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## DART-BIO: A technical description

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# ABSTRACT

## DART-BIO: A technical description

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The goal of this technical paper is to present in a transparent way a detailed description of the DART-BIO model – the bioeconomy and land use version of the DART model. Key feature of the DART-BIO model is the explicit representation of the vegetable oil industry and the biofuel sector. The paper describes the construction and aggregation of the database used for the DART-BIO model. Further the theoretical structure of the model is elaborated. Thereby, crucial assumptions, elasticities and parameters embedded in the model are presented.

Keywords: CGE model, bioeconomy, climate policy, land use

JEL classification: C68; Q16; Q24

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# DART-BIO: A TECHNICAL DESCRIPTION

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## 1 Introduction: 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. The DART model was first developed in the late 1990's at the Kiel Institute for the World Economy (Springer 1998) to analyze international climate policies (e.g. Springer 1998; Klepper and Peterson, 2006; Weitzel et al., 2014) and environmental policies (e.g. Weitzel et al., 2012), energy policies (e.g. Klepper and Peterson, 2006b), and has been extended to analyze agricultural and biofuel policies (e.g. Kretschmer et al., 2009; Calzadilla et al., 2014; Zabel et al., 2019; Delzeit et al., 2018; Schuenemann and Delzeit, 2019).

The DART model is based on the social accounting matrices (SAM) of the Global Trade Analysis Project (GTAP), which encompasses multiple sectors and regions. In the DART model, a competitive economy with flexible prices and market clearing conditions is modelled for each region that trades with other regions under the Armington assumption of imperfect substitutes. Each region exhibits a fully specified economic structure including production, investment and final consumption by consumers and the government. The model is of the recursive-dynamic type so that the development of each economy over time is reproduced by a sequence of single-period static equilibria where capital accumulation and changes in labor supply are updated between the periods. We start by elaborating on the database of DART-BIO in section 2 and 3 and then will explain the theoretical structure of the model in more detail in section 4.

## 2 Overview over database and aggregation of DART-BIO

DART-BIO is the bioeconomy and land-use version of the DART model and shares the same core characteristics. However, DART-BIO focuses on the heterogeneity of land, the complex production process chains of biofuels and includes several activities/commodities not present in the original GTAP database. The DART-BIO model is calibrated to an extended version of the GTAP9 database (Aguiar et al., 2016), which represents the global economy in 2011 and covers 57 sectors and 140 regions. The current DART-BIO model aggregation has 21 regions, 51 sectors and 21 factors of production.

The DART-BIO model is centred around the analysis of feedback effects of bioeconomy policies and other shocks or policies that affect land use and agricultural production. Therefore, the regional aggregation concentrates on the large agricultural producers and consumers (e.g. the USA, Brazil, China) as well as regions with dedicated Bioeconomy strategies such as the European Union (Table 1). Moreover, a special focus is given to regions that are prone to land use changes as well as those that exhibit high population and economic growth and subsequent changes in consumption patterns (e.g. Malaysia, Indonesia and China) (Table 1).

***Table 1:*** **List of regions in DART-BIO**

| | | | |
|---|---|---|---|
| **Central and South America** | | **Europe** | |
| BRA | Brazil | FSU | Rest of former Soviet Union |
| PAC | Paraguay, Argentina, Uruguay, Chile | CEU* | Central European Union with Belgium, France, Luxembourg, Netherlands |
| LAM | Rest of Latin America | DEU* | Germany |
| | | MED* | Mediterranean with Cyprus, Greece, Italy, Malta, Portugal, Spain |
| **Middle East and Northern Africa** | | MEE* | Eastern European Union with Austria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Romania, Bulgaria, Croatia |
| MEA | Middle East and Northern Africa | NWE* | North-Western European Union with Denmark, Finland, Ireland, Sweden, United Kingdom |
| AFR | Sub-Saharan Africa | RNE | Rest of Northern Europe: Switzerland, Norway, Lichtenstein, Iceland |
| **Asia** | | **Northern America** | |
| CHN | China, Hong Kong | CAN | Canada |
| IND | India | USA | United States of America |
| EAS | Eastern Asia with Japan, South Korea, Taiwan, Singapore | | |
| MAI | Malaysia, Indonesia | **Oceania** | |
| ROA | Rest of Asia | ANC | Australia, New Zealand, Rest of Oceania |
| RUS | Russia | | |

*Members of the European Union

Table 2 gives an overview over the sectoral aggregation in the DART-BIO database. Modelling the Bioeconomy requires a detailed view of several key sectors, which are part of very aggregated sectors in the original GTAP database. Therefore, these sectors had to be separated from the more aggregated ones which is described in more detail in the next section. In total, 26 new sectors were added to the standard GTAP database. The DART-BIO database thus includes 43 production activities and 51 commodities, since some activities produce more than one commodity (Table 2). This also means that we differentiate between activities and commodities unlike the standard GTAP database.

The sectoral aggregation mirrors the clear focus on the Bioeconomy, where conventional and advanced biofuels play a major role. Dedicated sectors capture the production of bioethanol from sugar cane/beet, wheat, maize, other grains and agricultural residues as well as the production of biodiesel from palm oil, soybean oil, rapeseed oil other oilseed oils, and used cooking oil (UCO). Moreover, the database features explicit sectors for various by-products of biofuel processing and the joint production of vegetable oils and meals in the vegetable oil industry: this includes the by-products of bioethanol production from grains, i.e. dried distillers grains with solubles (DDGS), as well as oilseed meals/cakes which are co-produced during the processing of vegetable oils.

Since biofuel targets in most regions apply to renewable energy use in the transport sector, the database also includes dedicated sectors for motor gasoline and motor diesel.

Table 3 shows the number of primary factors in the database. For labor, capital and natural resources, we keep the same disaggregation as in the standard GTAP database. In order to capture land use change in detail, the DART-BIO database features the 18 disaggregated land types of the GTAP-AEZ (agro-ecological zone) framework, which cover 18 agro-ecological zones that differ with respect to the length of growing period (LGP) and climatic zone (see Table 4). This allows to incorporate land heterogeneity as well as to allocate land to different uses (i.e. cropland, pasture and forest) via a CET structure within each AEZ and region.

***Table 2:*** **Sectors in DARTBIO**

| **Agricultural related products (29)** | | **Energy products (14)** | |
|---|---|---|---|
| Crops | | COL | Coal |
| PDR | Paddy rice | CRU | Oil |
| WHT | Wheat | GAS | Gas |
| *MZE* | *Maize* | *MGAS* | *Motor gasoline* |
| GRON | Other cereal grains | *MDIE* | *Motor diesel* |
| *PLM* | *Oil Palm fruit* | OIL | Petroleum and coal products |
| *RSD* | *Rapeseed* | ELY | Electricity |
| *SOY* | *Soy bean* | _ETHW*_ | *Bioethanol from wheat* |
| OSDN | Other oil seeds | _ETHM*_ | *Bioethanol from maize* |
| C_B | Sugar cane and sugar beet | _ETHG*_ | *Bioethanol from other grains* |
| AGR | Rest of crops | *ETHS* | *Bioethanol from sugar cane* |
| *STR* | *Agricultural residues* | *ETHC* | *Cellulosic Bioethanol from agricultural residues* |
| Processed agricultural products | | | |
| VOLN | Other vegetable oils | Biofuels | |
| SGR | Sugar | *BETH* | *Bioethanol* |
| FOD | Rest of food | *BDIE* | *Biodiesel from all other oilseeds* |
| _PLMoil*_ | *Palm oil* | *BDIE_PLM* | *Biodiesel from Palmoil* |
| _RSDoil*_ | *Rapeseed oil* | *UCOME* | *Biodiesel from used cooking oil* |
| _SOYoil*_ | *Soy bean oil* | | |
| _OSDNoil*_ | *Oil from other oil seeds* | **Non-energy products (3)** | |
| _SOYmeal*_ | *Soy bean meal* | CRPN | Other chemical rubber plastic products |
| _OSDNmeal*_ | *Meal from other oil seeds* | ETS | Paper, minerals and metals |
| _PLMmeal*_ | *Palm meal* | OTH | Other goods and services |
| _RSDmeal*_ | *Rapeseed meal* | | |
| _DDGSw*_ | *DDGS from wheat* | **Forest and forest products (2)** | |
| _DDGSm*_ | *DDGS from maize* | FRS | Forestry |
| _DDGSg*_ | *DDGS from other cereal grains* | FRI | Forest related industry |
| *UCO* | *Used cooking oil* | | |
| Meat and dairy products | | | |
| OLVS | Outdoor livestock and related animal products (cattle and other grazing animals, raw milk and wool) | | |
| ILVS | Indoor livestock (swine, poultry and other animal products from indoor livestock) | | |
| PCM | Processed animal products | | |

***Note*: New products are in cursive. All goods are produced by an analogous industry, except where indicated by an asterisk (*), which indicates 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 3*: Production factors in DART-BIO**

| Land: agro-ecological zones (18) | Other factors (3) | |
|---|---|---|
| AEZ1 | LAB | Labor |
| AEZ2 | CAP | Capital |
| AEZ3 | RES | Natural resources |
| AEZ4 | | |
| AEZ5 | | |
| AEZ6 | | |
| AEZ7 | | |
| AEZ8 | | |
| AEZ9 | | |
| AEZ10 | | |
| AEZ11 | | |
| AEZ12 | | |
| AEZ13 | | |
| AEZ14 | | |
| AEZ15 | | |
| AEZ16 | | |
| AEZ17 | | |
| AEZ18 | | |

***Table 4*: GTAP-AEZs**

| GTAP class | Moisture regime | Climate zone |
|---|---|---|
| AEZ1 | Arid | Tropical |
| AEZ7 | (LGP 0-59 days) | Temperate |
| AEZ13 | | Boreal |
| AEZ2 | Dry semi-arid | Tropical |
| AEZ8 | (LGP 60-119 days) | Temperate |
| AEZ14 | | Boreal |
| AEZ3 | Moist semi-arid | Tropical |
| AEZ9 | (LGP 120-179 days) | Temperate |
| AEZ15 | | Boreal |
| AEZ4 | Sub-humid | Tropical |
| AEZ10 | (LGP 180-239 days) | Temperate |
| AEZ16 | | Boreal |
| AEZ5 | Humid | Tropical |
| AEZ11 | (LGP 240-299 days) | Temperate |
| AEZ17 | | Boreal |
| AEZ6 | Humid; year-round growing season | Tropical |
| AEZ12 | (>300 days) | Temperate |
| AEZ18 | | Boreal |

***Source*: Monfreda et al., 2008. LGP stands for length of growing period.**

# 3 Construction of the DART-BIO database

We substantially extend the GTAP database to account for the most important sectors in the Bioeconomy. This is done by splitting large aggregated sectors using the software SplitCom[1] and developing specific code in GAMS in order to disaggregate output from one production activity into different commodities. All new sectors are introduced for the full regional and factor disaggregation of GTAP9 (140 regions, 18 primary factors) to ensure flexibility for different model aggregations.

Splitting and constructing new sectors requires data on production, consumption and trade. For the agricultural sector, most of this data comes from the 2011 data from the Statistics Division of the Food and Agriculture Organization (FAOSTAT)[2], while for the biofuel industry we rely on the world bioethanol and biofuel reports published by F.O.Licht[3] (F.O.Licht, 2015) and the Biofuel Annuals for different countries of the Global Agricultural Information Network (GAIN) from the United States Department of Agriculture (USDA) Foreign Agricultural Service (e.g. for Brazil GAIN 2017f) and the production costs for bioethanol and biofuels provided by the meó Consulting Team[4]. We also use other data sources for splitting specific sectors that are explained in more detail in the following

## 3.1 Maize (MZE)

Maize is an important feedstock for bioethanol production. Almost half of the world bioethanol is produced from maize in the USA. The United States Department of Agriculture (USDA 2021) estimates that in the last decade around 40% of the US maize is used in the bioethanol industry, raising concerns about its effect on food supply and food prices.

Maize in the standard GTAP database is part of the "cereal grains nec[5]" (GRO) sector which also includes (barley, millet, oats, rye, sorghum, and other cereals). For splitting maize from GRO we use 2010-2012 production, price, and bilateral trade data from FAOSTAT and calculate 3-years average values. Following Calzadilla et al. (2016), for each commodity in the GRO sector, we use producer price information to convert production in tonnes into USD (currency unit in GTAP database). While total production in USD of "cereal grains nec" in FAO and GTAP match in most of the regions, there are some differences in regions like China and Russia. These differences are compensated by using the FAO shares of maize production in total GRO production to split GRO into maize (MZE) and the rest of other cereal grains (GRON). The production technologies for the split sectors (MZE and GRON) are assumed to be identical to those in the original GTAP sector (GRO).

Similarly, we use bilateral trade data from FAO to compute trade shares of maize in total GRO trade for each bilateral trade flow. We assume that MZE and GRON have similar transportation costs,

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*[1] SplitCom is a Windows program which enables to split or disaggregate one of the sectors in the GTAP database into two or more new sectors [Horridge 2005]. It ensures that the new database will be balanced and that all accounting identities will be preserved. The user needs to provide consistent and as much detailed information as possible to get satisfactory results. The input data includes consumption, production technology, bilateral trade and taxes either in monetary terms or as shares for all the new sectors involved.*

*[2] Data is available through the following website: www.faostat.fao.org.*

*[3] F.O. Licht is a commodity analyst that report statistical data of a wide range of commodities including bioethanol and biodiesel (https://ihsmarkit.com/research-analysis/fo-licht-services-changing.html).*

*[4] meó Consulting Team is a company providing consulting services with a special focus on renewables sustainability and climate change (www.meo-consulting.com).*

*[5] Not elsewhere classified.*

tariffs, and export taxes or subsidies as the original GTAP GRO sector. Since there is no more detailed information available, the split of sales into the new two sectors to firms, households, the government, and exports as well as changes in stock are in proportion to the production shares and considering that total consumption of each new sector must be equal to domestic consumption plus imports minus exports. The resulting regional production of maize and other cereal grains is shown in Figure A1 in the appendix.

