

# **HOW-TO GUIDE FOR THE TIMES-AFOLU MODEL**

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# 1 Introduction

As nations confront the urgent imperative to address climate change and transition toward carbon-neutral economies, energy system modeling has become indispensable for informing policy decisions and conducting scenario analysis. Despite its critical importance, the Agriculture, Forestry, and Other Land Use (AFOLU) sector has received insufficient attention in existing modeling frameworks, even though it exerts substantial influence on energy systems and climate mitigation pathways. This methodology note presents an approach to bridge this gap by developing a comprehensive AFOLU module for TIMES, thereby enhancing the model's capacity to support integrated long-term scenario analysis.

The AFOLU sector plays a pivotal role in climate change mitigation and profoundly influences energy system planning. Critical questions regarding forest carbon sequestration potential, irrigation system optimization, and land allocation for bioenergy production demand rigorous analytical frameworks. The primary methodological objective is to develop a standardized, flexible AFOLU module that integrates seamlessly with TIMES models. This advancement provides the ETSAP community with enhanced modeling capabilities to conduct holistic scenario analysis that captures the complex interdependencies between energy systems and the AFOLU sector.

The methodology incorporates several key components. Water resource tracking will be implemented to account for competing demands and availability constraints. Greenhouse gas emissions or uptake from livestock, crop production, and forests will be comprehensively accounted for and subject to optimization within the modeling framework. Thereby, the projection of AFOLU technologies, such as the evolution of crop types, livestock, and manure management in response to climate change, is found.

The primary objective is to develop an AFOLU module capable of generating decarbonization pathways while accounting for emissions, water use, and land use changes associated with AFOLU activities. To ensure compatibility with existing TIMES implementations, the AFOLU components are modeled using conventional energy system optimization model (ESOM) structures – namely commodities, processes, and their associated parameters (efficiency, costs, emission factors). This design ensures that each stand-alone AFOLU instance can be integrated into TIMES models without requiring code modifications.

Throughout the development process, flexibility and adaptability for national-level implementations remain paramount considerations. Consequently, the module is constructed in accordance with established AFOLU activity data and emissions accounting frameworks, ensuring consistency with IPCC guidelines for greenhouse gas inventory preparation and reporting.

The model is available here: <https://github.com/Energy-Modelling-Lab/TIMES-AFOLU/tree/ReleaseTag>

This report describes how to work with the model and create a first model instance for a country of the user's own choice.

## 2 Overview of the model files

The AFOLU module can be found in a repository: <https://github.com/Energy-Modelling-Lab/TIMES-AFOLU>

The repository includes:

- Sets-TIMES-AFOLU: Defines sets for easier results handling – the sets are not used in the model.
- SysSettings: Includes basic definitions as normally found in SysSettings for the demo models but includes one sheet (AFOLU specific) with definitions necessary for the AFOLU-module:
  - Aggregation of commodities into GHG-emissions and conversion to CO2eq
  - Allowing the objective function to be negative
  - Allowing the commodities AFOBGACH4, AFOBGAN2O, and AFOFRSCO2 to become negative
- VT\_REG\_AFOLU: Includes all the necessary data, existing technologies, and some mitigation options. In the following it is described how the file is structured and how to populate it with data
- Scenario files:
  - Scen\_AreaUse: The file can be used for restricting the allowed area use for the AFOLU sector (AreaUse-sheet) and linking the amount of grassing animals with the pasture area
  - Scen\_GHGtax: A scenario file showing how to include a tax on GHG-emissions
- Cases.json, Groups.json, and Settings.json: Includes two scenarios (a base scenario and a scenario with a GHG-tax) defined in Veda and their settings

The main model file is VT\_REG\_AFOLU, which will be described in the following.

### 2.1 Structure of the VT-file

The VT-file is structured with a colour-code to ease the overview of the file. The **green** sheets are sheets that Veda reads (hereafter Output sheets), the **purple** sheets are calculation sheets where the input data is used for calculating the necessary parameters for the output sheets, and the **blue** and **light blue** sheets are input data sheets. White sheets and **red** sheets are described under other sheets below.

#### 2.1.1 Input sheets

The input sheets are the only sheets that needs to be updated when applying the AFOLU-module to a new country. These are shortly described in Table 1 and the process of filling in the data that is globally available is further described in section 3 - Finding and including global data.

