared to STRD.

In China and India, sectoral subsistence quantity shares under LES_e and LES_cal are almost identical to STRD with a 90% share of food commodities, although the meat share is 4 percentage points lower compared to STRD. Generally, LES_e and LES_cal are very similar for all regions except for Africa as Frisch parameters in LES_cal are close to -1, and both demand specifications are calibrated to the same set of income elasticities. Under LES_e and LES_cal, Latin American countries have a higher food subsistence share (about 10 percentage points higher than in STRD, of which 6% is meat) as well as a higher energy commodity share at the expense of industry. Similarly, Brazil has higher share of energy goods in subsistence consumption (16% versus 6%) compared to STRD at the expense of food due to the slightly lower income elasticities of energy goods in LES_e and LES_cal as in STRD. Africa is again a special case since the change in order of magnitude of the income elasticities under LES_e leads to a much higher industry goods share compared to STRD (i.e. 20% versus 2% in STRD) and a lower share of food commodities (76% versus 95%).

Under all demand specifications, there is thus a decrease in the share of food (both vegetarian and meat) in total subsistence quantities. However, this sectoral breakup does not necessarily allow for statements on food demand reactions to income and price changes under different demand specifications. Because even though the share of food commodities of total subsistence quantities is smaller in LES_GNI compared to the other specifications, the overall subsistence share in total consumption is much larger under LES_GNI, so that total demand is less elastic on average. Nevertheless, the subsistence quantity shares will help us to understand the impact of different demand systems on demand, prices and land use under GDP and population growth as examined in the next section.

4.2 The impact of different demand systems on consumption, prices, and land use

As explained in section 3, we run DART-BIO with different demand specifications from 2007 to 2029 to understand how these specifications influence consumption, prices, and land use. , Overall, there is an increase in total global consumption from 2007 to 2030 in all specifications and we compare the results of each demand specification to STRD in the following. Figure 3 shows the change in total global consumption (including private, government and intermediate demand) in 2030 under the new specifications compared to STRD. We begin with differences between STRD and LES_GNI as these are most pronounced and the result of complex interactions between the large subsistence quantities under LES_GNI. As shown in the previous section, LES_GNI is the only specification with a subsistence share of “OTH”, the commodity group with the largest average and marginal budget share in every region. This makes total private demand under LES_GNI relatively less elastic to price and income changes compared to STRD. Moreover, the large fixed consumption of “OTH” is compensated for by a reduction in the supernumerary consumption of all other commodities with a large marginal budget share (i.e. ILVS, PCM, FOD), which mirrors the above mentioned lower share of food compared to industry in subsistence consumption. At the same time the price of OTH declines even more than in STRD (Figure 4), but since such a large consumption share of OTH is fixed in LES_GNI, the reaction to lower prices is less pronounced, so that the increase in consumption of OTH is smaller over time than in STRD. In addition, all food commodities exhibit a large fixed subsistence consumption, which drives up prices of staple crops as shown in Figure 4 relative to STRD. Note that prices of indoor livestock and processed foods (ILVS, PCM, FOD) do not increase as much because they also use OTH as an input, which has relatively lower prices than in STRD. This leads to a decrease in demand for most staple crops compared to STRD. However, the lower demand for certain staple crops is mostly driven by the decreased demand for indoor livestock, which uses these staple crops (PDR, WHT, SOY, RSD, OSDN) as feedstock. As a consequence of the lower demand for oilcrops and their by-products from the livestock industry, vegetable oil and meal production decreases emphasizing the link between livestock and biofuel production. All these effects have important implications for global land use change under LES_GNI relative to STRD. Figure 5 shows the change in total global land use in 2029 compared to STRD and mirrors the changes in total consumption with the largest decreases in land use for WHT and oilseeds under LES_GNI. The large fixed subsistence quantities under LES_GNI clearly have substantial and complex interwoven effects on total demand and land use. Large fixed demand shares have a dampening impact on private consumption as households can only partly react to income and price changes. Moreover, this demand specification demonstrates the strength of livestock industries to other sectors and how small changes in livestock demand influence land use change in all other sectors.

Changes are not as pronounced under LES_e and LES_cal and generally go in the other direction than LES_GNI. Overall subsistence shares are a bit smaller under the two specifications relative to STRD making private demand even more elastic to income and price changes. As incomes grow in all regions between 2007 and 2029 there is thus an increase in the consumption of those commodities with a large marginal budget share, mainly processed foods and livestock (Figure 3). Interestingly, ILVS, FOD and PCM have a smaller subsistence share under LES_e and LES_cal than under STRD, whereas the subsistence share of OTH is the same (effectively zero) under all three specifications. As consequence, the consumption of ILVS, FOD and PCM is larger relative to STRD, whereas OTH stays basically the same. This increases the demand for inputs from staple crops (WHT and all oilseeds), whose prices rise relative to STRD as shown in Figure 4. Again, prices for livestock and processed foods do not rise as much due to low prices for the input OTH that exhibits not demand increase relative to STRD. In contrast to LES_GNI where the production of oilseeds and their by-products was lower than in STRD, the increase in meat demand in LES_e and LES_cal leads to higher vegetable oil and meal production. The increases in total demand directly translate into land use changes as shown in Figure 5. Land use of oilseeds and wheat is slightly larger under LES_e and LES_cal than STRD. However, total changes under LES_e and LES_cal pertaining consumption, prices and land use are small compared to STRD and are all around 1% in 2029. Nevertheless, the two demand specifications provide for some larger flexibility of demand to income and prices changes that mirror the projected developments in terms of increased meat demand in the next decades and might therefore be preferred to STRD. In addition, the insignificant differences between LES_e and LES_cal imply that the Dellink (2005) formula is a suitable alternative to calibrating subsistence quantities and saves the additional calibration of Frisch parameters. On the other hand, the LES_GNI specification exhibits undesirable impacts in terms of demand interactions. The fact that this specification is based on a 30 year old formula (when average national incomes were much lower than today) makes this specification much less suitable for reproducing today's demand patterns. This experiment certainly shows how much demand specifications can influence final results especially in terms of land use and demand systems should therefore be chosen very carefully.