## 3.2 Oilseeds: palm fruit (PLM), rapeseed (RSD) and soybean (SOY)

Vegetable oil from oilseeds is the predominant biodiesel feedstock. While many oilseeds can be used to produce biofuels, we focus on oil palm fruit, rapeseed and soybean – the most commonly used energy crops for biodiesel.

The oilseed (OSD) sector in the original GTAP database is a broad sector containing all oilseeds and oleaginous fruits. Based on FAO data, we use 2010-2012 production and price information to compute the production shares of oil palm fruit (PLM), rapeseed (RSD) and soybean (SOY) in total oilseed crop production, and calculate 3-year averages. The “rest of oilseeds” (ODSN) includes olives, sesame seed, sunflower seed, mustard seed, groundnuts, coconuts including copra, and other oil crops. The calculated production shares are used to split the original GTAP OSD sector into PLM, RSD, SOY and OSDN. As in case of the MZE split, we assume that the production technologies in all new sectors in each country are similar as those in the original GTAP sector.

The original trade matrix in GTAP is split using trade shares for each bilateral trade flow. These trade shares are computed based on 2010-12 FAO data using 3-year averages. Transportation costs, tariffs, and export taxes or subsidies in the new split sectors are equivalent to the original GTAP OSD sector. As in the case of maize, the split of sales of the new sectors are in proportion to the production shares and considering that total consumption of each new sector must be equal to domestic consumption plus imports minus exports. The resulting regional production of oil palm fruit, rapeseed, soybean and other oilseeds is shown in the appendix, Figure A2.

## 3.3 Vegetable oils and meals (PLMoil, PLMmeal, RSDoil, RSDmeal, SOYoil, SOYmeal, OSDNoil, OSDNmeal)

Vegetable oils are the major feedstock in the biodiesel industry. Currently, about 75% of the globally produced biodiesel is based on the three vegetable oils: rapeseed oil (20%), soybean oil (25%), and palm oil (30%) (OECD-FAO 2021). Since the vegetable oil sector is highly relevant when modelling biofuel production, DART-BIO is designed to provide a detailed representation of this sector. A special attribute of the model is that it covers a vegetable oil sector for each oilseed crop used for biodiesel production (PLMoil, RSDoil, SOYoil, OSDNoil). This allows us to account for price and policy driven substitution effects between those oilseed oils. As a result, we can analyze feedback effects on agricultural markets and land use in the regions where the respective oilseed crops are produced.

A further important attribute of the DART-BIO model is that it considers the co-production of oilseed meals. Oilseed meals accrue after oilseed crushing, and thus are a byproduct in the oilseed oil production process. These meals are dominantly used as protein-rich animal feed. Via this mechanism, we can observe and account for the linkages between the consumption/production of animal products and biofuels. Table 5 shows the global average extraction shares of oilseed oils and meals from the oilseed processing industry. These are monetary value shares, and derived by combining country level production data from FAO with price data from USDA (2012) and IEA (2009)

***Table 5*: Global average extraction shares in the oilseed industry in per cent**

| Oilseeds | Oil | Meal |
|---|---|---|
| **Oil palm fruit** | 99.8 | 0.2 |
| **Rapeseed** | 77 | 23 |
| **Soybean** | 42 | 58 |
| **Other oilseeds** | 85 | 14 |

***Source*: DART-BIO, based on FAO data, USDA [2012] and IEA [2009].**
***Note*: Shares computed based on monetary terms.**

In the original GTAP 9 database, the oilseed oil and meal sectors are covered by the sector “vegetable oils and fats” (VOL). This sector includes all crude and refined oils (soybean, rape, coconut palm, palm kernel, olive, sunflower-seed and cotton-seed among others), animal or vegetable waxes, fats and oils; and their byproducts from the manufacturing process (cotton linters, oil-cake, flours, meals and other solid residues). We use this sector to split the individual oilseed oils, as well as a minor share of the oilseed meals. As elaborated in Calzadilla et al. (2016), most of the meals are located in the GTAP sector “food products nec” (OFD), so we split the main fraction of the oilseed meals from there.

In the splitting routine, the meals are first shifted from OFD to VOL, and in the next step all oil and meal sectors are separated from the VOL sector. The production structure of each new vegetable oil sector is similar to the original VOL cost shares, and we allow each oilseed industry to produce oils and meals jointly. Oilseeds that are not used for biofuel production are processed in the remainder of the VOL sector, called VOLN.

It needs to be noted that a fraction of palm fruit, rapeseed, soybean, and other oilseeds still enters the VOLN sector. The reason for this is that with the given data structure from the GTAP dataset, the oilseed crop production data from FAO and the production shares in the oilseed processing industry cannot be harmonized. The GTAP livestock sectors are not consuming enough meals to keep the real oilseed processing extraction shares. Thus, in case all oil production of the four individual oilseeds would only take place in the respective oilseed oil sector, the share of meals in the production process would be much to low, with strong regional variation. As the co-production is an important attribute of the DART-BIO model, we decided to keep the correct production shares, and to allow the oilseeds to also enter the VOLN sector.

Apart from the biodiesel sector, the oilseed oils are also consumed by other industries, households, and the government sector. Therefore, meals are exclusively consumed as animal feed by the livestock and fish sector. Both product groups are also traded internationally. Here, we exploit FAO bilateral trade data and price data from IAE and USDA to calculated the trade shares of the respective sectors in relation to the original VOL sector. It is assumed that the oil and meal products have the same transportation costs, tariffs, and export taxes or subsidies as the original GTAP VOL and OFD sectors.

The resulting regional production of oils and meals from palm, rapeseed, soybean and other oilseeds as well as other vegetable oils is shown in the appendix, Figure A3.

## 3.4 Motor gasoline and motor diesel (MGAS, MDIE)

Bioethanol and biodiesel are mainly used as road transport fuels. Since they can be blended with gasoline or diesel or used directly in slightly modified spark-ignition or compressed-ignition engines we display motor gasoline and motor diesel separately in the database. This allows us to assess the substitution between bioethanol and biodiesel with fossil fuel consumption.

The "petroleum, coal products" (P_C) sector in the original GTAP database includes coke oven products, refined petroleum products and processing of nuclear fuel. For splitting motor gasoline and motor diesel from P_C we use production data from the United Nations Energy Statistics Division, and price and trade data from COMTRADE.

The GTAP P_C sector corresponds to the following 16 energy classes from the United Nations Energy Statistics Database:

- Aviation gasoline
- Bitumen
- Lignite Brown Coal
- Coke Oven Coke
- Coke Oven Gas
- Gas Coke
- Gas Oil / Diesel Oil
- Gasoline-type jet fuel
- Other Kerosene
- Lubricants
- Motor Gasoline
- Naphtha
- Petroleum Coke
- Paraffin Waxes
- Fuel Oil
- White spirits and special boiling point industrial spirits

To calculate the value of production, prices from COMTRADE are used. The sum of production value of the 16 energy sectors is used to calculate the share of motor gasoline and diesel in total petroleum and coal product for the GTAP regions. Since the regions included in the GTAP database and the United Nation Energy Statistics do not fully match, we created a mapping to allocate regions to another.

The resulting production shares are used to split motor gasoline and diesel from the original P_C sector into MGAS, MDIE, and OIL. Following Calzadilla et al. (2016), we assume that the production technology in all new sectors are similar to the original P_C sector in GTAP.

Similarly, we use bilateral trade and price data from COMTRADE to compute trade shares of motor gasoline and motor diesel in total P_C trade for each bilateral trade flow. Again, following Calzadilla et al. (2016), we assume that MGAS, MDIE and OIL have similar transportation costs and taxes/subsides as the original GTAP P_C sector.

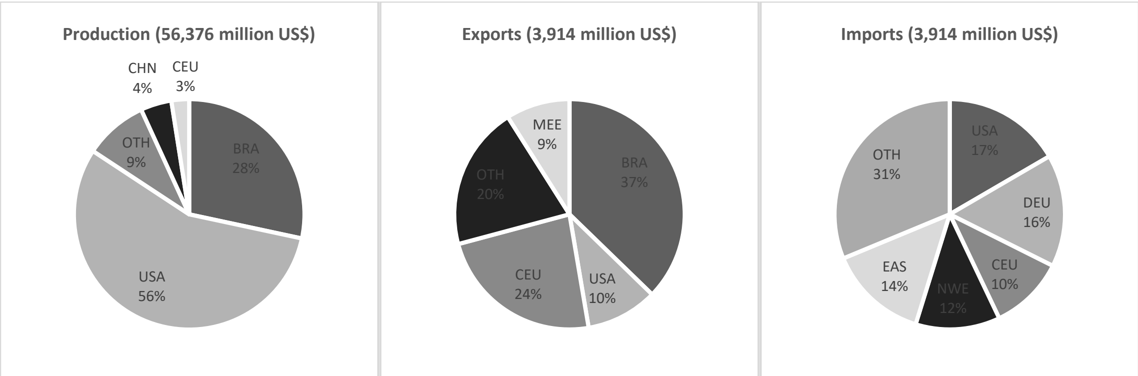
The energy data from the United Nations Statistics Division allows to distinguish between household and industry consumption of MGAS, MDIE and OIL. Government consumption and changes in stock are split using the production shares and considering total consumption of each new sector must be equal to domestic consumption plus imports minus exports. Since trade data from COMTRADE and data on production and consumption from the United Nations Statistic Divisions are not consistent, the splitting weights needed to be adapted in some cases to result in a balanced SAM.

## 3.5 Bioethanol (ETHs, ETHm, ETHw, ETHg, ETHc, BETH)

The original GTAP9 database does not feature individual biofuel sectors, but bioethanol is included in the aggregate chemical sector. Since we want to capture ethanol from different feedstock types such as maize and sugarcane, we split different bioethanol types from the different aggregated sectors (e.g. processed food and chemical sectors) with respect to bioethanol output, consumption and trade using data from a variety of sources as explained below. We then feed this data into the software SPLITCOM that employs cross entropy methods in order to rebalance the newly disaggregated national and global social accounting matrices (SAM). To establish our database for ethanol disaggregation, we collected information on production, exports, imports and domestic consumption of bioethanol in physical units for all GTAP regions. This data comes from the world bioethanol and biofuel reports by F.O.Licht (F.O. Licht, 2015). We then use information on market prices from F.O.Licht and international markets (UNICA, 2013; Platts Futures Rotterdam and personal communication with the meó Consulting Team) to arrive at bioethanol production and trade values in US$ with a global average prices of 0.67 US$ per litre in 2011.[6]

We begin by constructing the trade matrix for ethanol to split ethanol trade from aggregate trade values in the aggregated sectors. Since we found that several countries are re-exporters of ethanol, we subtracted these re-exports from the database to avoid double counting. In Figure 1 below, we have listed the 5 largest producers, exporters and importers of bioethanol. The USA and Brazil are the largest producers of ethanol with 84% of global production. Whereas Brazilian ethanol is based on sugarcane, US ethanol is produced from maize/corn. In CEU, ethanol is produced from both wheat and maize, whereas China produces ethanol from maize only. All other regions produce only relatively small values. While Brazil is the largest exporter, US ethanol is mainly consumed domestically. France ("CEU") and Middle European countries ("MEE") also export a large share of their ethanol production. In terms of imports, EU countries account for the largest share, which also reflects relatively large intra-European trade. Overall, trade of ethanol is relatively small as only 7% of production is traded.

***Figure 1*: Top 5 producers, exporters and importers of bioethanol (2011)**




***Source*: DART-BIO. Note: For abbreviations see table 1.**

[6] The global average price for bioethanol is based on a weighted average of prices for Asia (1.07 $/liter), Europe (0.81 $/liter), North America (0.61 $/liter) and Latin America (0.70 $/liter).

Interestingly, the US is both the largest producer and the largest importer of ethanol. This is because US regulations with respect to biofuel mandates distinguish between ethanol made from sugarcane and ethanol from maize. As sugarcane-ethanol is classified as an advanced type of biofuel that receives higher blending credits compared to ordinary renewable ethanol made from maize (EPA, 2021), it is lucrative to import Brazilian sugarcane-ethanol to fulfil the US biofuel mandates.

In a second step, we build a production matrix for all GTAP regions to disaggregate the correct ethanol processing technology from the input-output vectors of the aggregated sectors. Our ethanol input-output vectors are based on cost estimates by the meó Consulting Team and can be found in Table 6 below. Our database contains four different production technologies depending on the type of feedstock from which ethanol is made: i) bioethanol from sugar cane/beet for all countries except Brazil; ii) bioethanol from sugarcane produced in Brazil; and iii) bioethanol from cereal grains (i.e. wheat, maize and other grains), iv) bioethanol from agricultural residues in all countries. To match the correct production technology in terms of feedstock for each country, we collected data on which ethanol feedstocks are used in which regions. Most of this information is based on country level Biofuels Market Outlooks by the USDA foreign agricultural service. A list of sources is provided in the appendix A in Table A7. We then multiply the respective feedstock shares and the respective production technology with the ethanol output values from F.O.Licht to arrive at the correct input-output vector for each region.

***Table 6*: Input-Output shares of bioethanol processing from different feedstock**

| | Feedstock type | | | |
|---|---|---|---|---|
| | Sugar cane/beet | Sugarcane Brazil | Cereal grains | Agricultural residues |
| Feedstock | 0.58 | 0.56 | 0.62 | 0.33 |
| Other inputs | 0.03 | 0.03 | 0.00 | 0.20 |
| Energy | 0.15 | 0.17 | 0.15 | 0.04 |
| Capital | 0.20 | 0.22 | 0.20 | 0.37 |
| Labour | 0.03 | 0.02 | 0.03 | 0.06 |

***Source*: Production technology in DART-BIO. Based on meó Consulting Team. Technology for ethanol form agricultural residues, i.e. lignocellulosic biomass from Sassner et al., 2008**

A central feature of our biofuel database is that we explicitly consider by-products of ethanol industry in terms of dried distiller grains and solubles (DDGS), which are used as inputs in the livestock industry. This way, we can capture the linkages between biofuel production and livestock feed. On average, the processing of a bushel of maize into ethanol yields 2.7 gallons of ethanol and 17.5 pounds of distillers spent grains (ERS-USDA, 2010). Based on this information we calculate the output of DDGS from ethanol produced from grain feedstocks. Estimations by the meó Consulting Team show that the sale of DDGS yields about 0.16 US$ per liter of ethanol. We multiply this price with the ethanol/DDGS shares and arrive at an average share of 70% bioethanol vis-à-vis 30% share of DDGS in terms of output value in the grain-ethanol industry as shown in Table 7: Global average extraction shares of ethanol and byproducts in the bioethanol industry (%). below.

