



My First CLEWs Country Model

Guidelines for a complete CLEWs model

Aims and Objectives

This resource provides guidance for those who have completed the OL course 'Introduction to CLEWs' available at '[Open Learn](#)' and are seeking to take the next step and develop a country model. There are four key components of this resource followed by future guidance, references, and an appendix:

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How to use this Resource

The below instructions are designed to help you find and format the data for building your country model for use in the **UNDESA 'OSeMOSYS' User Interface** (abbreviated UI) as used in Hands-on-1 of the Open learn course 'Introduction to CLEWs'.

Some key differences with the Hands-on OL course to be aware of:

- Days and Seasons (we suggest using **4 seasons** and **2 day types**)
- There are more 'Naming conventions' regarding technologies and commodities to be aware of (see and they need to be spelt correctly for the OSeMOSYS-Cloud to recognise them.
- The model will operate from **2020 – 2050** (or 2070) - not just four years!
- Scope for customisation - you will decide what technologies /commodities to build into the model.

It is important to build the model horizontally:

E.g. MINCOA->PWRCOA001 ->ELC001->PWRTRN ->ELC002, that is, one supply chain at a time, from resource to final demand, and then run the model.

And then, for the next supply chain: MINHYD ->PWRHYD001-> ELC001-> PWRTRN -> ELC002.

- You will need to 'run' the model regularly to see if it works – if it doesn't 'run' you can find the error easier if you build horizontally.
- To check for data input errors, you can use this website before running the model:

<http://lee2d2.pythonanywhere.com/>

Health Warning: Attempting to use this resource without first completing the Open Learn Course 'Introduction to CLEWs' will cause mass confusion, dizziness and in some cases nausea.



Energy

Finding Energy Data: CCG's Starter Data Kits

Go to <https://climatecompatiblegrowth.com/starter-kits/> and find your assigned country. Click the first link then scroll down and open the file that has **SAND** and **BASE** in the title - this will open an excel spreadsheet with all your necessary data. It covers a time period from 2015-2070 so when entering the data you will need to copy and paste it into the OSeMOSYS User interface – (use **Ctrl C** and **Ctrl V** to do this). In your country model we want to cover 2020-2050.

Note 1: you are building a CLEWs model, but the interface is called OSeMOSYS as that's the underlying code

Note 2: If your country does not have a starter kit, you may proceed with one of the following options: a) pick a country, not yours, that does have a starter kit, you'll still be able to learn the concepts; b) if you are already familiar with the data needs for an OSeMOSYS energy system model and you can retrieve good data yourself, use those for energy (you may then follow all instructions for the other systems); c) if none of the above works, refer to the tutors.

Please note the different 'pages' the tabs at the bottom of this SAND spreadsheet. The 2nd tab 'SETs' for example highlights in detail the complex naming conventions you will need to use in the model- for example 'PWR SOL' might not be accurate if it's a specific type of solar power plant you are adding (i.e. off grid or on-grid utility solar).

Also, make sure all the columns are visible A-L in the sand spreadsheet .

To find the necessary data to populate your model will need to click on the 'Parameters' tab and then apply filters to the columns to find the correct data.

Please note that there are currently only stater data kits for LEDCs. For EU countries, for which there are no starter data kits either, you may use the datasets of a recently published electricity system model of the EU27 + Norway, Switzerland and UK. The model is called OSeMBE. The data sets are available publicly on GitHub, at this link: [GitHub EUdata](#). The data is divided by OSeMOSYS parameter. However, for each parameter the data for every country in the EU + 3 is given, so you need to extract the data related only to the country of your interest by filtering names containing at the beginning the two-letter code referring to the country of choice. For reference on 1) how to read the data, 2) the sources of the data, 3) the naming convention utilised, you may refer to this publication: [EUDataOpenSource](#). for further questions on the data sets you may contact the corresponding author of the paper. For suggestions of improvements of the data sets you may open 'issues' in the model's GitHub repository.'



Can you find your own data?

The short answer is, yes. To further that, you should actively look to get more accurate UpToDate data. The strong recommendation, however, is to first use the data within the starter data kits which this resource is catered around. An explanation on how to update starter data kit data can be found in the Appendix at the end of this document if you want to create a more accurate and detailed model.