4.3 Demand shock: changing income elasticities of livestock products

In order to better understand how different demand systems influence final modeling results in terms of land use and to test for the implications of Engel's law in dampening the demand increasing effects of income growth, we introduce a demand shock by reducing income elasticities for livestock products in India by 21% and China by 32% as estimated by Yu et al. (2003). Recalibration of the different demand specifications to the new income elasticities firstly changes the subsistence shares in China and India in the scenarios compared to the baseline reference. The subsistence quantities of livestock products under STRD and LES_e directly increase, as commodities with lower income elasticities have higher subsistence shares in the Dellink (2005) formula. Following Engel's law reduction in income elasticities also leads to lower marginal budget shares of livestock products in all specifications, which increases the subsistence shares under both LES_GNI and LES_cal[1] (see equation 6). This makes demand for livestock products in India and China in all specifications less elastic to income and price changes relative to its respective reference run without the income elasticity shock.

Figure 6 shows the change in total global consumption in 2030, where the scenario results in each specification are compared to its respective reference run. In each specification, the demand shock in China and India evokes a reduction global livestock product demand (ILVS, PCM) except for outdoor livestock, for which demand from China and India is small. This simultaneously reduces the demand for livestock production inputs, especially wheat and oilseeds and oilseed products. Impacts for LES_e and LES_cal completely coincide and exhibit the highest reductions in demand relative to the other specifications as demand is most elastic. LES_GNI on the other hand has the smallest reductions due to the relative inelastic demand and high subsistence shares, while the STRD results are between LES_GNI and the other two specifications.

Figure 7 explains the large demand decreases in both China and India that influence global results in more detail. The total demand decreases in Figure 7 are driven by the reduction in

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[1] Higher subsistence quantities for livestock products are also accompanied by slightly higher Frisch parameters for India and China under LES_cal, but do not influence the subsistence share of other commodity groups.

the marginal budget shares of private demand for livestock products, which lead to large reductions in livestock demand relative to the reference run. In China (India) private consumption of meat products decreases by 13.5% (4.4%) under LES_GNI and 15.7% (4.9%) under LES_e and LES_cal in 2030 compared to the respective reference run (not shown here). In the overall budget allocation, the share of meat consumption on total consumption drops by 0.8% in China and 0.2% in India under all specifications. This is again followed by lower demand for livestock inputs (especially wheat and soymeal, but also rice), which is much more pronounced in China than in India due to the relatively larger reductions of a much bigger total demand in China relative to India. As effects are not only relatively more pronounced in China but also absolutely due to the large size of the Chinese economy, the demand reductions in China dominate the global effects compared to India. The overall differences between the demand specifications for India and China follow the global results in a sense that the more elastic total private demand, the larger the reductions in demand for livestock products and their inputs. The unusual results for India under LES_GNI, are largely driven by the decreased demand for outdoor livestock products. Even though the percentage reduction is small, OLVS in India is much important than ILVS and PCM with a large average budget share and is much more affected by the elasticity shock, which also leads to lower demand for feedstock in LES_GNI.

Lower demand for livestock products and their inputs translates into lower prices in India and China as shown in Figure 8. Paddy rice prices in China fall by around 4% in all demand specifications. Even though the relative reduction in rice demand is small, PDR is a large sector in China so that the absolute price reduction is large. Prices of vegetable oils that are jointly produced with meals rise substantially (8% for soy oil, others not shown), since the loss in revenues due to low meal prices are compensated by higher oil prices. The different demand specifications show no significant impact on price changes in China. India on the other hand, has stronger price effects under LES_GNI compared to the other specifications, which is due to the abovementioned dominance of outdoor livestock in Indian livestock product consumption. Lower demand and prices of outdoor livestock cause all input prices to decline. Interestingly, Indian soy oil prices are also affected by the price increase in China.

Due to China’s dominance on the world market relative to India, global price effects in the scenarios closely track price effects in China as illustrated in Figure 8. The lower prices for oilseed meals and high prices for vegetable oils in China have thus directly translated into changes of world market prices, albeit to a lesser extent. Looking at the change in harvested area in 2030 compared to the reference runs in Figure 10 mirrors the production and price effects: globally, there is a reduction in land use for wheat, soy and other oilseeds. Again, this reduction is less pronounced in the relatively inelastic LES_GNI specification and more under under LES_e and LES_cal.

To understand how the price and demand changes affect other regions, we take a closer look to changes in trade flows. As expected, China and to a lesser extent India exhibit large decreases in net imports for both livestock products and feedstock under all demand specifications in 2030 under the "livestock" scenario. Net imports of processed meat (PCM) to China decrease by more than 10% under the different specifications. Similar reductions apply to net imports of ILVS and to a lesser extent to feedstocks used in the livestock industry (between two to five percent for different oilseeds). On the other hand, imports for vegetable oils increase due to the high prices in China. Most of these changes affect trade with China's largest trade partners for these products, i.e. Brazil and the USA. Brazilian net exports to China make up about 72% of total soybean exports of Brazil and drop by 2.7-3.4% under the meat scenario. Even though all other regions increase their imports from Brazil, this does not fully compensate the reduced Chinese imports such that total net exports of soybeans from Brazil are reduced by 1.3-1.8% depending on the specification. This leads to a decrease in land use for soybeans of about 1% in Brazil. In China on the other hand, land use of wheat decrease by around 8% and is mostly compensated for by increased land use of oilseeds. An interesting result is that Russia ceases to export wheat to India due to low wheat prices on the world market, so that India starts to produce the formerly imported wheat domestically, leading to some land use change (less than 1 %) as well. In general, there is some land use change at the expense of either soybeans or wheat in favor of oilseeds in all regions but the percentages remain very small around 1%. This implies that changes in demand of livestock products in emerging economies do indeed affect land use in other regions, even though the impacts are small. Moreover, China's size alone has significant influences on world market prices and any demand change directly translates into changes on the world market.