As mentioned above, the new ethanol sectors need to be split from aggregated GTAP sectors. In the case of ethanol produced from grains, this is straightforward as all grain ethanol production and trade is included in the processed food sector “OFD”. Splitting ethanol produced from sugar crops is a bit trickier since input-output tables of the national SAMs are based on national accounts that classify ethanol under different headers depending on the country. For most countries, we can split production of ethanol based on sugarcane/beet from the GTAP sugar sector "SGR". Trade of sugar-based ethanol on the under hand is included in the "B_T" (beverages and tobacco products) sector in GTAP, so that we split our ethanol trade matrix from this sector.

***Table 7*: Global average extraction shares of ethanol and byproducts in the bioethanol industry (%).**

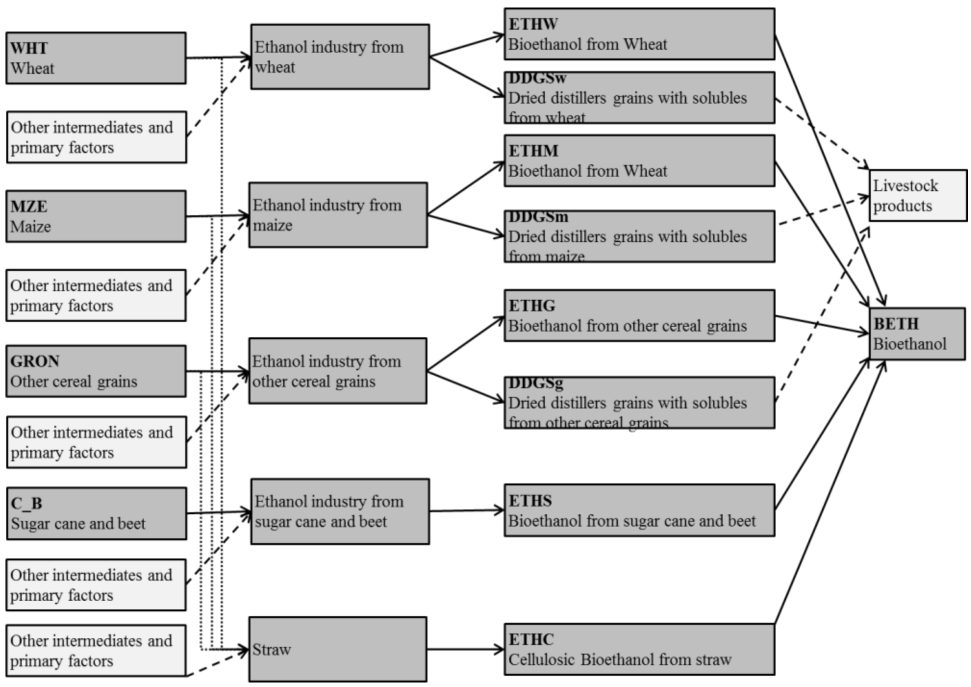
| Cereal grains | Bioethanol | DDGS |
|---|---|---|
| Maize | 71 | 29 |
| Wheat | 70 | 30 |
| Other grains | 69 | 31 |

***Source*: DART-BIO.**
***Note*: Shares computed based on monetary terms.**

There are several exceptions from this rule. Especially in Brazil, the SGR sector alone does not account for Brazil's enormous ethanol production, as ethanol is also listed under the "CRP" (chemical, rubber, plastic products) and the "B_T" sectors in GTAP. Similarly, for Australia, Indonesia, Ecuador, Guatemala and Mexico, we have to split sugar-based ethanol from "B_T". For Ecuador, we also have to split additional ethanol output from the "RMK" (raw milk) sector and for Korea form "OFD".

Finally, we take our trade and production matrices to subtract four bioethanol sectors from the just described aggregated sectors (*ETHs – sugar-based ethanol, ETHm - maize-based ethanol, ETHw-wheat-based ethanol, ETHg - other grain-based ethanol)*. In the model, we also add ethanol produced from lignocellulosic biomass (*ETHC*) as a latent technology using the technology from Sassner et al. (2008). We calibrate the producer subsidies paid to ethanol sectors to reflect the observed market shares in 2011. Other tariffs, taxes and transport margins are added according to the shares in the aggregated GTAP sectors.

***Figure* 2: Scheme of bioethanol production in DART-BIO.**



In addition, we add an aggregated ethanol blending sector (ETH) that collects the ethanol from all feedstock types. This blended ethanol is then consumed by households and traded at international markets. Figure 2 visualizes this structure and the input-output linkages along the ethanol value chain. Given the relative low value of DDGS, we assume that DDGS is mostly sold and consumed domestically by the indoor and outdoor livestock industry. However, the USA is a major exporter of DDGS and we therefore allow for US DDGS to be exported (Calzadilla et al., 2016).

## 3.6 Biodiesel (BDIE_PLM, UCOME, BDIE)

In contrast to bioethanol, where we only have one sector, three biodiesel sectors are generated: BDIE, BDIE_PLM and UCOME. BDIE covers biodiesel based on rapeseed oil, soybean oil and other oilseed oil; BDIE_PLM only includes palm oil biodiesel; and UCOME represents biodiesel produced from used cooking oil (UCO). We distinguish between those three sectors to be able to replicate the biofuel policies in the renewable energy directive (RED II) of the European Union. According to the high-ILUC risk criterium formulated in the RED II, the EU will phase-out the use of palm oil-based biodiesel until 2030 (European Union, 2019). To be able to model this policy, palm oil-based biodiesel needs to be represented in an individual sector. Moreover, UCOME is treated differently than conventional biodiesel in the RED II and consequentially also modeled explicitly.

***Table 8*: Production costs of biodiesel industries.**

| | Biodiesel from vegetable oils |
|---|---|
| Feedstock | 0.69 |
| Energy | 0.04 |
| Capital | 0.26 |
| Labor | 0.01 |

***Source*: DART-BIO, based on FAO data, USDA [2012] and IEA [2009].**
***Note*: Shares computed based on monetary terms.**

The biodiesel database is built on production, consumption and trade data from F.O. Licht (2015). As the F.O. Licht data is provided in quantity terms, we weight it with market prices to receive monetary values. The here used global market prices is 100 USD cent/l, which is the weighted average of the 2011 market price in Brazil (97 USD cent/l), the USA (117 USD cent/l) Germany (98 USD cent/l), and Asia (95 USD cent/l). Price information is also provided by F.O. Licht (2015).

A special attribute of the DART model is that biodiesel is produced from vegetable oils, and not directly from oilseed crops, as implemented by other models. Therefore, we can make use of the detailed representation of the vegetable oil industry, as elaborated in the section above and shown in Figure 3. The production cost shares for the biodiesel industry are estimates of the meó Consulting Team (Table 8). We apply the same cost shares for each region and biofuel feedstock.

Following Calzadilla et al (2016), we use two sectors to split production and trade of biodiesel from the GTAP database: the “food products nec” (OFD) sector is used for European countries and the “vegetable oil” (VOL) is used for the rest of the countries. Special cases are USA, Argentina and some Asian countries. Here it is assumed that different biodiesel feedstocks are captured in different sectors. As a result, for these countries we split production and trade from VOL and OFD. Biodiesel is consumed by households and traded at international markets. Transportation costs, tariffs, and export taxes/subsidies for the biodiesel sectors are assumed to be likewise to those in the original embedded

GTAP sectors. Figure 4 displays the regions with the highest production, imports and exports of biodiesel and palm-based biodiesel combined in 2011. The biggest producer for biodiesel is the USA, followed by European countries. There is strong trade of biodiesel within European regions and central Europe is a major region for imports as well as exports. Germany is the biggest exporter of biodiesel because its production capacity is much larger than domestic demand.

***Figure 3*: Scheme of biodiesel production in DART-BIO.**

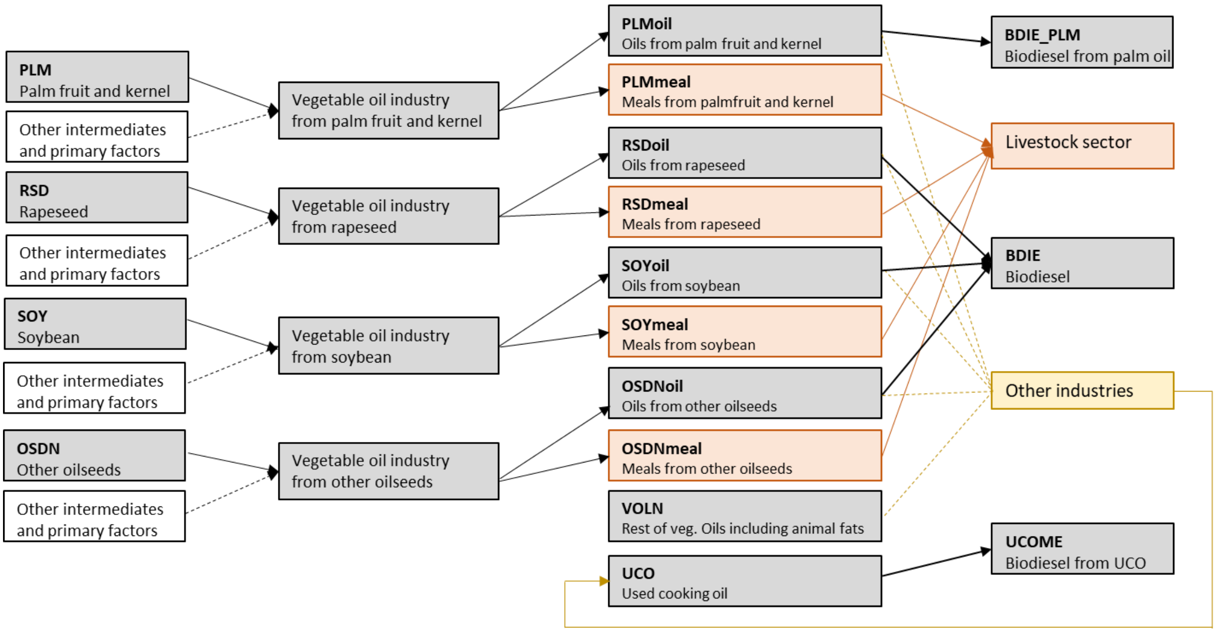
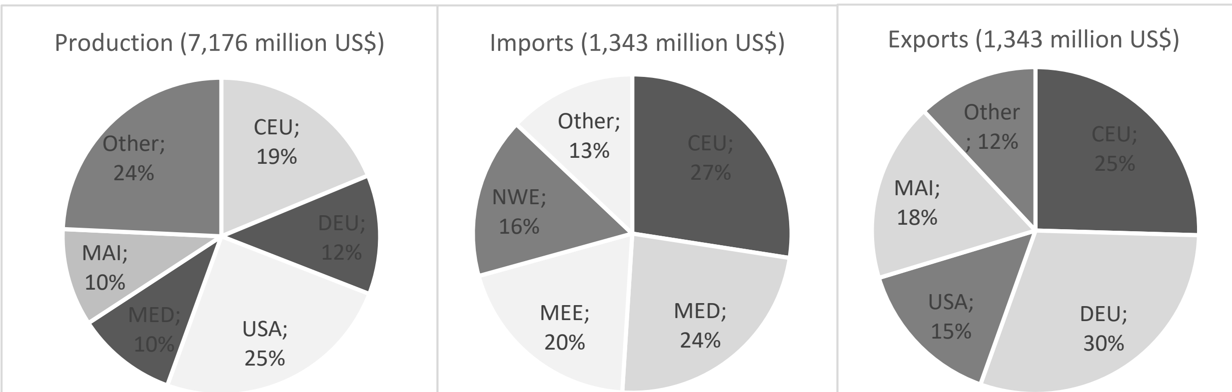



***Figure* 4: Top 5 producers, exporters and importers of biodiesel (2011)**




**Source: DART-BIO. Note: For abbreviations see Table 1.**

## 3.7 Uco and UCOME

UCO is the major feedstock for biofuel production in China, Japan and Korea (GAIN 2017a, GAIN 2017b). Other countries with high shares of UCOME (used cooking oil methyl esther biodiesel based on UCO) in their biofuel production portfolios are India and Canada (GAIN 2017c, GAIN 2017d). In the EU, UCO contributed to almost 20% of biodiesel production in 2017 (GAIN 2017a), after introducing double counting of the contribution of so-called “advanced” biofuels (including UCO) towards the 10 percent biofuel target of energy used in the transportation sector until 2020 in some of the EU countries (European Union, 2015)

The production pathway for UCO consist mainly of the collection and recycling of used oils and fats used for cooking and frying in hotels, restaurants, the food industry but also in private households (Tsoutsos and Stavroula 2013). Depending on the local cooking habits, UCO originates from both vegetable and animal fats and oils. It is estimated that around 2011 about 90% of cooking oils and fats used in the EU are produced from vegetable oils (Peters et al. 2013).