Table 1: Overview of the input sheets in the VT-file

Sheet name	Description
Input data - emissions	<p>Country level data on emissions, crops, livestock, forest, and area can all be found in FAOSTAT. For each sheet, the direct reference to the data in FAOSTAT is provided.</p> <p>The data can easily be replaced with data from other sources if available, but FAOSTAT covers all countries.</p> <p>For the livestock sheet, it is worth noting that column G use the LOOKUP table sheet for handling the aggregation of the species. The remaining sheets are purely input data.</p>
Input data - area	
Input data - livestock	
Input data - forest	
Input data - crops	
Input data - water	Here the water consumption for the agricultural sector is given. The data can be found through AQUASTAT.
Input data - other	Input data that is not available from international sources and must be adapted to the country at hand
Irrigation shares	Data has been collected for all countries through the FAO crop calendar and converted into a format, which can be used for all countries.
Default AFOLU	All default data for the model, which there are no data for in global statistics and seldomly data for on country level.

### 2.1.2 Calculation sheets

In the calculation sheets, the input data is transformed into data that can be used for setting up the model. If there are no updates to the structure of the data, i.e., the user is only updating the values, the calculation sheets do not need to be updated. Each calculation sheet represents calculations for the different output sheets for the model.

Table 2: Overview of the calculation sheets in the VT-file

Sheet name	Description
Calc - crops	Calculation of yield, area, and emissions for crops. Utilising the data from the input sheet on crops and the Calc - land emissions sheet
Calc - livestock	Calculation of stock and emissions from livestock
Calc - water	Water consumption from each sector and process
Calc - forest biomass	Calculation of biomass potentials from forests
Calc - land emissions	Calculation of land emissions
Calc - land area	Reading of land area data in correct format

### 2.1.3 Output sheets

The output sheets are used to give the data in the right format to be used by Veda. These sheets does not need to be adjusted by the user. In Table 3, an overview of these sheets can be found.

Table 3: Overview of the output sheets in the VT-file

Sheet name	Description
Fuel-Technology	Commodity definition for AFOLU sector to be read by VEDA
Crops	Process definition for crops to be read by VEDA
Crops Demands	Process and commodity definition for demand of crops to be read by VEDA
Livestock	Process definition for livestock to be read by VEDA

Livestock Demand	Process and commodity definition for demand of livestock to be read by VEDA
Forest	Process definition for forestry to be read by VEDA
Pasture	Process definition for pasture to be read by VEDA
Pasture Demands	Process and commodity definition for demand of pasture to be read by VEDA
MNR	Process definition for manure to be read by VEDA

#### 2.1.4 Other sheets

The remaining sheets are a bit different in nature as presented in Table 4. Only the first sheet is to be updated, and the last sheet should be removed if linked to an energy systems model.

Table 4: Overview of the remaining sheets in the VT-file

Sheet name	Description
Intro	Overview of colour coding and insertion of basic model data.
Lookup tables	Connection of animal/crop name and IPPC category.
RemoveWhenLinked	Contains export processes for the generated commodities (MNR, WSA, etc.), which, when one links the AFOLU-module to an existing model, should delete and make sure that the output commodities have the same names as in the model that is linked to.

## 3 Finding and including global data

In the following, it is described how to populate the model with data that is globally available through FAOSTAT and AQUASTAT or country level data.

### 3.1 Input data – emissions

The input data sheet for emissions relies on data from the Emissions totals data from FAOSTAT<sup>1</sup>, as seen in Figure 1.