The results are rather surprising in terms of biofuels: even though there is a decrease for livestock demand and subsequently oilseed meals, there is actually an increase in the production of vegetable oils due to the higher prices. In contrast to Taheripour et al. (2011) and Calzadilla et al. (2016) who find a positive impact of biofuel production on livestock output, our findings suggest that the link between biofuels and livestock is not reciprocal and requires further exploration of our results. In addition, our analysis also confirms Engel's law in a sense that even though China's and India's incomes are growing, the decreasing marginal budget shares of livestock products do not translate income growth into proportional demand growth.

5. Conclusion

Global land use change today is strongly influenced by changes in diets towards more livestock products due to population and income growth as well as additional demand for biomass from a growing biofuels industry. At the same time, biofuel and livestock production are linked to each other via the use of biofuel byproducts as fodder (Calzadilla et al., 2016). These developments affect land use worldwide but global simulation models trying to quantify future food demand and subsequent land use change provide different projections due to general model features but also due to different demand specifications and demand elasticities. In order to isolate the impact of demand specifications and elasticities on food demand and subsequent land use change we calibrate the global CGE model DART-BIO to different demand specifications and test the effect of changing income elasticities for livestock products in emerging Asian economies on food demand and land use. In addition, we explore whether the positive impact of biofuel production on livestock output as found by other studies is reciprocal.

Our findings confirm the importance of demand specifications and income elasticities in influencing final models results. The size of fixed subsistence quantities in the linear expenditure system (LES) determines the size of the expenditure share that is elastic to income and prices and therefore the overall flexibility of private demand. We find that the DART-BIO standard version of LES calibration can be improved by using the original income elasticities estimated by Hertel et al. (2014) and not recalculate income elasticities from the the CDE parameters provided in the GTAP database. The original elasticities provide for a better flexibility in terms of reactions to income and price changes. Moreover, the simple formula provided by Dellink (2005) to calibrate subsistence quantities only with income elasticity data is a suitable alternative to calibrating subsistence quantities from Frisch parameters. We also use a formula from the 1970s based on regional GNI to calibrate Frisch parameters and subsistence quantities in the LES, but find that this leads to very large subsistence quantities that dampen private demand due to smaller reactions to income and price changes. The latter also leads to unrealistic reductions in global land use. The use of the original elasticities for LES calibration on the other hand mirrors projected increases in livestock demand and subsequent increases in land use of feedstock crops.

We then proceed to shock the different demand specifications with the reductions in income elasticities of livestock demand estimated by by Yu et al. (2003) for China and India to test for the implications of Engel's law in dampening the demand increasing effects of income growth. As expected, demand for livestock products decreases in both India and China and leads to lower consumption of all livestock fodder crops. The decreases are largest in the demand specifications with the original income elasticities as private demand in these systems is most responsive to income and price changes. We find that the demand and price effects especially in China directly affect the world market and thus entail some land use change in other regions. In general, there is some land use change at the expense of either soybeans or wheat in favor of oilseeds in all regions but the percentages remain very small around 1%. This implies that changes in demand of livestock products in emerging economies do indeed affect land use in other regions, even though the impacts are small. Moreover, even though there is a decrease for livestock demand and subsequently oilseed meals, there is actually an increase in the production of vegetable oils due to the higher prices. This result is in contrast to Taheripour et al. (2011) and Calzadilla et al. (2016) who find a positive impact of biofuel production on livestock output and implies that the link between biofuels and livestock is not reciprocal.

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Tables and Figures

Table 1: List of sectors (industries) and products (goods) in DART-BIO

Agricultural related products (29)		**Energy products (13)**	
PDR	Paddy rice	**COL**	Coal
WHT	Wheat	**CRU**	Oil
MZE	Maize	**GAS**	Gas
GRON	Other cereal grains	**MGAS**	Motor gasoline
PLM	Oil Palm fruit	**MDIE**	Motor diesel
RSD	Rapeseed	**OIL**	Petroleum and coal products
SOY	Soybean	**ELY**	Electricity
OSDN	Other oil seeds	**ETHW***	Ethanol from wheat
C_B	Sugar cane and sugar beet	**ETHM***	Ethanol from maize
OLVS	Outdoor livestock[1]	**ETHG***	Ethanol from other grains
ILVS	Indoor livestock[2]	**ETHS**	Ethanol from sugar cane
AGR	Rest of agriculture	**BETH**	Bioethanol
FRS	Forestry	**BDIE**	Biodiesel
PLMoil*	Palm oil		
PLMmeal*	Palm meal		
RSDoil*	Rapeseed oil	**Non-energy products (3)**	
RSDmeal*	Rapeseed meal	**CRPN**	Other chemical rubber plastic prods
SOYoil*	Soybean oil	**ETS**	Paper, minerals and metals
SOYmeal*	Soybean meal	**OTH**	Other goods and services
OSDNoil*	Oil from other oil seeds		
OSDNmeal*	Meal from other oil seeds		
VOLN	Other vegetable oils		
SGR	Sugar		
FOD	Rest of food		
PCM	Processed animal products		
FRI	Forest related industry		
DDGSw*	DDGS from wheat		
DDGSm*	DDGS from maize		
DDGSg*	DDGS from other cereal grains		

Source: Calzadilla et al. 2016, Table 2.

Note: New products are highlighted in blue. All goods are produced by an analogous industry, except where indicated.

[1] Includes cattle, raw milk, wool;

[2] Includes animal products neg

*jointly produced goods. Bioethanol and DDGS are jointly produced by the bioethanol industry (3 types of industries); and oilseeds oil and meal are jointly produced by the vegetable oil industry (4 types of industries).