The splitting of UCO and UCOME is closely related to the splitting of other biodiesel. We first determine the overall amount of UCOME production in each region by multiplying the overall biodiesel production with the market share of UCOME, which we collect from various sources (e.g. GAIN reports). The amount of UCO needed for the resulting UCOME production is determined via the cost share of UCO in UCOME production. In order to calculate this share, we first derive the average cost shares of energy, labor and capital inputs in line with biodiesel production from other feedstocks. These cost shares are based on estimates on the general production costs of the biodiesel industry made by the meó Consulting Team and result in an average cost share of 74% of UCO in UCOME production.

For production of UCOME outside the EU, we assume that only domestically collected UCO is used for UCOME production. The double counting mechanism strongly increased the demand for UCO in the EU, and therefore triggered imports of UCO for UCOME production. Thus, for the EU countries we assume an import share of minimum 58% (Greenea, 2016). Trade shares of non-EU countries in imports of EU countries are based on trade under the HS Code 15180095 (Harmonized System Code: Inedible mixtures or preparations of animal or of animal and vegetable fats and oils and their fractions) and expert knowledge of the meó Consulting Team. In the final data set, non-EU countries produce UCO for their own UCOME production (if any) and for exporting to the EU. EU member states produce UCOME both from domestic collection of UCO, and from importing UCO from non-EU states. The possible surplus of domestic UCO collection in the EU member states is consumed by the domestic chemical sector.

We split the production and trade of UCOME as well as the trade of UCO (HS Code 1518 ISIC 242) from the GTAP CRP (chemical rubber products) sector. Depending on the analysis, in the final dataset, UCOME is aggregated to the biodiesel sector BDIE or kept as a separate sector.

In line with the International Standard Industrial Classification (ISIC) sectors, we split production of UCO from GTAP OSG. Since UCO is collected from hotels and restaurants as well as from food production we assume a production technology that includes the GTAP sectors TRD (trade including hotels and restaurants), OFD (other food) and OTP (other transport) as intermediate inputs. Due to lacking information about actual cost shares in UCO production technology, we assume that the cost shares of these inputs are the proportional cost share in the original OSG sector.

# 4 The theoretical structure of the DART-BIO model

DART-BIO is a classical CGE model based on Walrasian general equilibrium theory. A large number of linear and non-linear equations depict the economic behavior of representative consumers and producers. Closure rules govern the equilibrium on all markets and ensure macroeconomic consistency of individual decisions. Equations are calibrated to our above described empirical database.

The economy of each region underlies the assumption of a competitive economy with flexible prices and market clearing conditions. The DART model is a single agent model, in which the agent simultaneously represents the utility maximizing consumer, the profit maximizing producer, and the regional government. Thereby, the production within the sectors faces constant returns to scale, and follows a multi-level nested constant elasticity of substitution (CES) system as elaborated in the next section. Goods are consumed by governments, domestic households, the export market, the investment sector, and other industries. Households generate income by providing labor, land and capital to the production industries. Thereby perfect competitive factor markets and full employment are assumed. A fixed share of the income of each time period is saved and invested into the production sectors, while the rest is spent on goods to maximize utility. Tax revenues allow the government to finance the provision of public goods. Governments regulate trade by imposing import tariffs and dispensing export subsidies. Regions interact economically by bilateral trade following the Armington assumption. This means that domestic and imported goods are considered to be imperfect substitutes distinguished by country of origin. The Armington elasticities for bilateral trade and the regional preferences for imported and domestic goods are displayed in tables A5 and A6 in the appendix. The next subsections provide a detailed description of production and consumption within the DART-BIO model.

## 4.1 Production and Trade

The production structure in DART-BIO is based on a multi-level nested CES system. **Fehler! Verweisquelle konnte nicht gefunden werden.** displays the general nesting of the production structure for the sectors in the DART-BIO model. Table 9 shows the corresponding elasticities for the CES functions. If there is no elasticity indicated for a sector in the table, then this sector does not include that particular production nest. For instance, the production of most of the sectors is only based on intermediate inputs and the production factors (KLE: Capital, Labor, Energy). In general, producers maximize their profits for a given output at constant returns to scale. Via the constant elasticity of transformation (CET) the output can be sold on the domestic or export market (σ=2). On the production side, we have a linear Leontief function (σ=0) in the top nest prohibiting substitution between production factors (KLE/KLLE/KLLEF: Capital, Labor, Energy, Land, Feed) and intermediate inputs. The intermediate inputs reflect the Armington aggregate of non-energy inputs from domestic production and imports. In most cases the intermediate inputs are nested in a Leontief function. An exemption is the production of biodiesel and bioethanol. For biodiesel, the different vegetable oils are aggregated via a CES (σ=10) function to allow for substitution between the three vegetable oil types. The same is assumed for the different types of bioethanol in the bioethanol production aggregate. The production factors (KLE) are modeled as a value-added-energy composite. While we have a Cobb-Douglas function for the value-added Capital and Labor nest, a CES function with σ=0.5 is implemented for the value-added-energy nest.

For the agricultural sectors, land enters the production structure as additional production factor. The CES elasticity *ld* depends on the type of agricultural product. In the livestock production structure, additionally the feed composite is nested directly with the production factors. The reason is that the production factor land is used as pasture livestock and is therefore a substitute for animal feed. While the animal feed composite is nested with a CES of σ=2, animal feed and the production factors are nested with a CES of σ=0.2. Thus, the KLLE nest exists exclusively for agricultural commodities, and KLLEF only for livestock.

***Figure 5*: General nesting of sectoral production structure in the DART-BIO model.**

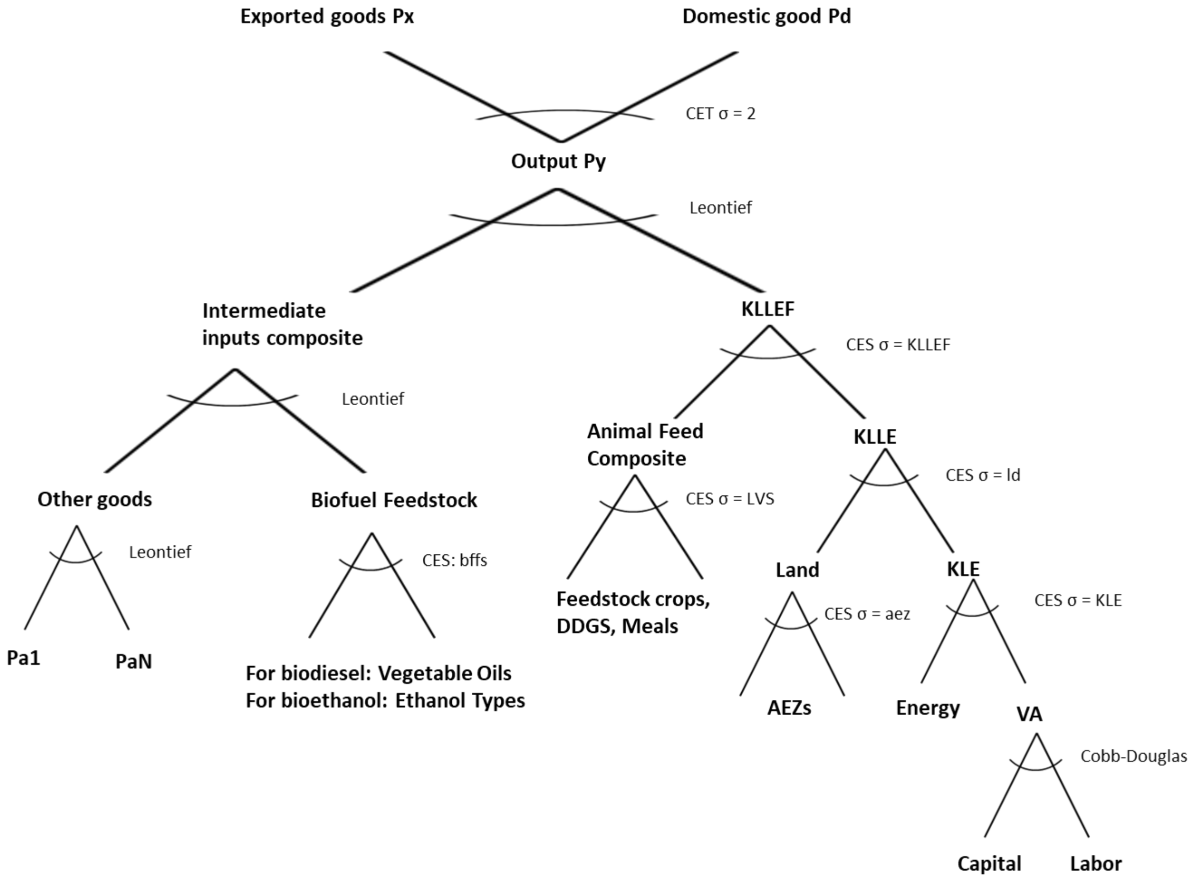


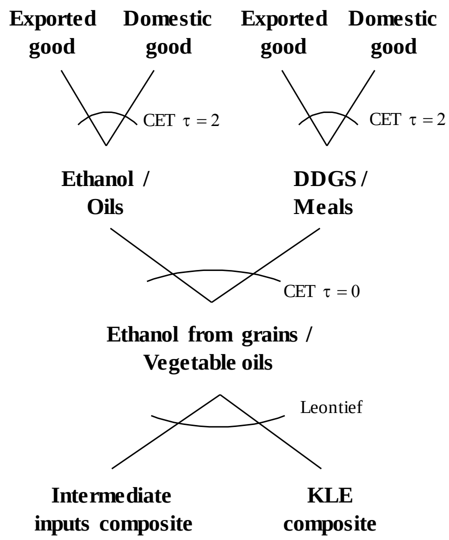

***Table 9*: CES elasticities**

| Sector \ Elasticity | VA | KLE | ld | aez | lvs* | bffs** | res*** |
|---|---|---|---|---|---|---|---|
| Annual Crops | 1 | 0.5 | 0.25 | 5 | - | - | - |
| Paddy Rice | 1 | 0.5 | 0.25 - 0.3 | 5 | - | - | - |
| Perennial Crops | 1 | 0.5 | 0.25 - 0.3 | 5 | - | - | - |
| Forest | 1 | 0.5 | 0.8 | 5 | - | - | - |
| Livestock | 1 | 0.5 | 0.25 | 5 | 2 | | |
| Liquid Biofuels | 1 | 0.5 | - | - | - | 10 | - |
| Electricity | 1 | 0.1 | - | - | - | - | - |
| Non-Electric Energy | 1 | 0 | - | - | - | - | ESUB_ES |
| All Other Sectors | 1 | 0.5 | - | - | - | - | - |

* Elasticity for livestock feed
**Elasticitiy for biofuel feedstock. For initial feedstock shares see Table A1 and Table A2.
*** Natural resource for fossil energy production. Nested in the highest nest with the composite of primary factors and intermediate inputs. For values of ESUB_ES, see Table A3 in appendix.

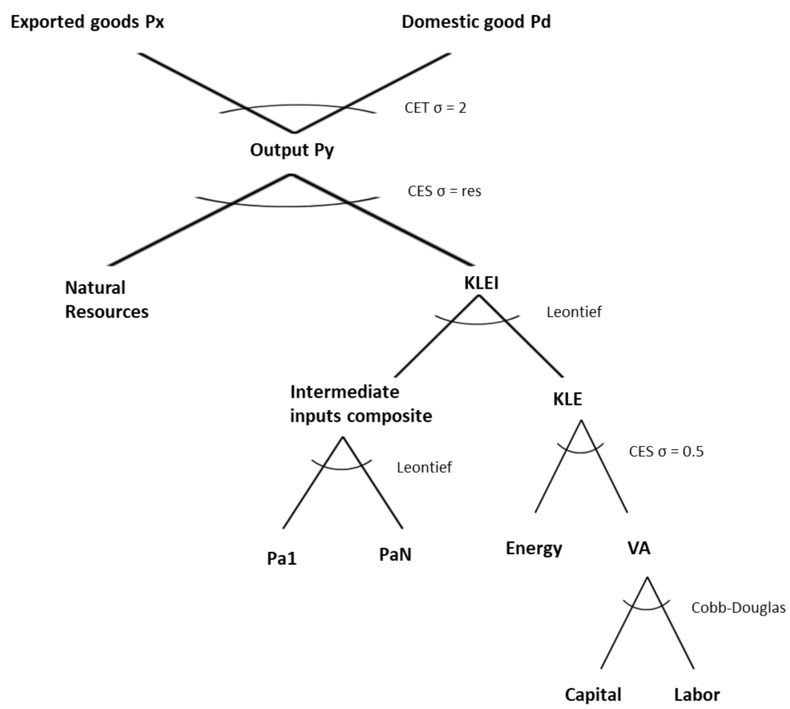
As highlighted in the section above, bioethanol and DDGS, as well as oilseed oil and meals respectively, are produced jointly within one production process. Thus, an additional nest that separates the jointly produced products is added to the upper part of the production structure. This is displayed in Figure 6. First, the joined production is separated at fixed shares by a CET function (τ=0), before they are distributed to domestic and export markets via a second CET function (τ=2). The DDGS and oilseed meals are exclusively used as animal feed in the livestock and fish production.

***Figure 6*: Nesting of by-products in the vegetable oil and ethanol industry**




Another special case is the production of non-electric energy goods. These goods require natural resources in their production process. They are nested with the composite of intermediate inputs and KLE in the highest nest of the production structure, as displayed in Figure 7.

***Figure 7*: Nesting of non-electricity energy production.**



As already mentioned above, trade takes place under the Armington assumption of imperfect substitution between domestic and imported commodities. This imperfect substitution is governed by two CES functions according to two types of Armington elasticities that are provided with the GTAP database, respectively. We call the elasticity that governs substitution between imports and domestic products regardless of the origin of the imports "ARMEL" (see Table A6) and the elasticity that governs substitution between imports from different regions "ARMREG" (see Table A5). Hertel and van der Mensbrugghe (2016) give an overview over these elasticities and their origin. In general, the substitution elasticity between imports of different origins is always double the substitution elasticity between imports domestic production following the Jomini et al. (1991)

## 4.2 Consumption

Households maximize their utility subject to their budget constraint, by purchasing various goods and save a share of income according to an exogenous savings rate. The saving rate is provided by the OECD and differs across countries (OECD, 2018c).