Model Making Guidelines (Energy)

When following the guidance, make sure you read the entire step before commencing.

Step 1.

Do some research on your country's current energy system. Identify the largest two different types of power plants they use. Also consider what type of powerplants the country might invest in, in the future, or that you would like to see them invest in. Thus, you should develop a list of at least 6 different powerplants, using 6 different resources, that you want your model to consider i.e., refrain from having a large natural gas and a small natural gas powerplant as they use the same commodity (NGS). They should be a mix of fossil fuel and renewable. Also include hydro if the country has that potential.

Now pick one powerplant to initially add to your model, ideally the largest power plant your country currently uses. Please note that the naming conventions are more detailed than in the hands-on exercises. Use the 'SETS' tab/page in the SAND spreadsheet to work out what the more detailed naming conventions refer to. However, you may simplify the naming convention in tune with the OL course. i.e. PWRCOA001 can just be PWRCOA (the OSeMOSYS cloud does not recognise numbers currently in naming conventions).

Note: off-grid solar is referred to as PWSOL002 in the Sand spreadsheet (and has significantly higher capital and fixed costs than PWSOL001 which refers to large scale 'utility' solar farms). If you want to include off-grid solar in your model convert PWSOL002 into PWRPVR.

Eg., MINSOL -> PVR (&SOL) -> PWRPVR -> ELC002

(It is unlikely off-grid solar will appear on your graphs due to its costs vs. on-grid solar if you have both)

Step 2.

Start a new model on the OSeMOSYS interface - give it a title (Country name and your initials), 4 seasons and two day types, USD currency and a timespan of 2020-2050. Add Your first powerplant and all the other relevant **horizontal** information.

For example, add the 'commodities' (i.e. ELC001/ELC002 and the 'technologies' that produce the commodities, i.e. the MIN***/ technologies and PWRTRN (electricity transmission tech) alongside the power station.



NOTE: On the BASE SAND sheet for your country, PWRTRN will have an Output Activity Ratio of 0 for ELC002. This is because these kits are designed for detailed energy modelling and they include PWRDST as a technology (electricity Distribution), which would usually have an Output Activity Ratio of 1 to ELC002. As we are **NOT** using PWRDST in these CLEWs models, **you need to add a value of 0.96 for the Output Activity Ratio of PWRTRN to ELC002 (that is, we are considering Transmission and Distribution together).**

Now add the relevant **input and out activity ratio** data for your first power plant across **all years (2020-2050).**

Step 3.

Once this is done it is important to add an energy demand to the model. As this is 'energy' we need to input data that concerns '**year split**', '**specified demand profile**' and '**specified annual demand**' (as demand for energy fluctuates across days and seasons).

We will begin with '**YEAR SPLIT**'. In your country's model we suggest you use 8 time splices: 4 seasons and two day types (so adjust your model accordingly, note that in the hands-on exercises we only had 2 seasons and two day types). Next go to the '**year split**' parameter in the OSeMOSYS user interface (where you are building your model) and add **0.125** to all 8 time slices for all years. This means that you are dividing the year in time slices of equal length. This is an assumption, which you may want to change later when you work on improving your model.

Step 4.

Now we need to add a '**specified demand profile**'. As the SAND spreadsheet operates on the basis of 96 time slices, we need to convert it to 8. Open up the spreadsheet converter (a supplementary file) . The left side of the spreadsheet is concerned with the 96 time slices of data, change data here to receive the required 8 slices of data on the right side of the page.

To obtain the 'specified demand profile' data, open your country's SAND spreadsheet and apply the filters 'Specified demand profile' to 'parameter' and 'INDEL' to 'fuel' - INDEL refers to industrial demand. Copy the data from one yearly column (96 entries) into the spreadsheet converter under the correct column and this will provide you with **eight digits** in the respective column on the right side of the spreadsheet.

Copy and paste these digits into your OSeMOSYS model – under **specified demand profile** - for ELC002 for all years.

See this youtube video on how to reduce timeslices: [reduce time slices](#) for guidance (in the 2nd part of the video it discusses inputting the data into another SAND spreadsheet- you however, will input into the CLEWs 'OSeMOSYS' UI).