Table 2: List of regions in DART-BIO

EU (7)		**Non-EU (16)**	
GER	Germany	**USA**	USA
GBR	United Kingdom, Ireland	**CAN**	Canada
FRA	France	**ANZ**	Australia, New Zealand
SCA	Finland, Sweden, Denmark	**JPN**	Japan
BEN	Belgium, Netherlands, Luxemburg	**RUS**	Russia
MED	Spain, Portugal, Italy, Greece, Malta, Cyprus	**FSU**	Rest of Former Soviet Union and Europe
REU	Rest of European Union	**BRA**	Brazil
		PAC	Paraguay, Argentina, Uruguay, Chile
		LAM	Rest of Latin America
		CHN	China
		IND	India
		MAI	Malaysia, Indonesia
		SEA	South East Asia
		MEA	Middle East, North Africa
		AFR	Sub-Saharan Africa
		ROW	Rest of the World

Source: DART-BIO.

Table 3: Linear expenditure system

Indices	
i, j	Commodities
r	Regional households
Parameters	
$C_{r,i}$	Consumption of commodity i by regional household
P_i	Price of commodity i
Y_r	Household expenditure/income
$\gamma_{r,i}$	Subsistence minimum of commodity i by regional household
$\beta_{r,i}$	Marginal budget share of commodity i by regional household
$\eta_{r,i}$	Expenditure elasticity of commodity i by regional household
$\alpha_{r,i}$	Average budget share of commodity i by regional household
φ_r	Frisch parameter for regional household

Equations

$$C_{r,i} = P_i * \gamma_{r,i} + \beta_{r,i} * (Y_r - \sum_j P_j * \gamma_{r,j}) \tag{1}$$

$$\beta_{r,i} = \eta_{r,i} * \alpha_{r,i} \tag{2}$$

$$\gamma_{r,i} = \left(\frac{Y_r}{P_i}\right) * \left(\alpha_{r,i} + \frac{\beta_{r,i}}{\varphi_r}\right) \tag{3}$$

$$\varphi_r = \frac{Y_r}{Y_r - \sum_i P_i * \gamma_{r,i}} \tag{4}$$

Source: Linear expenditure system following Dervis et al. (1982)

Table 4: Demand specifications

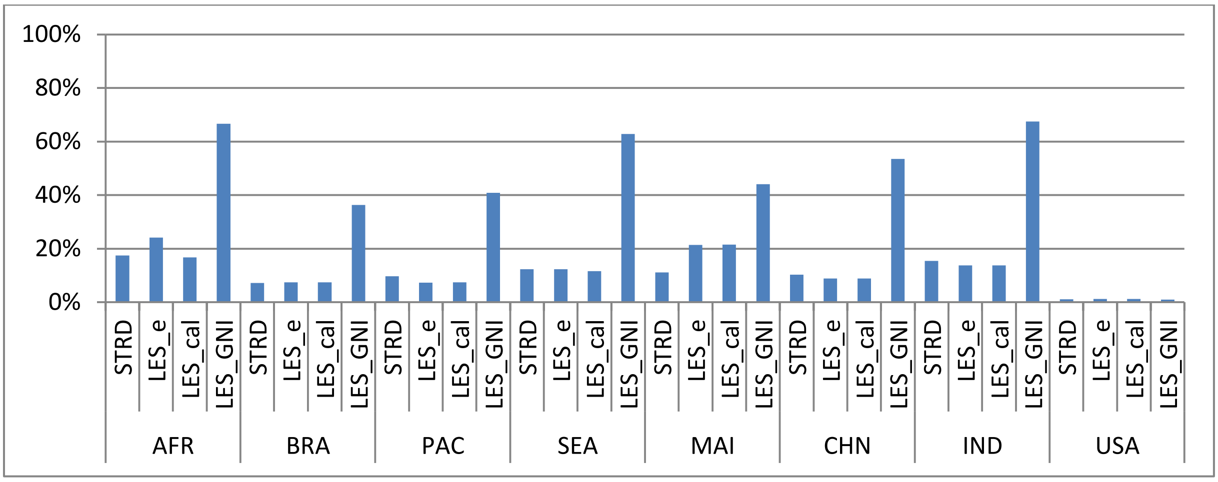
Specification	**Model structure**	**Demand calibration**
STRD (Baseline)	Standard DART-BIO with LES	Subsistence quantity calibration following Dellink (2005) with income elasticities from GTAPinGAMS calibration
LES_e	Standard DART-BIO with LES	Subsistence quantity calibration following Dellink (2005) with original income elasticities estimated with AIDADS
LES_cal	Standard DART-BIO with LES	Subsistence quantity calibration using the original formula with Frisch parameter and marginal budget shares: model based calibration of Frisch parameters and subsistence quantities following Bloningen et al. (1997)
LES_GNI	Standard DART-BIO with LES	Subsistence quantity calibration using the original formula with Frisch parameter and marginal budget shares: Frisch parameters are first calculated with the gross national income (GNI) formula developed by Lluch et al. (1977), which enables subsequent calculation of subsistence quantities
CDE	Extension of DART-BIO with CDE demand system equations	Calibration of demand using the CDE utility functions which are implemented into the original model following Chen (2016) and Rutherford and Lanz (2016)

Table 5: Total expenditure and Frisch parameters of demand specifications

	Total expenditure	GNI per capita	Frisch calibrated	Frisch_GNI (original)	Frisch_GNI (updated)
GER	1880	40.700	-1,02	-0,79	-1,00
GBR	1902	47.790	-1,02	-0,74	-1,00
FRA	1504	40.250	-1,03	-0,79	-1,00
SCA	489	51.310	-1,03	-0,73	-1,00
BEN	640	55.480	-1,03	-0,71	-1,00
MED	2484	27.764	-1,03	-0,91	-1,00
REU	932	16.026	-1,10	-1,10	-1,10
USA	9944	48.640	-1,01	-0,74	-1,00
CAN	801	41.220	-1,02	-0,78	-1,00
ANZ	551	32.725	-1,02	-0,85	-1,00
JPN	2489	38.740	-1,03	-0,80	-1,00
RUS	655	7.560	-1,14	-1,45	-1,45
FSU	274	2.757	-1,16	-2,08	-2,08
BRA	810	5.980	-1,08	-1,57	-1,57
PAC	262	4.907	-1,08	-1,69	-1,69
LAM	1282	4.581	-1,10	-1,73	-1,73
CHN	1428	2.510	-1,10	-2,15	-2,15
IND	730	930	-1,16	-3,07	-3,07
MAI	342	4.180	-1,27	-1,79	-1,79
SEA	224	1.340	-1,13	-2,69	-2,69
MEA	1303	8.746	-1,12	-1,37	-1,37
AFR	523	992	-1,20	-3,00	-3,00
ROW	1552	12.900	-1,05	-1,19	-1,19