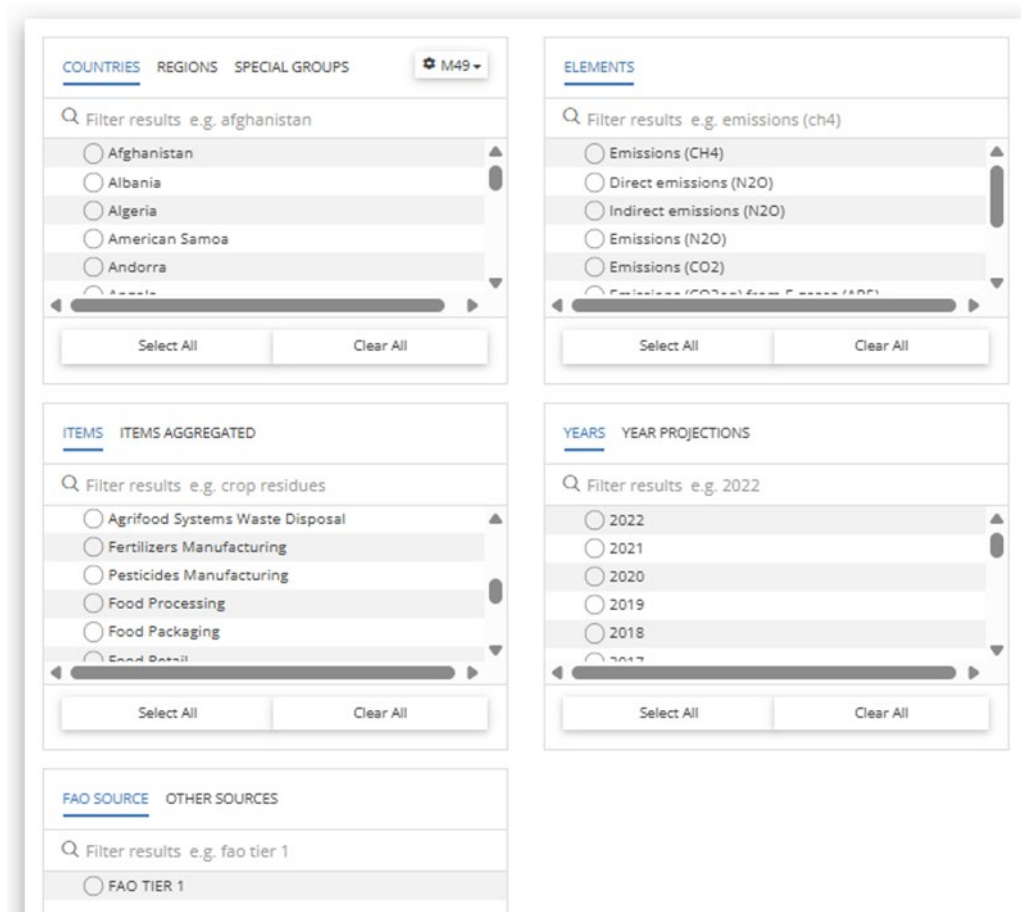
On the website, the user selects the relevant data:

1. The country or region of interest
2. The Elements: Emissions (CH<sub>4</sub>), Emissions (N<sub>2</sub>O), and Emissions (CO<sub>2</sub>)
3. The Items: Select all – the calculation sheets will find the relevant emissions for the AFOLU sector
4. The years: Select the base year of the model. If one wants to use an average over more years, select the relevant years and make an average. The Year column in the input sheet should have the base year for the model for the averaged data.

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<sup>1</sup> <https://www.fao.org/faostat/en/#data/GT>

The data needs to be slightly modified to be included in the VT-file to delete irrelevant columns.



The screenshot shows a web interface for filtering emissions data. It is organized into five main sections, each with a search bar and a list of items with radio buttons for selection. Below each list are 'Select All' and 'Clear All' buttons.

- COUNTRIES:** Filter results e.g. afghanistan. List includes Afghanistan, Albania, Algeria, American Samoa, Andorra, and a scroll bar.
- ELEMENTS:** Filter results e.g. emissions (ch4). List includes Emissions (CH4), Direct emissions (N2O), Indirect emissions (N2O), Emissions (N2O), Emissions (CO2), and a scroll bar.
- ITEMS:** Filter results e.g. crop residues. List includes Agrifood Systems Waste Disposal, Fertilizers Manufacturing, Pesticides Manufacturing, Food Processing, Food Packaging, and a scroll bar.
- YEARS:** Filter results e.g. 2022. List includes 2022, 2021, 2020, 2019, 2018, and a scroll bar.
- FAO SOURCE:** Filter results e.g. fao tier 1. List includes FAO TIER 1.

Figure 1: The Emissions totals data from FAOSTAT

### 3.2 Input data – area

The area occupied by Agriculture, Forest and Pastures can be easily downloaded by for the year and region of interest from the Land Use data from FAOSTAT<sup>2</sup> as seen in Figure 2.