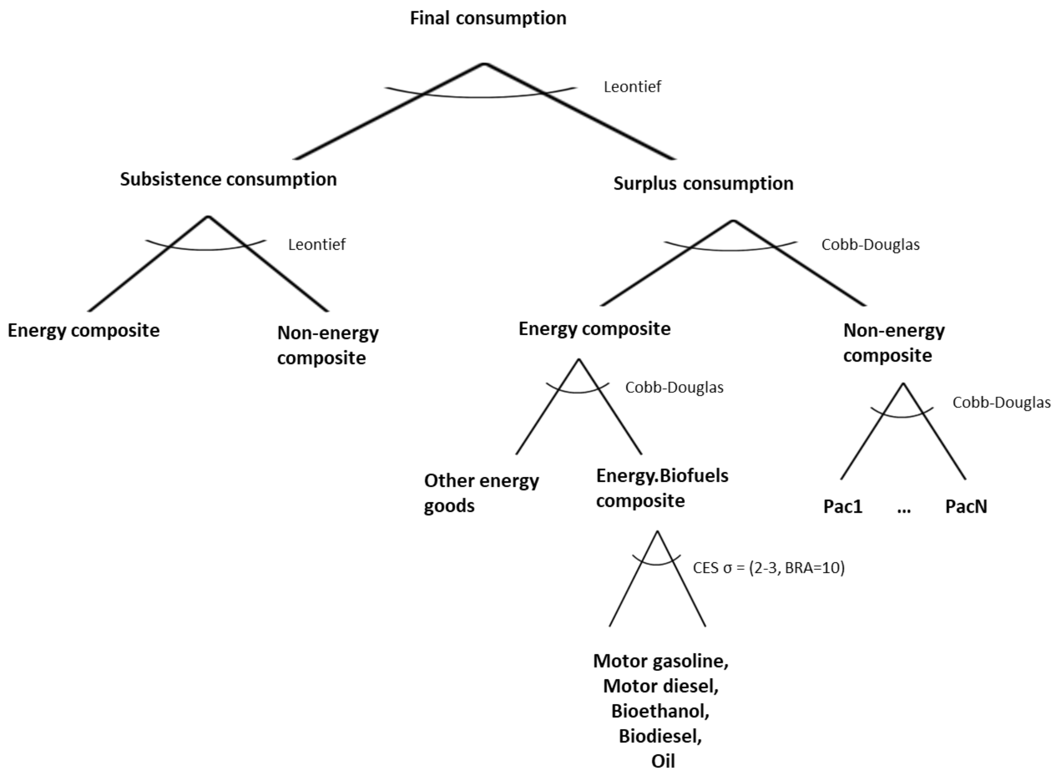
Private consumption is modelled by implementing a linear expenditure system (LES) based on a Stone-Geary utility function (Stone, 1954; Dervis et al., 1982) that is calibrated to empirical income elasticities of demand for each sector from Hertel and van der Mensbrugghe (2016), see Table A4 in the appendix. The LES accounts for two types of consumption: subsistence and surplus (also called supernumerary) consumption. Private consumers spend a fixed share of their income on a subsistence quantity for each good and allocate their supernumerary income to different commodities according to fixed marginal budget shares (product of average budget shares and income elasticities). It is this division of total consumption into the two parts that ensures non-homothetic preferences and enables calibration to non-unitary income elasticities. We calibrate the subsistence quantities using a transformation by Dellink (2005): the subsistence quantities are calculated depending on the size of each commodity's income elasticity relative to the highest income elasticity in the total consumption bundle:

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

Equation (1) shows that the subsistence minima are independent of income and prices, but still influence how total demand reacts to price changes given that they are fixed. Because even though the supernumerary quantities of consumption are endogenous and allow for substitution between different commodities, they have unitary income elasticities (Dellink, 2005) and thus correspond to a Cobb Douglas function as shown in Figure 8 below. This also means that as the share of the subsistence quantities in total consumption approaches zero when income of households increases, the LES converges to a Cobb-Douglas system and approaches homothetic preferences. We avoid this problem in DART-BIO through scaling the subsistence quantities with population growth in each period following Van Der Mensbrugghe (2005).

In both the subsistence and the surplus consumption, we differentiate between an energy and a non-energy bundle. Subsistence consumption of the energy bundle is nested in fixed shares with the subsistence consumption of the other commodities. For the surplus consumption, the energy bundle is nested with a unitary substitution elasticity, i.e. a Cobb-Douglas function. The energy composite has a Cobb-Douglas function for nesting the energy-biofuel bundle with other energy goods, and a CES function with σ=2-3 within the energy-biofuel bundle. An exception is brazil because its extraordinary share of flexible fuel cars. Therefore, in this country we assume σ=10.

***Figure 8*: Final consumption in DART-BIO.**




## 4.3 Integration of land into the DART-BIO model

A feature of the DART-BIO model is that it integrates the GTAP-AEZ database as elaborated in section 1. Thereby, the model also accounts for different land types within the AEZs, which are forest land, pasture land, perennial crop land, and annual crop land. These land types are nested in a three-level CET function displayed in Figure 9. The elasticities of transformation indicate the mobility of land between the different types of use and are listed in Table 10: Elasticities of transformation. Perennial crop land and annual crop land are nested on one level, but with different prices for land. In contrast to other studies, such as Bouët et al. (2010) and Laborde and Valin (2012), we do not assume different land prices for annual crops, as farmers can alter their crop decision on a yearly basis. This is not the case for perennial crop land which is less mobile, and therefore faces different land prices.

***Figure 9*: Land transformation function in DART-BIO.**

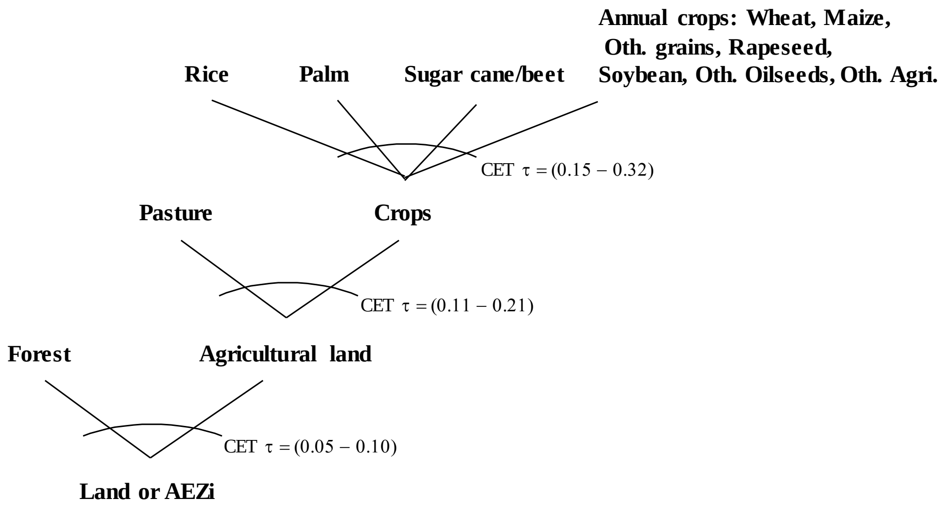



***Table 10*: Elasticities of transformation**

| | BRA | PAC | LAM | MEA | AFR | CHN | IND | EAS | MAI | ROA | RUS | FSU | CEU | DEU | MED | MEE | NWE | RNE | CAN | USA | ANZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CET1 | 0.05 | 0.05 | 0.1 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.1 | 0.05 |
| CET2 | 0.21 | 0.21 | 0.11 | 0.15 | 0.21 | 0.21 | 0.21 | 0.11 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 | 0.11 | 0.14 | 0.15 | 0.17 |
| CET3 | 0.22 | 0.22 | 0.3 | 0.24 | 0.4 | 0.22 | 0.22 | 0.15 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.15 | 0.32 | 0.32 | 0.3 |

***Source*: Abler (2000) and Salhofer (2000) as used in the OECD's PEM model.**

***Note*: Since the OECD model only covers developed countries plus Mexico, Turkey, and South Korea, we assume certain similarities for several countries. CET1 denotes the nest between forest and agricultural land, CET2 the nest between cropland and pasture land, CET3 the nest between land for different perennial and annual crops.**

## 4.4 Integration of GHG emissions and climate policies into the DART-BIO model

The GTAP database on $CO_2$ (Lee, 2008; Aguiar, 2016) and non-$CO_2$ (Chepeliev, 2020) emissions are introduced into the model. Thus, DART-BIO includes both $CO_2$ and non-$CO_2$ emissions with respect to input use of fossil fuels and chemicals in production and final consumption, with respect to non-$CO_2$ emissions of land input and livestock input (treated as capital input in the GTAP database) as well as output related non-$CO_2$ emissions in several sectors, e.g. fossil fuel production, livestock production and chemicals. In contrast to the original GTAP database, we do not differentiate between $CO_2$ emissions of imported and domestic fossil fuel inputs and summarize all non-$CO_2$ gases. For the splitted sectors, intermediate input and land use related $CO_2$ and non-$CO_2$ emissions are splitted according to the value shares of intermediate and land inputs allocated to the splitted sectors. In the production function, $CO_2$ and non-$CO_2$ emissions associated with input use are linked in a sub-level nest in fixed terms to input quantities. Output related non- $CO_2$ emissions are introduced to the production function by adding a top-level nest with the non-$CO_2$ emissions quantities with an elasticity of substitution of zero. The price per unit of emissions is endogenous to the model. Related climate policies that set emission reduction targets can be introduced in a scenario to DART-BIO by limiting the amount of emission allowances. The model is flexible with respect to the sectors, sources of emissions and regions included into such cap and trade system.

### 4.5 Dynamics and calibration

DART-BIO is a recursive-dynamic model. Recursive-dynamic means that it solves for a sequence of static one-period equilibria covering all future time periods. The consecutive equilibria are linked via capital accumulation and changes in labor supply.

Labor supply depends on changes in the labor forces, the rate of labor productivity and the change in human capital accumulation. An increase of effective labor can be rooted in the growth of any of these three factors, but also by a combination of them. Changes in labor productivity are determined exogenously and differ by region. Labor productivity is used to calibrate the GDP of the model. Also, rates of human capital and the growth rates of the labor force are exogenous and differ regionally. They are taken from the PHOENIX model (Hilderink, 2000) and correspond to recent OECD projections. Population estimates, and thus population growth is also used from the OECD (OECD, 2018b).

The capital accumulation is driven by the savings rate and the gross rate of return on capital. The capital stock of each period is determined by investments and depreciation in the preceding period. Savings are equal to investments. Capital is allocated among sectors according to the intra-period optimization of firms. The savings rate is exogenous and provided by the OECD (OECD, 2018c). For a more detailed description of the general DART model see Springer (1998) and Klepper et al. (2003).

# REFERENCES


Abler, D.G. (2000) Elasticities of Substitution and Factor Supply in Canadian, Mexican and US Agriculture, Report to the Policy Evaluation Matrix (PEM) Project Group, OECD, Paris.

Aguiar, A., Narayanan, B. & McDougall, R., (2016). An Overview of the GTAP 9 Data Base. Journal of Global Economic Analysis, 1(1), pp. 181-208.

Baldos, U. L., (2017). Development of GTAP 9 Land Use and Land Cover Data Base for Years 2004, 2007 and 2011. GTAP Research Memorandum No. 30.

Bouët, A., Dimaranan, B. V. and Valin, H. (2010) Modeling the global trade and environmental impacts of biofuel policies, IFPRI Discussion Paper 01018, International Food Policy Institute, Washington DC.

Calzadilla, A., Delzeit, R. and Klepper, G. (2014) DART-BIO: Modelling the interplay of food, feed and fuels in a global CGE model, Kiel Working Paper 1896, Institute for the World Economy, Kiel.

Calzadilla, A., Delzeit, R. & Klepper, G., (2016). Assessing the Effects of Biofuel Quotas on Agricultural Markets. *World Scientific Reference on Natural Resources and Environmental Policy in the Era of Global Climate Change*, Volume 3, pp. 399-442. 10.1142/9789813208179_0013.

Chepeliev, M. (2020). Development of the Non-CO2 GHG Emissions Database for the GTAP 10A Data Base. GTAP Research Memorandum No. 32, May 2020 https://www.gtap.agecon.purdue.edu/resources/download/10041.pdf

COMTRADE, United Nations Comtrade Database, https://comtrade.un.org/.

Dellink, R., 2005. Modelling the Costs of Environmental Policy - A Dynamic Applied General Equilibrium Assessment. Edward Elgar, Cheltenham, Northhampton, MA.

Delzeit, R., Klepper, G., Zabel, F. & Mauser, W., (2018). Global economic-biophysical assessment of midterm scenarios for agricultural markets – biofuel policies, dietary patterns, cropland expansion, and productivity growth. Environmental Research Letters, Volume 13.

EPA, (2021). Overview for Renewable Fuel Standard. https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard; access date: 26.7.2021

European Union, (2015). Directive (EU) 2015/1513 of the European Parliament and of the Council of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (Text with EEA relevance). Official Journal of the European Union, L239/1 of 15.9.2015.

European Union, (2019). COMMISSION DELEGATED REGULATION (EU) 2019/807 of 13 March 2019 supplementing Directive (EU) 2018/2001 of the European Parliament and of the Council as regards the determination of high indirect land-use change-risk feedstock for which a significant expansion of the production area into land with high carbon stock is observed and the certification of low indirect land-use change-risk biofuels, bioliquids and biomass fuels. *Official Journal of the European Union*, L133/1 of 21.05.2019.

F.O. Licht (2015). https://ihsmarkit.com/research-analysis/fo-licht-services-changing.html.

FAOSTAT, Food and Agriculture Organization Corporate Statistical Database, http://faostat.fao.org/.