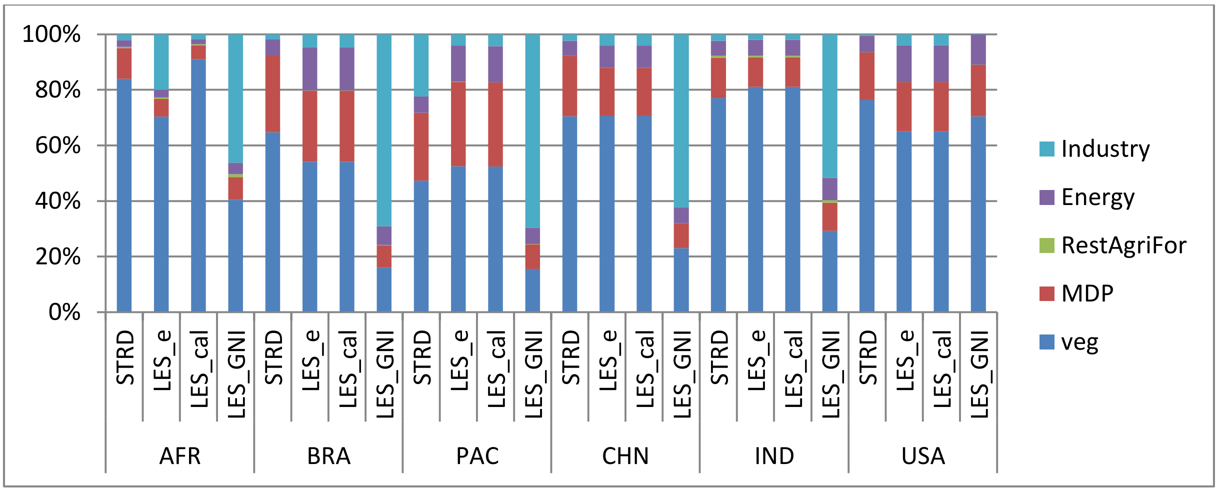
Source: own calculations using data from World Bank (2017) and formulas from Bloningen et al. (1997) and Lluch et al. (1977).

Figure 1: Share of subsistence consumption on total private consumption under different LES specifications in 2007 for selected regions



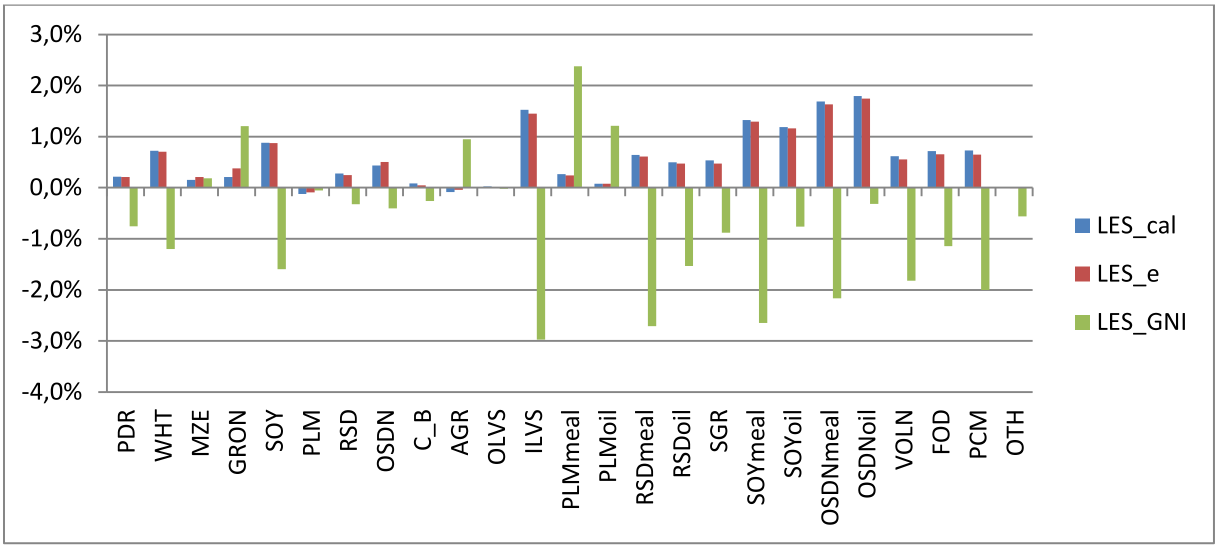
Source: Own calculations using DART-BIO.