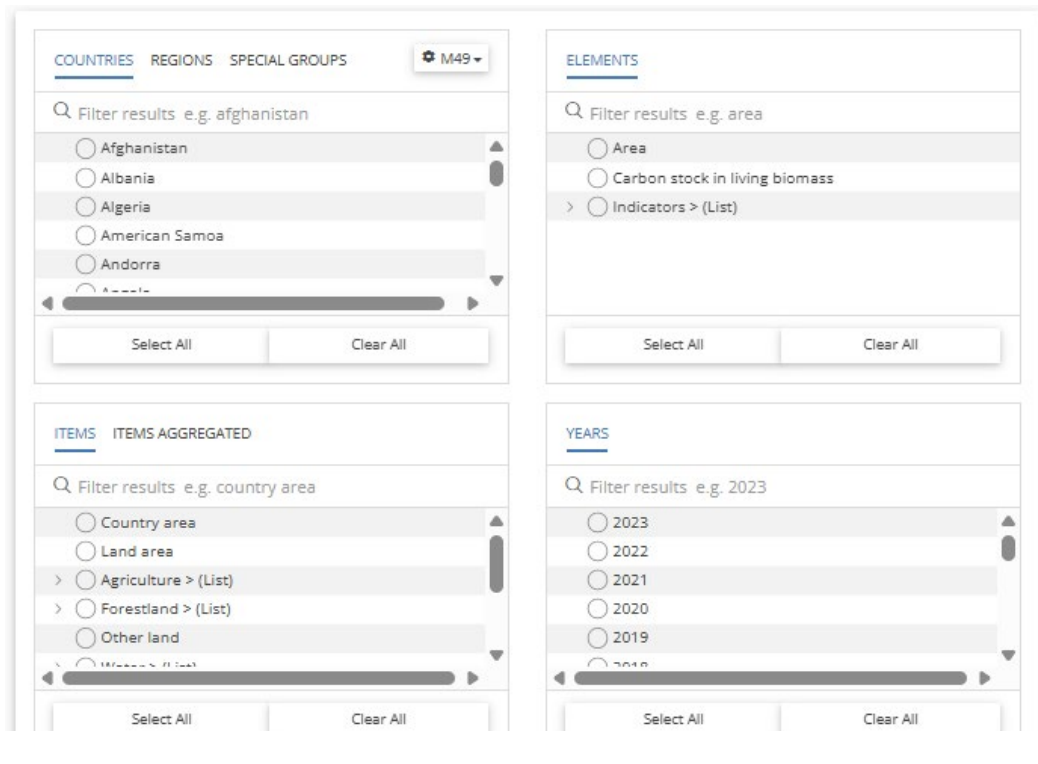


Figure 2: The Land use data from FAOSTAT

The user needs to select the following elements:

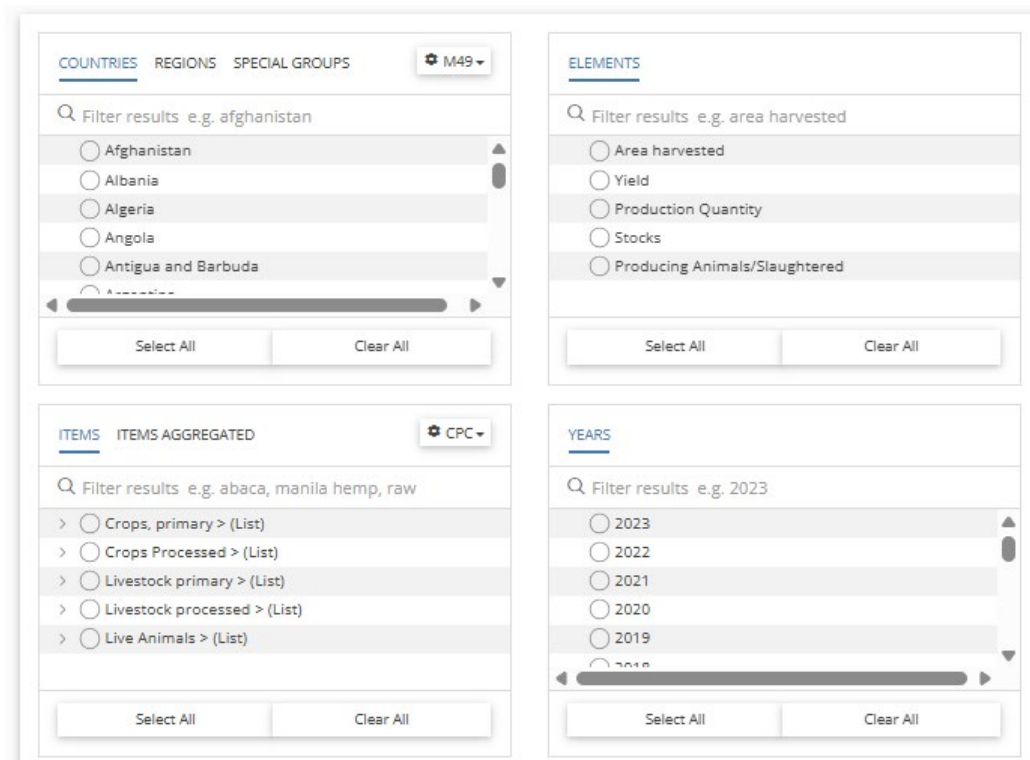
1. The country or region of interest
2. The Elements: Area
3. The Items: Select all – the calculation sheets will find the relevant emissions for the AFOLU sector
4. The years: Select the base year of the model. If one wants to use an average over more years, select the relevant years and make an average. The Year column in the input sheet should have the base year for the model for the averaged data.