Global Agricultural Information Network (GAIN), (2017a). EU Biofuels Annual 2017. Gain Report Nr. NL7015. USDA Foreign Agriculture Service (USDA)

Global Agricultural Information Network (GAIN), (2017b). China Biofuels Annual 2017. Gain Report Nr. CH16067. USDA Foreign Agriculture Service (USDA)

Global Agricultural Information Network (GAIN), (2017c). Japan Biofuels Annual 2017. Gain Report Nr. A5022. USDA Foreign Agriculture Service (USDA)

Global Agricultural Information Network (GAIN), (2017d). India Biofuels Annual 2017. Gain Report Nr. IN7075. USDA Foreign Agriculture Service (USDA)

Global Agricultural Information Network (GAIN), (2017e). Canada Biofuels Annual 2017. Gain Report Nr. CA16038. USDA Foreign Agriculture Service (USDA)

Global Agricultural Information Network (GAIN), (2017f). Biofuels Annual – Brazil. GAIN Report Number BR17006, USDA Foreign Agricultural Service.

Greenea, (2016). Waste-based biodiesel market in 2016. Presentation on Biofuels International 2016 Conference. 20th – 22nd September 2016, Ghent, Belgium. Retrieved from https://www.greenea.com/wp-content/uploads/2016/09/Biofuels-International-2016.pdf

Hertel, T. and van der Mensbrugghe, D., 2016. Chapter 14: Behavioral Parameters, GTAP 9 Data Base Documentation, GTAP Resource #5138.

Hilderink, H.B.M. (2000) PHOENIX plus: the population user support system version 1.0, www.mnp.nl/phoenix.

Horridge, M. (2005) SplitCom - Programs to Disaggregate a GTAP Sector, Centre of Policy Studies, Monash University, Melbourne, Australia.

IEA (2009) A Global Overview of Vegetable Oils, with Reference to Biodiesel, A report of the IEA Bioenergy task 40.

Jomini, P., J.F. Zeitsch, R. McDougall, A. Welsh, S. Brown, J.Hambley and J. Kelly. 1991. SALTER: A General Equilibrium Model of the World Economy, Vol. 1. Model Structure, Data Base, and Parameters. Canberra, Australia: Industry Commission

Klepper, G., Peterson S. and Springer, K. (2003) DART97: A Description of the Multi-regional, Multi-sectoral Trade Model for the Analysis of Climate Policies, Kiel Working Paper 1149, Institute for the World Economy, Kiel.

Klepper, G. and Peterson, S. (2006a). Emissions Trading, CDM, JI and More - The Climate Strategy of the EU, *The Energy Journal*, 27(2), pp. 1-26.

Klepper, G. and Peterson, S. (2006b). Marginal Abatement Cost Curves in General Equilibrium, The Influence of World Energy Prices, *Resource and Energy Economics*, 28(1), pp. 1-23.

Kretschmer, B., Narita, D. and Peterson, S. (2009). The Economic Effects of the EU Biofuel Target, *Energy Economics*, 31, pp. 285-294.

Laborde, D. and Valin, H. (2012) Modelling Land Use Changes in a Global CGE: Assessing the EU biofuel mandates with the MIRAGE-BioF model, *Climate Change Economics*, 3(3) 1250017.

Lee, H. L. (2008). The combustion-based CO2 emissions data for GTAP Version 7 Data Base. Center for Global for Global Trade Analysis, Purdue University: West Lafayette.

Monfreda, C., Ramankutty, N., Hertel., T., (2008). Global Agricultural Land Use Data for Climate Change Analysis. GTAP Working Paper No. 40.

OECD, (2018a). GDP long-term forecast (indicator). doi: 10.1787/d927bc18-en (Accessed on 06 February 2020)

OECD, (2018b). Population projections. https://stats.oecd.org/index.aspx?r=3671b (Accessed on 06 February 2020)

OECD, (2018c). Saving rate. https://data.oecd.org/natincome/saving-rate.htm (Accessed on 06 February 2020)

OECD/FAO (2021), *OECD-FAO Agricultural Outlook 2021-2030*, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en.

Peters, D., Toop, G., van den Bos, A., & Spöttle, M., (2013). Assessing the EC ILUC proposal: "Dutch national impact assessment" Utrecht: ECOFYS.

Salhofer, K. (2000) Elasticities of Substitution and Factor Supply Elasticities in European Agriculture: A Review of Past Studies, Diskussionspapier Nr. 83-W-2000, Institut für Wirtschaft, Politik und Recht, Universität für Bodenkultur, Wien, Austria.

Sassner, P., Galbe, M., Zacchi, G., (2008). Techno-economic evaluation of bioethanol production from three different lignocellulosic materials. Biomass and Bioenergy. 32, 422–430.

Schuenemann, F., Delzeit, R., (2019). Higher Income and Higher Prices: The Role of Demand Specifications and Elasticities of Livestock Products for Global Land Use. *Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaues e.V.*, Bd. 64, 185-207.

Springer, K. (1998) The DART General Equilibrium Model: A Technical Description, Kiel Working Paper No. 883, Kiel Institute for the World Economy, Kiel.

Stone, R. (1954). Linear Expenditure Systems and Demand Analysis: An Application to the Pattern of British Demand, *Economic Journal*, 64, pp. 511-527.

Tsoutsos, T., & Stavroula T., (2013). Assessment of best practices in UCO processing and biodiesel distribution - D4.3 - Guide on UCO processing and biodiesel distribution methods. Greece: Technical

University of Crete, RecOil Project report (supported by the European Commission within the frame of the Intelligent Energy for Europe Programme)

UNICA (Sugarcane Industry Association) (2013) Preço final de faturamento do ATR por produto - Modelo Consecana-SP - valores médios para o Estado de São Paulo, UNICA, Departamento de economia y estatistica.

USDA (United States Department of Agriculture) (2012) Oilseeds: World Markets and Trade. Foreign Agricultural Services, circular series FOP 12-12.

USDA (United States Department of Agriculture) (2021) U.S. Bioenergy Statistics. https://www.ers.usda.gov/data-products/us-bioenergy-statistics/ (Accessed on 12 July 2021)

Van der Mensbrugghe, D. (2005). LINKAGE Technical Reference document: version 6.0. WorldBank Development Prospects Group, Washington.

Weitzel, M., Hübler, M. and Peterson, S. (2012): Fair, Optimal or Detrimental? Environmental vs. Strategic Use of Carbon-based Border Measures, *Energy Economics*, 34(2), pp. 198-207.

Zabel, F., Delzeit, R., Schneider, J.M., Seppelt, R., Mauser, W., Václavík, T., (2019). Global impacts of future cropland expansion and intensification on agricultural markets and biodiversity. Nature Communications 10:.2844.

# Appendix

***Table A1*: Bioethanol feedstock shares in domestic production in 2011. In Percent.**

| Region | Sugar | Wheat | Maize | Other Grains |
|---|---|---|---|---|
| BRA | 100 | | | |
| PAC | 48 | 2 | 50 | |
| LAM | 100 | | | |
| AFR | 100 | | | |
| CHN | | | 100 | |
| IND | 100 | | | |
| EAS | 100 | | | |
| MAI | 100 | | | |
| ROA | 100 | | | |
| CEU | 24 | 42 | 34 | |
| DEU | 15 | 31 | 34 | 20 |
| MED | | 17 | 83 | |
| MEE | 7 | 16 | 66 | 11 |
| NWE | 7 | 75 | 17 | 1 |
| RNE | | 40 | 30 | 30 |
| CAN | | 22 | 78 | |
| USA | | | 100 | |
| ANZ | 14 | 68 | | 18 |

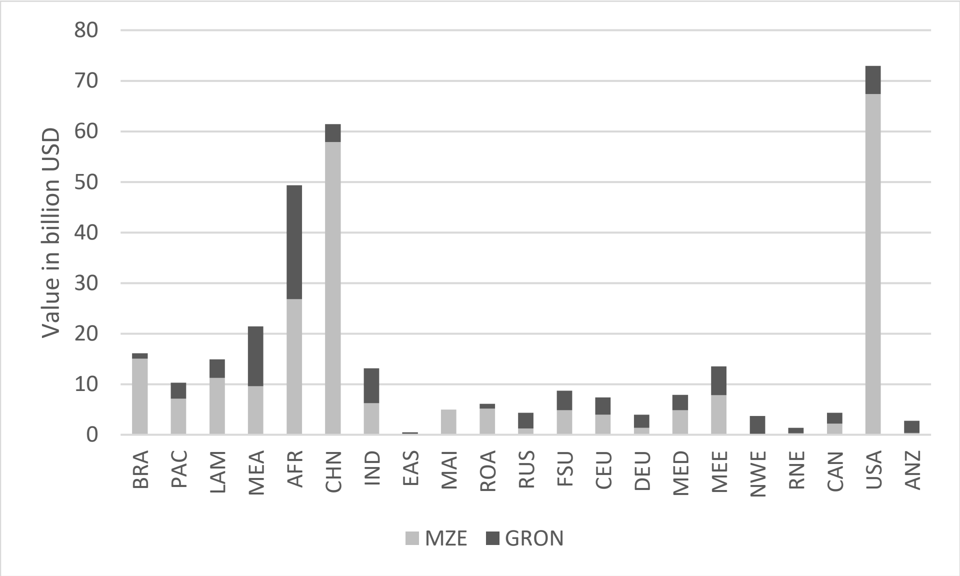
***Source*: See Table A8**

***Table A2*: Biodiesel feedstock shares in domestic production in 2011. In Percent.**

| Region | Rapeseed oil | Soybean oil | Other Oilseed Oil | Palm oil | UCO | Other feedstock |
|---|---|---|---|---|---|---|
| BRA | | 85 | 1 | | | 14 |
| PAC | | 99.5 | 0.5 | | | |
| LAM | | 1 | | 99 | | |
| AFR | | | 1 | | | |
| CHN | | | | | 1 | |
| IND | | | 61 | | 39 | |
| EAS | | 31 | | 26 | 43 | |
| MAI | | | | 100 | | |
| ROA | | | 43 | 57 | | |
| CEU | 61 | 21 | 8 | 1 | 3 | 5 |
| DEU | 76 | 8 | | 8 | 2 | 6 |
| MED | 22 | 32 | 6 | 29 | 10 | |
| MEE | 75 | 3 | 8 | | 8 | 6 |
| NWE | 55 | | | 7 | 33 | 5 |
| RNE | | | | 67 | 33 | |
| CAN | | | 20 | | 40 | 40 |
| USA | 11 | 52 | 1 | | 6 | 30 |
| ANZ | 97 | | 1.5 | | 1 | 0.5 |

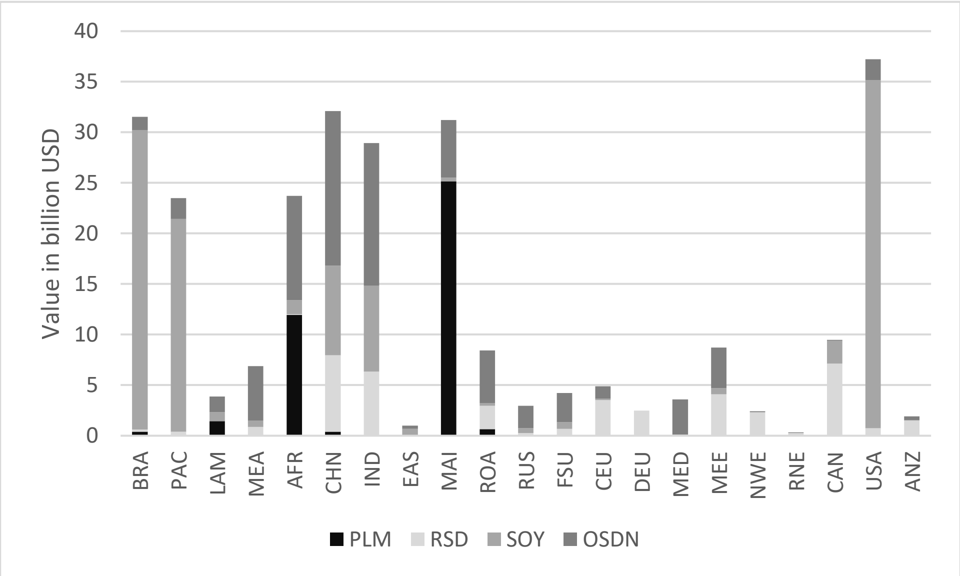
***Source*: See Table A7.**

***Figure A1***: **Regional production of maize and other grains.**



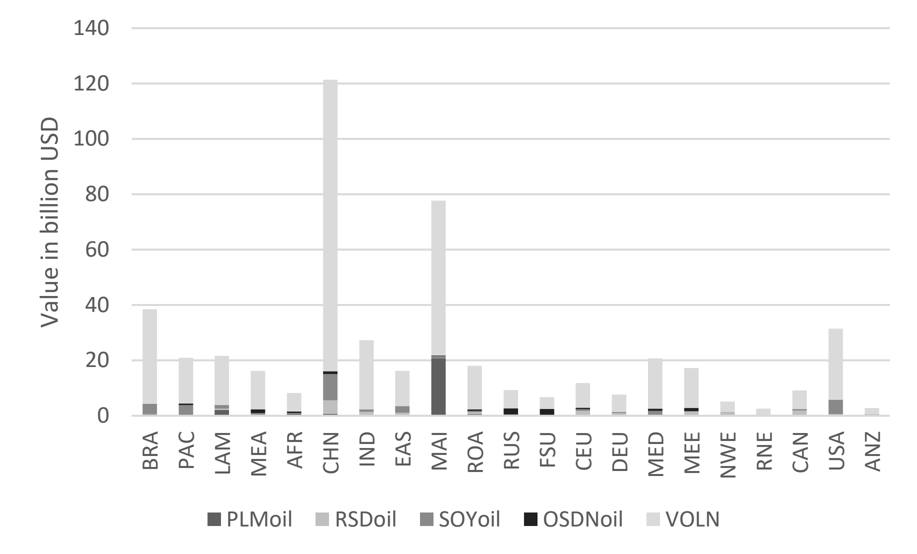

***Source***: **DART-BIO.**

***Figure A2***: **Regional production of oilseed crops.**




***Source***: **DART-BIO.**

***Figure A3*: Regional production of oilseed oils.**




***Source*: DART-BIO.**

***Table A3*: Elasticities for natural resource in fossil resource production (ESUB_ES).**

| Sector / Region | COL | CRU | GAS |
|---|---|---|---|
| BRA | 0.17 | 0.33 | 0.14 |
| PAC | 0.24 | 0.38 | 0.16 |
| LAM | 0.25 | 0.44 | 0.25 |
| MEA | 0.23 | 0.45 | 0.33 |
| AFR | 0.19 | 0.39 | 0.33 |
| CHN | 0.21 | 0.38 | 0.01 |
| IND | 0.25 | 0.41 | 0.08 |
| EAS | 0.20 | 0.37 | 0.00 |
| MAI | 0.27 | 0.45 | 0.27 |
| ROA | 0.21 | 0.38 | 0.12 |
| RUS | 0.19 | 0.40 | 0.05 |
| FSU | 0.19 | 0.36 | 0.19 |
| CEU | | 0.36 | 0.21 |
| DEU | 0.22 | 0.39 | 0.05 |
| MED | 0.22 | 0.41 | 0.20 |
| MEE | 0.21 | 0.34 | 0.02 |
| NWE | 0.18 | 0.42 | 0.08 |
| RNE | 0.17 | 0.44 | 0.42 |
| CAN | 0.22 | 0.40 | 0.32 |
| USA | 0.20 | 0.41 | 0.07 |
| ANZ | 0.20 | 0.40 | 0.29 |