Figure 2: Share of aggregated sectors in total subsistence quantities 2007



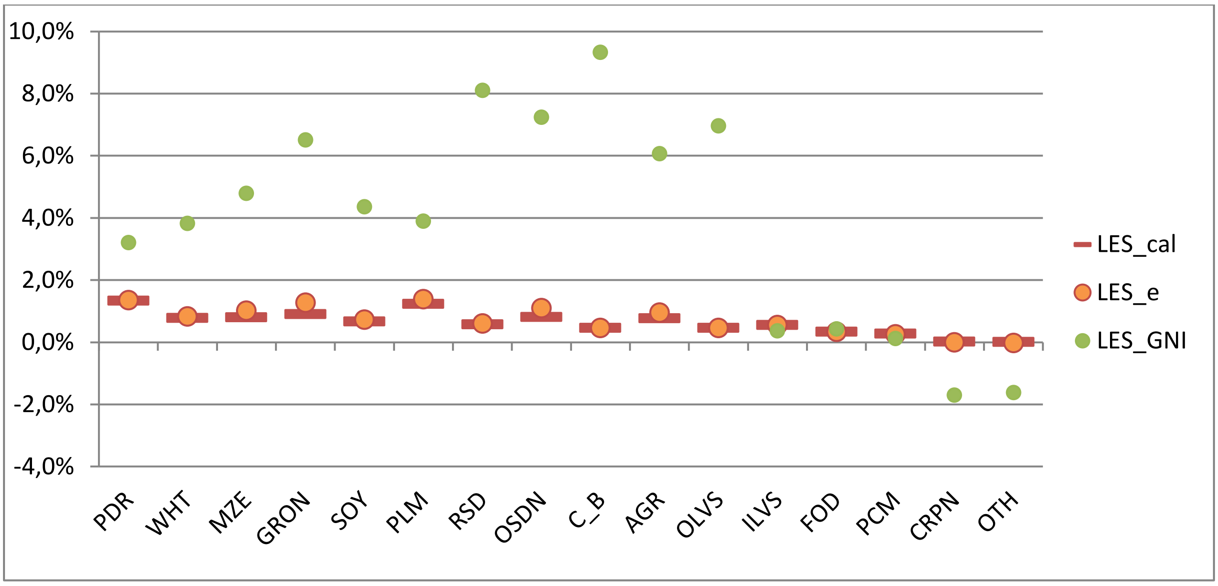
Source: Own calculations using DART-BIO.

Figure 3: Change in total global consumption in 2030 compared to standard DART-BIO model



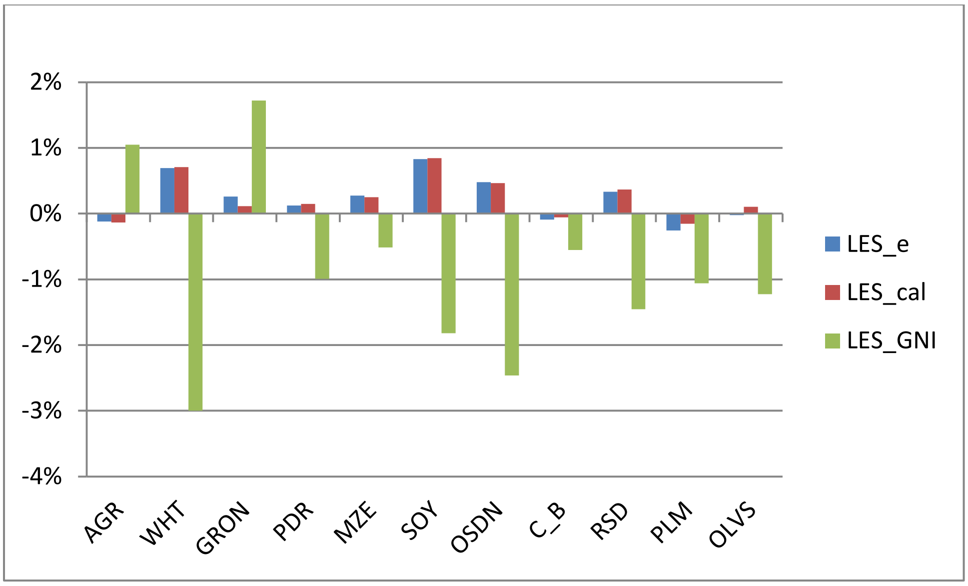
Source: Own calculations using DART-BIO.

Figure 4: Change in global average prices in 2030 compared to STRD



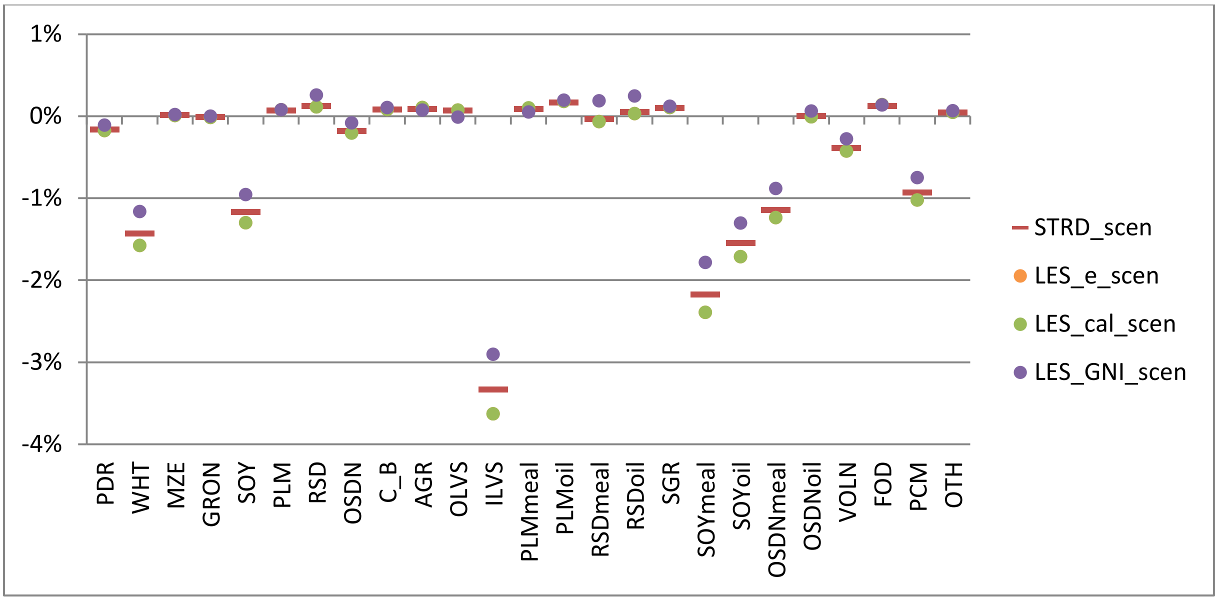
Source: Own calculations using DART-BIO.