The data must be pasted in the sheet “Input data – area” in the same format already used in the file.

<sup>2</sup> <https://www.fao.org/faostat/en/#data/RL>

### 3.3 Input data – crops

The data for the input sheet for crops is from the Crops and livestock products data from FAO-STAT<sup>3</sup>. The data can be selected in the format shown in Figure 3.



The screenshot shows a web-based interface for selecting input data for crops. It consists of four main panels arranged in a 2x2 grid:

- COUNTRIES:** Features a search bar with the text "Filter results e.g. afghanistan". Below it is a scrollable list of countries including Afghanistan, Albania, Algeria, Angola, and Antigua and Barbuda. At the bottom are "Select All" and "Clear All" buttons. A gear icon and "M49" are visible in the top right corner.
- ELEMENTS:** Features a search bar with the text "Filter results e.g. area harvested". Below it is a scrollable list of elements including Area harvested, Yield, Production Quantity, Stocks, and Producing Animals/Slaughtered. At the bottom are "Select All" and "Clear All" buttons.
- ITEMS:** Features a search bar with the text "Filter results e.g. abaca, manila hemp, raw". Below it is a scrollable list of item categories including Crops, primary > (List), Crops Processed > (List), Livestock primary > (List), Livestock processed > (List), and Live Animals > (List). At the bottom are "Select All" and "Clear All" buttons. A gear icon and "CPC" are visible in the top right corner.
- YEARS:** Features a search bar with the text "Filter results e.g. 2023". Below it is a scrollable list of years including 2023, 2022, 2021, 2020, 2019, and 2018. At the bottom are "Select All" and "Clear All" buttons.

Figure 3: Input data for crops from the FAO statistics

The user needs to select the following elements:

1. The country or region of interest
2. The Elements: Area harvested, Yield, Production quantities
3. The Items: Crops, primary > (List)
4. The years: Select the base year of the model. If one wants to use an average over more years, select the relevant years and make an average. The Year column in the input sheet should have the base year for the model for the averaged data.

For each of the primary crops, data have been modified to fit with the decided split on crop type used in the module. This is done in the calculation sheet for crops by aggregating the area harvested and production quantities and using this for calculating the crop yields. This approach simplifies the data from numerous crop-specific entries to a more manageable set of category-

<sup>3</sup> <https://www.fao.org/faostat/en/#data/QCL>

level values. This process, with all the association between single-species and macro-crop categories, is detailed in the “Lookup Table” sheet.

### 3.4 Input data – livestock

The data for the input sheet can be downloaded from FAOSTAT<sup>4</sup>. The data that can be selected are shown in Figure 4.