***Source*: GTAP, DART-BIO.**

***Table A4***: **Income Elasticities**

| | BRA | PAC | LAM | MEA | AFR | CHN | IND | EAS | MAI | ROA | RUS | FSU | CEU | DEU | MED | MEE | NWE | RNE | CAN | USA | ANZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PDR | 0.1 | | 0.22 | 0.33 | 0.67 | 0.44 | 0.61 | | | 0.75 | | 0.28 | | | | | | | | | |
| WHT | 0.1 | 0.08 | 0.32 | 0.39 | 0.69 | 0.44 | 0.61 | 0.03 | | 0.67 | 0.13 | 0.3 | 0.02 | 0.02 | 0.02 | 0.1 | 0.02 | 0.01 | 0.02 | 0.01 | 0.23 |
| MZE | 0.1 | 0.19 | 0.29 | 0.34 | 0.69 | 0.44 | 0.61 | 0.04 | 0.44 | 0.63 | 0.13 | 0.39 | 0.02 | 0.02 | 0.02 | 0.13 | | 0.01 | 0.02 | 0.01 | |
| GRON | 0.1 | 0.13 | 0.3 | 0.33 | 0.7 | 0.44 | 0.61 | 0.05 | 0.43 | 0.71 | 0.13 | 0.38 | 0.02 | 0.02 | 0.02 | 0.12 | 0.02 | 0.01 | 0.02 | | |
| PLM | | | 0.33 | | 0.66 | | | | 0.45 | 0.45 | | | | | | | | | | | |
| RSD | | | | 0.23 | 0.76 | 0.44 | 0.61 | 0.03 | | 0.73 | 0.13 | 0.27 | 0.02 | 0.02 | | 0.09 | 0.02 | | 0.02 | | |
| SOY | 0.1 | | 0.23 | 0.21 | 0.72 | 0.44 | 0.61 | 0.04 | 0.45 | 0.41 | 0.13 | 0.21 | | | | 0.09 | | 0.01 | 0.02 | 0.01 | |
| OSDN | | | 0.3 | 0.35 | 0.72 | 0.44 | 0.61 | 0.04 | 0.45 | 0.67 | 0.13 | 0.29 | | | 0.02 | 0.11 | | | | | |
| C_B | 0.1 | 0.08 | 0.17 | 0.33 | 0.56 | 0.44 | 0.61 | 0.02 | 0.24 | 0.73 | 0.13 | 0.36 | 0.02 | 0.02 | | 0.07 | 0.02 | 0.01 | 0.02 | 0.01 | 0.02 |
| AGR | 0.12 | 0.11 | 0.28 | 0.32 | 0.68 | 0.44 | 0.61 | 0.03 | 0.43 | 0.58 | 0.13 | 0.39 | 0.03 | 0.03 | 0.03 | 0.11 | 0.02 | 0.04 | 0.06 | 0.01 | 0.1 |
| OLVS | 0.74 | 0.75 | 0.74 | 0.78 | 0.92 | 0.71 | 0.78 | 0.89 | 0.7 | 0.87 | 0.74 | 0.77 | 0.9 | 0.9 | 0.88 | 0.82 | 0.91 | 0.96 | 0.91 | 0.92 | 0.83 |
| ILVS | 0.74 | 0.75 | 0.73 | 0.76 | 0.88 | 0.7 | 0.79 | 0.86 | 0.71 | 0.79 | 0.74 | 0.77 | 0.9 | 0.9 | 0.89 | 0.82 | 0.91 | 0.97 | 0.91 | 0.92 | 0.91 |
| PLMoil | 0.62 | | 0.63 | 0.66 | 0.86 | 0.63 | 0.72 | 0.76 | 0.62 | 0.82 | | | | | | 0.68 | 0.85 | | | | 0.82 |
| RSDoil | | 0.64 | 0.6 | 0.69 | | 0.62 | 0.72 | 0.82 | 0.58 | 0.87 | | 0.63 | 0.83 | | 0.8 | 0.7 | 0.83 | 0.93 | 0.84 | 0.86 | 0.82 |
| SOYoil | 0.62 | 0.66 | 0.62 | 0.67 | 0.72 | 0.62 | | 0.74 | 0.62 | 0.74 | 0.61 | 0.67 | 0.82 | | 0.8 | 0.73 | 0.84 | 0.93 | | 0.86 | 0.77 |
| OSDNoil | 0.62 | 0.66 | 0.63 | 0.66 | 0.7 | 0.62 | 0.72 | | 0.61 | 0.85 | 0.61 | 0.65 | 0.82 | 0.83 | 0.79 | 0.67 | 0.84 | 0.92 | 0.84 | | 0.78 |
| VOLN | 0.62 | 0.64 | 0.63 | 0.67 | 0.82 | 0.62 | 0.72 | 0.77 | 0.62 | 0.8 | 0.61 | 0.65 | 0.82 | 0.83 | 0.8 | 0.68 | 0.84 | 0.92 | 0.84 | 0.86 | 0.83 |
| SGR | 0.95 | 0.64 | 0.62 | 0.69 | 0.82 | 0.62 | 0.72 | 0.77 | 0.62 | 0.84 | 0.61 | 0.64 | 0.82 | 0.83 | 0.8 | 0.68 | 0.84 | 0.92 | 0.84 | 0.86 | 0.85 |
| FOD | 0.56 | 0.64 | 0.6 | 0.66 | 0.79 | 0.63 | 0.7 | 0.76 | 0.59 | 0.73 | 0.61 | 0.64 | 0.82 | 0.83 | 0.79 | 0.71 | 0.83 | 0.92 | 0.84 | 0.85 | 0.83 |
| PCM | 0.74 | 0.76 | 0.74 | 0.77 | 0.89 | 0.7 | 0.79 | 0.87 | 0.7 | 0.82 | 0.74 | 0.76 | 0.9 | 0.9 | 0.88 | 0.81 | 0.91 | 0.98 | 0.91 | 0.92 | 0.88 |
| CRPN | 1.03 | 1.05 | 1.09 | 1.09 | 0.98 | 1.01 | 0.87 | 1.03 | 1.03 | 0.99 | 1.08 | 1.1 | 1.03 | 1.03 | 1.03 | 1.09 | 1.02 | 1.01 | 1.02 | 1.01 | 1.01 |
| BETH | 1 | 1 | 1.02 | 1.05 | 1.11 | 0.97 | 0.99 | 1.01 | 0.98 | 1.02 | 1.02 | 1.06 | 1.01 | 1.01 | 1.01 | 1.04 | 1.01 | 1.01 | 1 | 0.99 | 1 |
| BDIE | 1 | 1 | 1.04 | 1.06 | 1.05 | 0.97 | 0.99 | 1.01 | 0.98 | 1 | 1.02 | 1.02 | 1.01 | 1.01 | 1.01 | 1.04 | 1.01 | 1.01 | 1 | 0.99 | 0.99 |
| BDIE_PLM | 1 | 1 | 1.04 | 1.06 | 1.05 | 0.97 | 0.99 | 1.01 | 0.98 | 1 | 1.02 | 1.02 | 1.01 | 1.01 | 1.01 | 1.04 | 1.01 | 1.01 | 1 | 0.99 | 0.99 |
| UCOME | 1 | 1 | 1.04 | 1.06 | 1.05 | 0.97 | 0.99 | 1.01 | 0.98 | 1 | 1.02 | 1.02 | 1.01 | 1.01 | 1.01 | 1.04 | 1.01 | 1.01 | 1 | 0.99 | 0.99 |
| MGAS | 1 | 1 | 1.02 | 1.05 | 1.11 | 0.97 | 0.99 | 1.01 | 0.98 | 1.02 | 1.02 | 1.06 | 1.01 | 1.01 | 1.01 | 1.04 | 1.01 | 1.01 | 1 | 0.99 | 1 |
| MDIE | 1 | 1 | 1.04 | 1.06 | 1.05 | 0.97 | 0.99 | 1.01 | 0.98 | 1 | 1.02 | 1.02 | 1.01 | 1.01 | 1.01 | 1.04 | 1.01 | 1.01 | 1 | 0.99 | 0.99 |
| OIL | 1 | 1 | 1.02 | 1.04 | 1.15 | 0.97 | 0.99 | 1.01 | 0.98 | 1.06 | 1.02 | 1.03 | 1 | 1.01 | 1.01 | 1.03 | 1.01 | 1.01 | 1 | 0.99 | 0.99 |
| COL | | | | 1.12 | 1.1 | 1.06 | 1.01 | 1.05 | | 1.1 | 1.09 | 1.14 | 1.03 | 1.03 | | 1.08 | 1.03 | | | | |
| CRU | | | | | 1.12 | | | | | 1.03 | | 1.03 | | 1.01 | | | | | | | |
| GAS | 1.06 | 1.05 | 1.08 | 1.12 | 1.06 | 1.06 | 1.01 | 1.04 | 1.07 | 1.14 | 1.09 | 1.09 | 1.03 | 1.03 | 1.03 | 1.09 | 1.03 | 1.01 | 1.02 | 1.01 | 1.01 |
| ELY | 1.06 | 1.05 | 1.1 | 1.12 | 1.12 | 1.06 | 1.01 | 1.03 | 1.07 | 1.12 | 1.09 | 1.13 | 1.03 | 1.03 | 1.03 | 1.09 | 1.03 | 1.01 | 1.02 | 1.01 | 1.01 |
| FRS | 1.05 | 1.06 | 1.1 | 1.12 | 0.99 | 1.01 | 0.87 | 1.03 | 1.02 | 0.77 | 1.08 | 1.17 | 1.03 | 1.03 | 1.03 | 1.08 | 1.03 | 1.01 | 1.02 | 1.01 | 1.01 |
| FRI | 1.05 | 1.05 | 1.12 | 1.1 | 0.96 | 1.04 | 0.88 | 1.03 | 1.05 | 1.05 | 1.09 | 1.14 | 1.03 | 1.03 | 1.03 | 1.08 | 1.03 | 1.01 | 1.02 | 1.01 | 1.01 |
| ETS | 1.05 | 1.05 | 1.09 | 1.09 | 0.95 | 1.01 | 0.87 | 1.03 | 1.03 | 0.98 | 1.08 | 1.1 | 1.03 | 1.03 | 1.03 | 1.09 | 1.03 | 1.01 | 1.02 | 1.01 | 1.01 |
| SERV | 1.11 | 1.1 | 1.15 | 1.18 | 1.36 | 1.22 | 1.29 | 1.05 | 1.23 | 1.27 | 1.15 | 1.25 | 1.04 | 1.04 | 1.05 | 1.12 | 1.04 | 1.01 | 1.03 | 1.02 | 1.03 |
| OTH | 0.95 | 0.92 | 0.95 | 0.96 | 0.97 | 0.89 | 0.82 | 0.99 | 0.95 | 0.92 | 0.99 | 0.95 | 0.99 | 0.99 | 0.97 | 1 | 0.99 | 1 | 0.99 | 0.98 | 0.98 |
| ETHL | 1 | 1 | 1.02 | 1.05 | 1.11 | 0.97 | 0.99 | 1.01 | 0.98 | 1.02 | 1.02 | 1.06 | 1.01 | 1.01 | 1.01 | 1.04 | 1.01 | 1.01 | 1 | 0.99 | 1 |

***Source***: **GTAP, DART-BIO.**

***Table A5*: Armington Elasticities for different regions**

| | BRA | PAC | LAM | MEA | AFR | CHN | IND | EAS | MAI | ROA | RUS | FSU | CEU | DEU | MED | MEE | NWE | RNE | CAN | USA | ANZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PDR | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| WHT | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 | 9 |
| MZE | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| GRON | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| PLM | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| RSD | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| SOY | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| OSDN | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| C_B | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| AGR | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| STR | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| OLVS | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| ILVS | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| PLMoil | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| PLMmeal | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| RSDoil | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| RSDmeal | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| SOYoil | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| SOYmeal | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| OSDNoil | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| OSDNmeal | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| VOLN | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| UCO | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| SGR | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| FOD | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| FSH | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| PCM | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| CRPN | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| ETHW | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| ETHM | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| ETHG | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| ETHS | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| BETH | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| BDIE | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| BDIE_PLM | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| UCOME | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| MGAS | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| MDIE | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| OIL | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| COL | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| CRU | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| GAS | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| ELY | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 |
| FRS | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| FRI | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| ETS | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| SERV | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| OTH | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| DDGSw | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| DDGSm | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| DDGSg | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| ETHL | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