Figure 5: Change in total global land use in 2030 compared to standard DART-BIO model



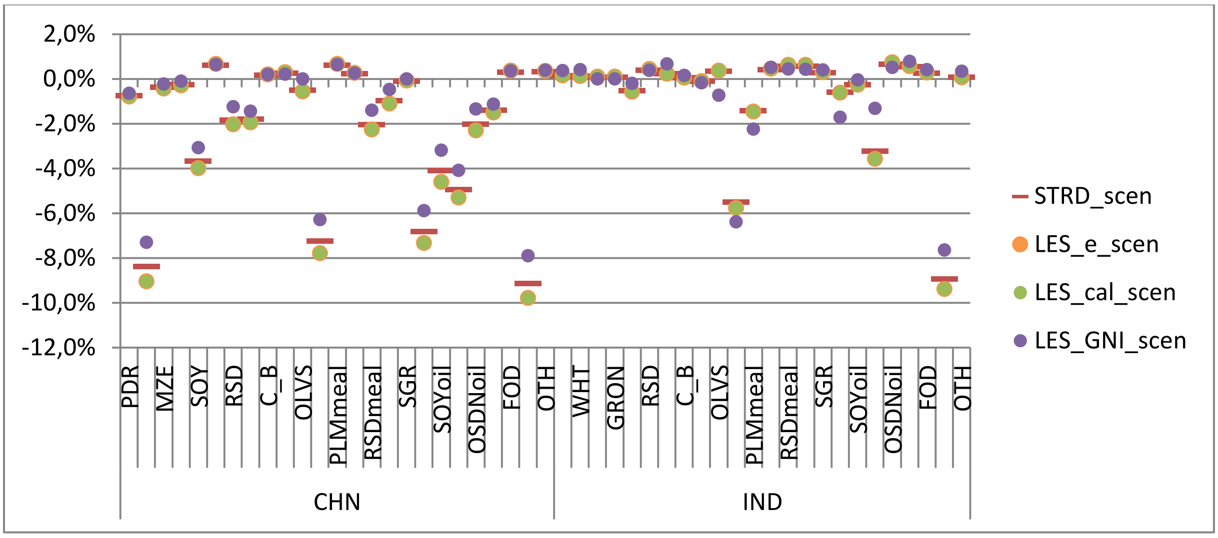
Source: Own calculations using DART-BIO.

Figure 6: Change in total global consumption in 2030 compared to reference runs



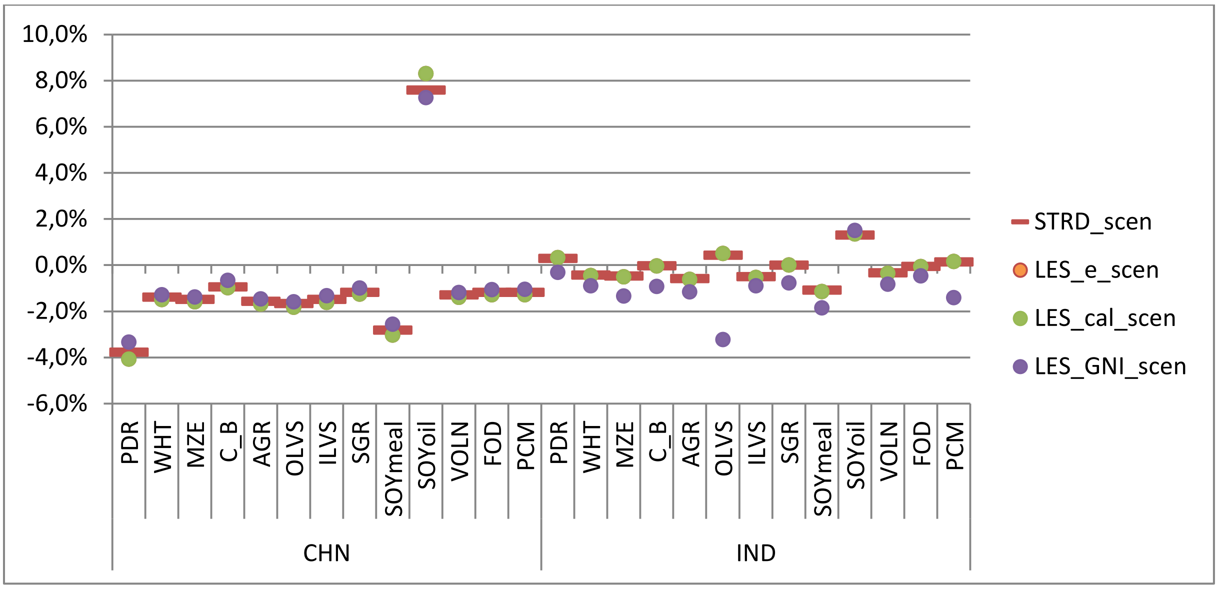
Source: Own calculations using DART-BIO.