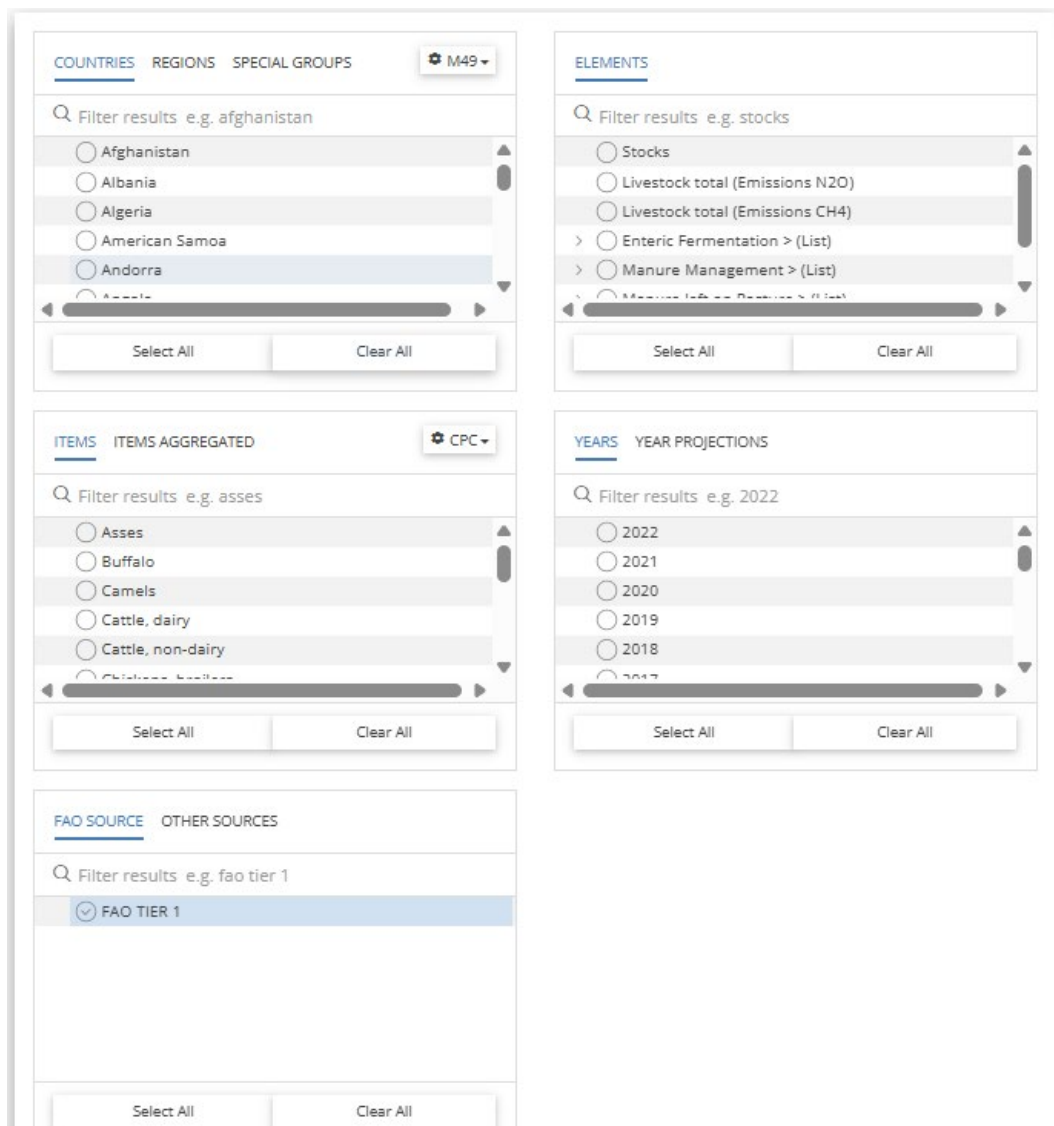


Figure 4: Input data for the livestock sector from FAOSTAT

<sup>4</sup> <https://www.fao.org/faostat/en/#data/GLE>

The user needs to select the following elements:

1. The country or region of interest
2. The Elements: Stock, Enteric fermentation (Emissions CH<sub>4</sub>), Manure Management (Emissions CH<sub>4</sub>), Manure Management (Emissions N<sub>2</sub>O)
3. The Items: Select all
4. The years: Select the base year of the model. If one wants to use an average over more years, select the relevant years and make an average. The Year column in the input sheet should have the base year for the model for the averaged data.
5. FAO source: Select FAO TIER 1

The data must be copied to the sheet in the same format as in the sheet already. In the items, there are more animal types than what is included in the AFOLU module. This is translated directly to the used types in the input data sheet in column H. The translation between the types in FAO and the AFOLU module is seen in the Lookup tables sheet.

### 3.5 Input data - forest

For the Forest sector from FAOSTAT<sup>5</sup> must be exported and put into the sheet. The data from FAO is in the format shown in Figure 5 and the following must be chosen:

1. The country or region of interest
2. The Elements: Production Quantity
3. The Items: Select all
4. The years: Select the base year of the model. If one wants to use an average over more years, select the relevant years and make an average. The Year column in the input sheet should have the base year for the model for the averaged data.

Again, the format must be updated to the format in the input sheet.

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<sup>5</sup> <https://www.fao.org/faostat/en/#data/FO>