Note 1: There is a new faster way to do reduce timeslices. See this YouTube video: [timeslices macro](#) for guidance (this is recommended as you will need the capacity factor information later). This will change the data in the starter data kit automatically ready for you to copy the new data to the user interface without needing to convert timeslices.

Note 2: As you may remember, for both the Year Split parameter and the Specified Demand Profile parameter, the summation of the values over all time slices in one year needs to be 1. Cross-check that this is the case, otherwise your model will not work.

Step 4.

Finally, we need to insert data into the '*specified annual demand*' parameter.

Note that the SAND spreadsheet divides energy demand into **three** (commercial, residential and industrial demand) – for the purposes of our model we will combine this into one. To do this, on the SAND spreadsheet apply the filters 'Specific Annual Demand' and (under fuel) INDELC, RESELC and COMELC. Use a different spreadsheet to add up all three values for all years considered and then input this data in your own OSeMOSYS model under the 'Specific Annual Demand' parameter, for ELC002.

Step 5.

Now that you have 'demand' and the input and output activity ratios between all your technologies and commodities, your model should be able to run. Only proceed beyond this step if your model runs successfully.

Note: If your model fails at this stage, check the previous steps, make sure in particular that your input and output flows are correct on the configuration home page (under the technology tab).

Step 6.

Now add your remaining 5 power plants following the instructions **outlined in Step 1.**

Be sure to do a run each time you add a single power plant, with the data, to make sure no data input mistakes have occurred.

At the end of step 5 and 6 you will likely not have sensible results, because you have not input the techno-economic information in the model. That information is essential because the cost-minimisation operated by OSeMOSYS is based on it. So, as long as the model runs, do not worry too much about unreasonable results. Just make sure that the energy supply meets the demand and that both figures are reasonable.



Step 7.

If your model still runs, copy your model (to save it) and add additional data for your 1st power plant technology in these parameters for all years (between 2020-2050). All this data is available from SAND starter data kit and the figures may change over time:

- *Capital Cost (\$/kW)*
- *Fixed Cost (\$/kW/yr)*
- *Variable Cost (\$/GJ)*
- *Operational Life (year)*
- *Capacity To Activity Unit (GW/x)*
- **Capacity Factors – no unit - Needs to be converted (from 96 to 8) via the time slice conversion sheet (see step 3)**
- *Discount Rate - can be found on the Country Appendix document (10%=0.1)*
- *Residual Capacity - GW*
- *Emission Activity Ratio (kg/GJ) Divide by a 1000 before adding to CLEWs model (if you have forgotten how to add this parameter revisit hands-on-9 from the OL course)*
- *Total Annual Max Capacity (GW)*
- *Total Annual Min Capacity (GW)*
- *Total Annual Max Capacity Investment (GW)*
- *Total Annual Min Capacity Investment (GW)*

Step 8.

Once this data is added to your **first power plant**, run your model to check if it runs successfully, and then copy your model again.

Step 9.

With this new model copy, begin adding this data (from step 7) to all your power plants, If the model fails to run at any point- or the graphs on the cloud are erratic please use <http://lee2d2.pythonanywhere.com/> to find troubleshoot errors.

Remember to back up /copy your model regularly- it should be saved as a zipped (.zip) folder!

Note: this website/diagram: [IEA.sankey](#) from the 'International Energy Agency' which provides a lot of the underlying data for the SAND spreadsheets - particularly regarding 'demand'.



Step 10: Check Naming Conventions

In the online OSeMOSYS cloud where the graphs are produced, the model won't differentiate between different power plants of the same resource. I.e., on grid solar (PWSOL001) and off grid solar (PWSOL002) will be combined and not differentiated (See note in Step 2). **This is important if you wish to add more power plants from the Starter Data Kit** in the future.

This issue of combining commodities/technologies will occur in other contexts, for example big hydro (PWRHYD001) and small Hydro (PWRHYD002) - the cloud graphs will merge them together. If you want to see them separate, you will need to call the small one something else and make your own 'key' i.e., call it PWRGEO (and the commodity going into its "GEO") and make a note that geothermal on your graphs is actually Small Hydro.