***Source*: GTAP, DART-BIO.**

***Table A6*: Armington elasticities for imported and domestic goods.**

| | BRA | PAC | LAM | MEA | AFR | CHN | IND | EAS | MAI | ROA | RUS | FSU | CEU | DEU | MED | MEE | NWE | RNE | CAN | USA | ANZ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PDR | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 | 5.1 |
| WHT | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 | 4.4 |
| MZE | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| GRON | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| PLM | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| RSD | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| SOY | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| OSDN | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| C_B | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| AGR | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| STR | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| OLVS | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 | 2.9 |
| ILVS | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| PLMoil | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| PLMmeal | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| RSDoil | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| RSDmeal | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| SOYoil | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| SOYmeal | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| OSDNoil | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| OSDNmeal | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| VOLN | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| UCO | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| SGR | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| FOD | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| FSH | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| PCM | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 |
| CRPN | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| ETHW | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ETHM | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ETHG | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| ETHS | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| BETH | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| BDIE | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| BDIE_PLM | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| UCOME | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| MGAS | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| MDIE | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| OIL | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| COL | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| CRU | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 | 5.2 |
| GAS | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| ELY | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 | 2.8 |
| FRS | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| FRI | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 | 2.2 |
| ETS | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| SERV | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 | 1.9 |
| OTH | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 | 3.7 |
| DDGSw | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| DDGSm | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| DDGSg | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

***Source*: GTAP, DART-BIO.**

***Table A7*: Sources for biodiesel feedstock shares**

| Country | Source |
|---|---|
| Australia | https://crawford.anu.edu.au/pdf/eerh/annual_08/CERF%20biofuels%20presentation.pdf |
| New Zealand | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/New%20Zealand%20Biofuel%20Report_Wellington_New%20Zealand_6-26-2009.pdf |
| China | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Beijing_China%20-%20Peoples%20Republic%20of_1-18-2017.pdf |
| Japan | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Tokyo_Japan_8-15-2017.pdf |
| Korea Republic of | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Bio-Fuels%20Production_Seoul_Korea%20-%20Republic%20of_2-10-2010.pdf |
| Taiwan | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/General%20Report_Taipei_Taiwan_5-19-2009.pdf |
| Indonesia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Jakarta_Indonesia_8-13-2018.pdf |
| Malaysia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Kuala%20Lumpur_Malaysia_10-24-2017.pdf |
| Philippines | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Manila_Philippines_10-18-2017.pdf |
| Thailand | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Bangkok_Thailand_6-23-2017.pdf |
| India | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_New%20Delhi_India_6-27-2017.pdf; https://onlinelibrary.wiley.com/doi/full/10.1002/ep.12800 |
| Canada | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Ottawa_Canada_4-6-2018.pdf |
| United States of America | https://www.agmrc.org/renewable-energy/biodiesel/feedstocks-used-for-us-biodiesel-how-important-is-corn-oil |
| Mexico | https://www.intechopen.com/books/biofuels-status-and-perspective/an-overview-of-biodiesel-production-in-mexico |
| Argentina | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Buenos%20Aires_Argentina_7-17-2017.pdf |
| Brazil | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_9-15-2017.pdf |
| Colombia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Bogota_Colombia_9-22-2017.pdf |
| Ecuador | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Quito_Ecuador_6-28-2012.pdf |
| Paraguay | http://www.thecropsite.com/reports/?id=4071 |
| Peru | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Lima_Peru_9-20-2017.pdf |
| Uruguay | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/General%20Report_Buenos%20Aires_Uruguay_6-4-2009.pdf |
| Caribbean | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuel%20Mandates%20in%20the%20EU%20by%20Member%20State%20in%202018_Berlin_EU-28_6-19-2018.pdf |
| Austria | http://www.biokraft-austria.at/#biodiesel |
| Belgium | http://www.cres.gr/biodiesel/pdf/fact%20sheets/Belgium%20fs.pdf |
| Czech Republic | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual%202016_Prague_Czech%20Republic_5-10-2016.pdf |
| Denmark | https://www.oecd-ilibrary.org/docserver/9789264287594-en.pdf?expires=1629393367&id=id&accname=ocid194350&checksum=EDD3067F3B76CD2FBFCAF231F84D5708 |
| Estonia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Production%20and%20Consumption%20of%20Renewable%20Energy._Warsaw_Estonia_7-7-2016.pdf |

| | |
|---|---|
| Finland | https://nordic.businessinsider.com/finlands-biodiesel-dreams-are-getting-crushed-2017-7/ |
| France | https://www.ufop.de/files/6713/3940/7568/Auszug_Biodiesel_E_2011_web-1.pdf |
| Germany | https://biokraftstoffe.fnr.de/kraftstoffe/biodiesel/rohstoffe/ |
| Greece | http://www.cres.gr/biodiesel/pdf/fact%20sheets/Greece%20fs.pdf |
| Hungary | http://www.etipbioenergy.eu/images/EBTP_Factsheet_Hungary.pdf |
| Ireland | https://www.teagasc.ie/media/website/publications/2010/MossieDonovan_18Feb10IrBea.pdf |
| Italy | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Italian%20Biofuels%202011_Rome_Italy_12-29-2011.pdf |
| Latvia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Market%20Outlook%20in%20Latvia%202016_Warsaw_Latvia_7-6-2016.pdf |
| Lithuania | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Lithuania%20-%20Biofuel%20Market%20Outlook%202016._Warsaw_Lithuania_6-30-2016.pdf |
| Netherlands | http://saee.gov.ua/sites/default/files/Kvant_0.pdf |
| Poland | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Market%20Outlook%20in%20Poland%202016_Warsaw_Poland_6-29-2016.pdf |
| Portugal | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Portugal%20Biofuel%20Market%20Outlook%20_Madrid_Portugal_6-21-2017.pdf |
| Slovakia | https://www.meroco.sk/en/products/biodiesel-en |
| Slovenia | slovenia: biofuel policies - OECD.org |
| Spain | https://www.google.com/search?client=firefox-b-ab&ei=J9GsW73hHcujwAL2jqiwBw&q=spain%3A+biofuel+policies+-+OECD.org&oq=spain%3A+biofuel+policies+-+OECD.org&gs_l=psy-ab.3...40011.40540.0.40682.5.5.0.0.0.0.106.365.4j1.5.0....0...1c.1.64.psy-ab..0.0.0....0.NplulRa930I |
| Sweden | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Stockholm_Sweden_6-24-2009.pdf |
| United Kingdom | https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/308142/uk-biofuel-producer.pdf |
| Switzerland | http://www.biosprit.org/?id=23&z=/Biodiesel |
| Belarus | https://mpra.ub.uni-muenchen.de/76725/1/MPRA_paper_76725.pdf |
| Croatia | http://www.avensonline.org/wp-content/uploads/JMMT-2474-4530-01-0009.pdf |
| Romania | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Romania%20Biofuels%20Market%20Overview_Bucharest_Romania_6-14-2017.pdf |
| Turkey | http://dergipark.gov.tr/download/article-file/361258 |
| Botswana | http://www.sundaystandard.info/ramotswa-factory-producing-biodiesel |
| Namibia | https://www.biofuelnamibia.com/biodiesel |

***Table A8*: Sources for bioethanol feedstock shares**

| Country | Source |
| --- | --- |
| Australia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Canberra_Australia_7-15-2016.pdf |
| China | http://eng.greensos.cn/ShowArticle.aspx?articleId=1174 |
| Japan | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Tokyo_Japan_8-15-2017.pdf |
| Korea Republic of | http://www.biofuelsdigest.com/bdigest/2016/03/10/south-korea-invests-34-million-in-laos-ethanol-facility/, https://gain.fas.usda.gov/Recent%20GAIN%20Publications/2017%20Bioethanol%20Workshop%20and%20Roundtable%20Seoul%20Korea_Seoul_Korea%20-%20Republic%20of_6-23-2017.pdf |
| Taiwan | https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4772250/ |
| Indonesia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Jakarta_Indonesia_6-20-2017.pdf |
| Malaysia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Kuala%20Lumpur_Malaysia_10-24-2017.pdf |
| Philippines | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Manila_Philippines_10-18-2017.pdf |
| Thailand | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Bangkok_Thailand_6-23-2017.pdf |
| Viet Nam | http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2015_events/3rd_Bioenergy_Week_25-29_May_Indonesia/26_5_3_HIEU.pdf |
| Bangladesh | http://www.reuters.com/article/us-bangladesh-ethanol-food/in-threat-to-food-security-bangladesh-moves-to-burn-grain-for-fuel-idUSKBN17X0VL https://biofuels-news.com/display_news/13302/bangladesh_to_allow_5_ethanol_blend/ |
| India | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_New%20Delhi_India_6-27-2017.pdf |
| Pakistan | https://pema.pk |
| Sri Lanka | http://www.colombopage.com/archive_13A/Mar22_1363971718CH.php |
| Canada | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Ottawa_Canada_8-19-2015.pdf |
| United States of America | https://www.fas.usda.gov/data/us-ethanol-exports-rebound-2014 |
| Mexico | http://www.nortonrosefulbright.com/knowledge/publications/132195/from-feedstock-to-fuel-the-latin-american-experience |
| Argentina | http://www.nortonrosefulbright.com/knowledge/publications/132195/from-feedstock-to-fuel-the-latin-american-experience |
| Bolivia | https://apps.fas.usda.gov/newgainapi/api/report/downloadreportbyfilename?filename=Bolivia%20Enters%20Ethanol%20Era_Lima_Peru_3-19-2018.pdf |
| Brazil | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Sao%20Paulo%20ATO_Brazil_9-15-2017.pdf |
| Chile | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Evolution%20of%20biofuels%20in%20Chile_Santiago_Chile_3-9-2012.pdf |
| Colombia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Bogota_Colombia_8-12-2016.pdf |
| Ecuador | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Quito_Ecuador_6-28-2012.pdf |
| Paraguay | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Buenos%20Aires_Paraguay_8-10-2015.pdf |
| Peru | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Lima_Peru_9-20-2017.pdf |
| CostaRica | http://www.globalbiopact.eu/case-studies/costa-rica.html |
| Guatemala | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual_Guatemala%20City_Guatemala_8-2-2013.pdf |

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|---|---|
| Nicaragua | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Sugar%20Annual_Managua_Nicaragua_3-15-2013.pdf |
| Austria | http://www.umweltbundesamt.at/umweltsituation/verkehr/kraftstoffe/biokraftstoff1/bioethanol/ |
| Belgium | http://www.belgianbioethanol.be/fr/faq.php |
| Czech Republic | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Annual%202016_Prague_Czech%20Republic_5-10-2016.pdf |
| Denmark | https://www.iea-bioenergy.task42-biorefineries.com/upload_mm/f/1/c/38f1f28a-3e56-4844-85b8-ac3be22608d5_Country_Report_Denmark_IEA_Bioenergy_Task42_2014.pdf |
| Estonia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Production%20and%20Consumption%20of%20Renewable%20Energy._Warsaw_Estonia_7-7-2016.pdf |
| France | https://www.ecologique-solidaire.gouv.fr/biocarburants |
| Germany | http://www.ble.de/SharedDocs/Downloads/DE/Klima-Energie/Nachhaltige-Biomasseherstellung/Evaluationsbericht_2015.pdf;jsessionid=02B3E09BDB29073B256DA63E9634BB15.1_cid325?__blob=publicationFile&v=1 |
| Hungary | http://www.pannoniaethanol.com/en/facts |
| Ireland | http://www.independent.co.uk/life-style/motoring/features/cleanrsquo-bioethanol-ireland-discovers-the-whey-to-go-399115.html |
| Italy | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Overview%202014_Rome_Italy_4-9-2014.pdf |
| Latvia | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Market%20Outlook%20in%20Latvia%202016_Warsaw_Latvia_7-6-2016.pdf |
| Lithuania | http://www.deutsche-melasse.de/wp/wp-content/uploads/USDA-30.06.2016-Lithuania-Biofuel-Market-Outlook-2016.pdf |
| Netherlands | https://english.rvo.nl/sites/default/files/2016/05/Sustainable-biomass-bioenergy-netherlands.pdf |
| Poland | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Market%20Outlook%20in%20Poland%202015_Warsaw_Poland_8-5-2015.pdf |
| Slovakia | https://www.enviral.sk/en/products/bioethanol |
| Spain | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Spain's%20Bioethanol%20Sector%20Overview%20_Madrid_Spain_7-31-2017.pdf |
| Sweden | http://www.energimyndigheten.se/en/facts-and-figures/publications/ |
| United Kingdom | http://epure.org/media/1418/ecofys-2016-low-carbon-biofuels-for-the-uk.pdf |
| Norway | http://task40.ieabioenergy.com/wp-content/uploads/2013/09/iea-task-40-country-report-2014-norway.pdf, http://www.topnest.no/attachments/article/12/Borregaard_TOPNEST_Case%20study.pdf |
| Bulgaria | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Biofuels%20Sector%20Update_Sofia_Bulgaria_8-13-2015.pdf |
| Croatia | http://hrcak.srce.hr/index.php?show=clanak&id_clanak_jezik=222832&lang=en |
| Romania | https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Romania%20Biofuels%20Market%20Overview_Bucharest_Romania_6-14-2017.pdf |
| Rest of Europe | http://epure.org/media/1627/feedstock-used-to-produce-renewable-ethanol-2016.png |
| Ethiopia | https://www.giz.de/fachexpertise/downloads/gtz2009-en-targetmarketanalysis-bioenergy-ethiopia.pdf, http://ethiopiansugar.com/index.php/en/factories/wonji-shoa-sugar-facory |
| Rest of Eastern Africa | https://www.unido.org/fileadmin/media/documents/pdf/Energy_Environment/senegal_presentations_side2_events_Biofuels_Eastern__Southern_Africa.pdf |