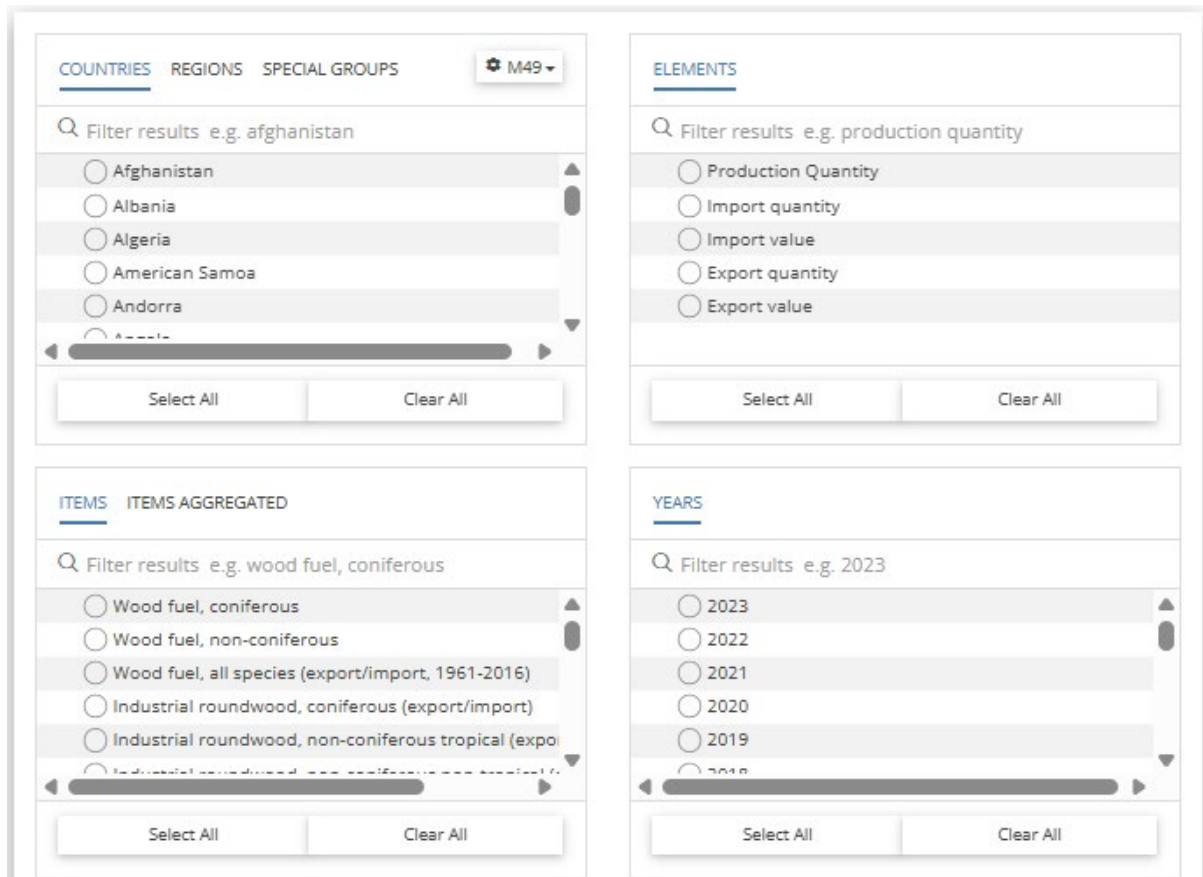


Figure 5: Input data for the forest sector from FAOSTAT

### 3.6 Input data – water

For the data on water consumption, data from FAO’s AQUASTAT<sup>6</sup> database must be used and an overview of the system is shown in Figure 6. The needed data for selection is:

1. The variables: Agricultural water withdrawal, Irrigation water requirement, and Water withdrawal for livestock (watering and cleaning)
2. The area: The region of interest
3. The years: Select the base year of the model. If one wants to use an average over more years, select the relevant years and make an average. The Year column in the input sheet should have the base year for the model for the averaged data.
4. The type: Country Level Data

<sup>6</sup> <https://data.apps.fao.org/aquastat/?lang=en&share=f-6132aa4c-a326-4337-987d-3f071be702fe>