Figure 7: Change in total consumption in 2030 compared to reference runs in India and China



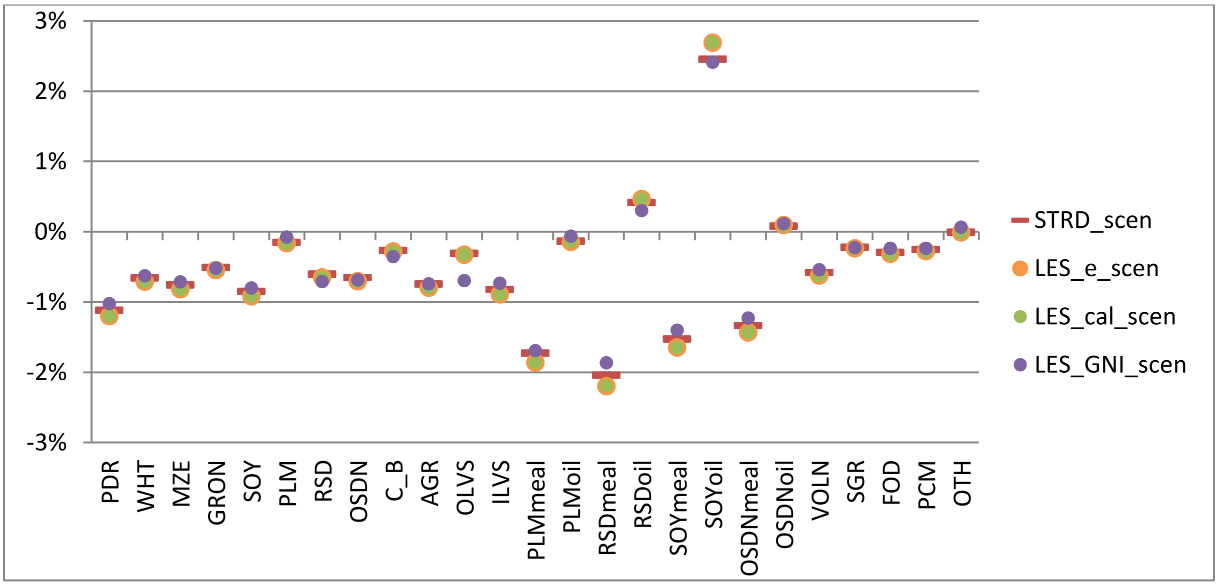
Source: Own calculations using DART-BIO.

Figure 8: Price changes of selected commodities in India and China in 2030 compared to reference runs



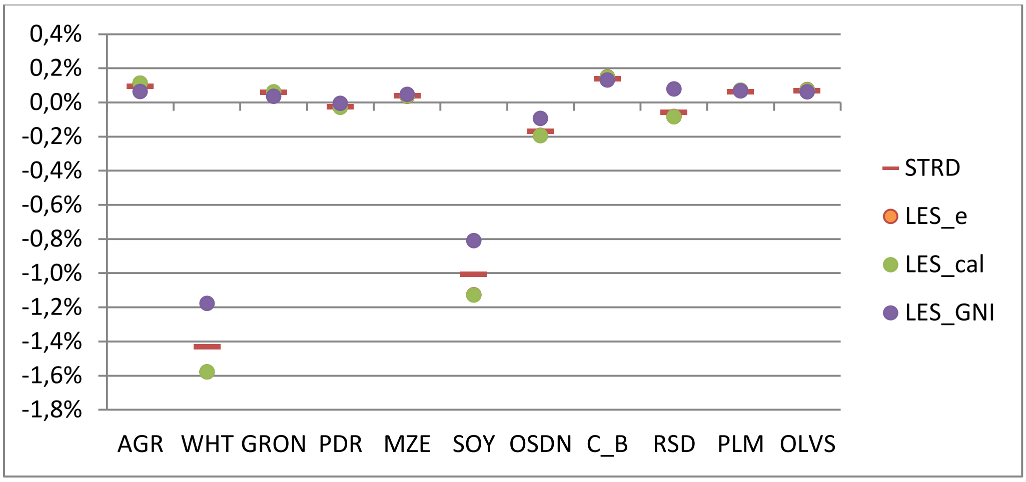
Source: Own calculations using DART-BIO.

Figure 9: change in global average prices in 2030 compared to reference runs



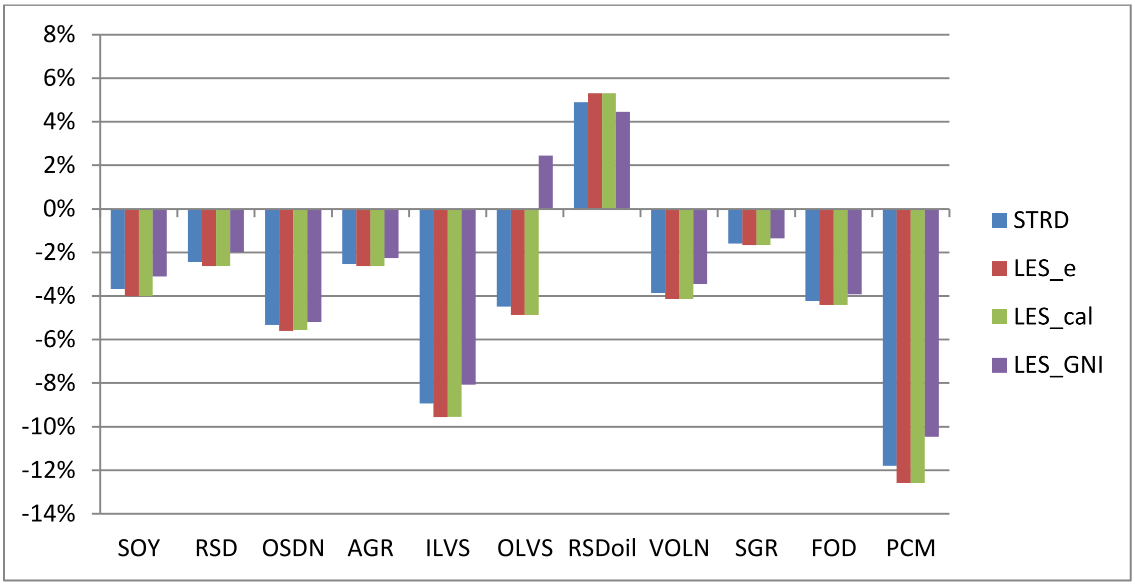
Source: Own calculations using DART-BIO.

Figure 10: change in harvested area in 2030 compared to reference run



Source: Own calculations using DART-BIO.

Figure 11: Change in imports to China in 2030 compared to reference run



Source: Own calculations using DART-BIO.