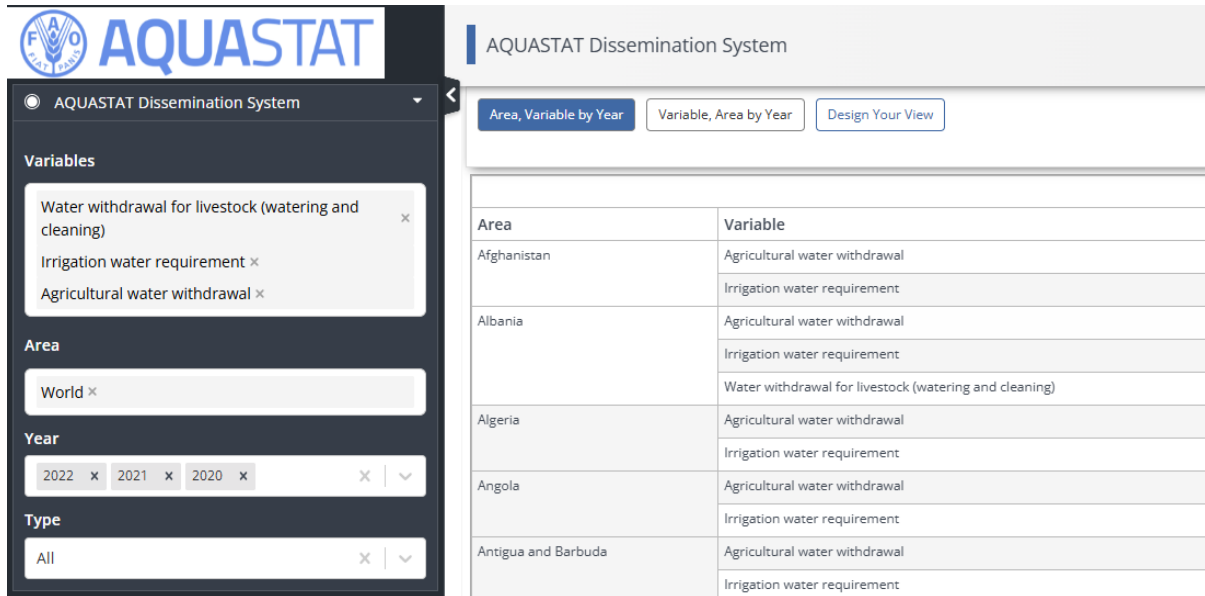


Figure 6: The AQUASTAT database

### 3.7 Input data – other

Although most of the data can be found in international databases, some of the data was not possible to find on a global level. In the Input data – other sheet, this data has been collected.

The first part of the data relates to costs for the crop sector. The investment costs for greenhouses and hydroponics are collected here based on numbers found online. For hydroponics there is also a calculator to estimate the cost in another country. The fixed O&M is based on rental cost of land, which in the repository is based on numbers for Sweden found in Eurostat.

The investment cost and fixed O&M for forests is included on this sheet, and the current reference is based on a Swedish source, so here an estimate must be found for the country in question.

The manure used for energy production should be given here. The source used refers to European data, but the user can also find national statistics on the use of manure for energy production.

The last parameter is the cost of transportation of manure to the energy production facility. It was decided to keep it in the AFOLU module although some TIMES-models might already have a delivery cost associated with manure for energy production. In that case, it should be set to Zero in this sheet. The number is hard to find on a national level and here, a paper on biogas in Denmark has been used to estimate the transportation costs.

In the lower part of the sheet, the split on subtypes is given. The first two are for crops and animals. The last table is for estimating the amount of manure management system per type of animal. These data might be possible to find on country level, else one must use an estimate, e.g., the

level of organic crops can maybe be found overall but not on subtype of the crop – then this can be used for all crop types.

### 3.8 Irrigation shares

In this sheet the data on water consumption per crop type is calculated. The data is based on data from FAO's crop calendar<sup>7</sup>. The data here does not need to be updated, however, FAOSTAT might come with an update to the database in which the water consumption per crop type becomes directly available. In that case, the AFOLU module can be updated to utilize the data directly from FAOSTAT.

### 3.9 DefaultAFOLU

This sheet includes background data for all the sectors for which there is no global data available. The data is based on different sources found. The data points in the sheet can potentially be updated when data becomes available, but the structure needs to be kept as is for the model to work properly. The data in the sheet includes a lot of different data points from lifetime manure management systems over water consumption of animals to biomass potential of straw from cereals. An overview of the data for each subsector is provided in Table 5.

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<sup>7</sup> <https://www.fao.org/aquastat/en/databases/crop-calendar>

Table 5. User hypothesis embedded in the AFOLU module

Category	Parameter	Description
Crop	CAP2ACT Ratio	Ratio to Open Field Yield, representing how much more tons of the crop a greenhouse, aquaponic or other growing method are compared to Open Field)
	Water Ratio	Ratio to Open Field Yield, representing how much more water consumption a greenhouse, aquaponic or other growing method are compared to Open Field)
	Biomass potential	Ratio between the mass of produced primary production and biomass straw
	Yield Reduction Ratio	Reduction from open field to organic cropping
	Energy content	Energy content of straw
Livestock	New Capacity Cost	Dummy cost for installing new livestock capacity
	Methane Yield	Energy content of methane
	Manure	Tons of manure per type of livestock
	Water consumption	Water consumption factor per livestock
	Water ratio	Water consumption farm animals compared to grassing
Forest	Wood Type	Wood type used to produce energy biomass
	Density (kg/m <sup>3</sup> )	Density per wood type
	HHV (MJ/kg)	Higher Heating Value per wood type
Manure	Activity Cost	Variable cost for emission removals by manure management
	Lifetime	Lifetime of the technology
	Reduction Factor	Emission reduction per manure management technology