If you have made changes, check that you re-did your output and input activity ratio's.

Use this Link to find alternative names that the 'model' and 'cloud' can read: [Cloud Naming Conventions](#)



Land

When following the guidance, make sure you read the entire step before commencing.

You have already added energy to your model, now it is time to accompany it with Land-Use data. Please note it is important that units are consistent, if mathematical units are unfamiliar to you, visit the 'Units' resource (supplementary file).

Before beginning these steps, copy and save your energy-only model!

Step 1: Country Size

First, add the 'technology' **MINLND** to your model and the 'commodity' **LND**. Then find out how large your country is in km^2 using this link: [world in data](#)

In our OSeMOSYS model 1 unit is = to 1000sq km if you are using the **unit 10^3km^2** . So work out how many units your MINLND is worth and round it up or down appropriately. E.g. Zambia **$743,390 \text{ km}^2 = 743 \text{ units}$** (10^3km^2).

It is important to remain consistent with your units throughout this Land Use stage. In other words, whenever you add land use data it must be converted to 10^3km^2 if that's the unit you've chosen to represent your land in your model.

Step 2

You then need to apply this figure (total land units) to your model, for all years, using the parameter '**total technology annual activity upper limit**' and apply it to MINLND. (E.g.) For Zambia this is 743.

Step 3: Including Crops

Now we need to decide which crops to add to our country's Land Use. The table below is a good way to group all of this data together in one table before inputting it into the model, you can set it up in excel.

NOTE: This isn't a necessity, but it can be helpful for setting up which crops you want to use and having a copy of the information should you need to refer back to it at any point.



Zambia	Crop Name	Naming Convention	Area Harvested (10 ³ km ²)	Production quantity (Kton)	Output Activity Ratio (per unit of land)	Capital Costs (Million dollars per 10 ³ km ²)	Operational Life (years)
	Crop 1 Rainfed					10	15
	Crop 1 Irrigated					80	15
	Crop 2 Rainfed					10	15
	Crop 2 Irrigated					80	15
	Crop 3 Rainfed					10	15
	Crop 3 Irrigated					80	15
	Crop 4 Biofuel					10	15

Step 3a:

We will add four different crops to our model, and for three of them, we will separate into rainfed and irrigated.

Using the resources provided ([FAOSTAT](#)), we suggest you work out which is your country's three 'largest' crops. I would choose the two largest in terms of **area harvested** and the first largest in terms of **production** in the most recent year. E.g. for Zambia 2019 this was Maize (841693 ha) Groundnut (208483 ha) and sugar cane (4682000 tonnes).

Input this data: Crop name, 'Area harvested' and 'production quantity' into your table (adjust the units accordingly).

Note: if your 'biggest' crop is described as "Cereals n.e.c." this refers to 'Teff'.

Step 3b:

Also add a fourth crop that can be converted into a biofuel – so include one of these 'biofuel' crops too into your model (one that is not the same as your first three): **Maize, Rapeseed/Canola, Sugarcane, Palm Oil, Jatropha, Soybeans, Cottonseed, Sunflowers, Wheat or Switchgrass**. *For the Zambia example below, Sunflower has been chosen.*

To work out the naming convention for your crop, please use the relevant supplementary 'naming convention' file. If you can't find a naming convention for your crop use 'OTC' - this will show up on your graphs as 'other crops'.



Once completed your table should look something like this:

Zambia	Crop Name	Naming Convention	Area Harvested (10 ³ km ²)	Production quantity (Kton)	Output Activity Ratio (per unit of land)	Capital Costs (Million dollars per 10 ³ km ²)	Operational Life (years)
Crop 1 Rainfed	Maize	CRPMAI(HR)	8.417	2004		10	15
Crop 1 Irrigated	Maize	CRPMAI(HI)	8.417	2004		80	15
Crop 2 Rainfed	Groundnut	CRPGRO(HR)	2.084	130		10	15
Crop 2 Irrigated	Groundnut	CRPGRO(HI)	2.084	130		80	15
Crop 3 Rainfed	Sugar Cane	CRPSGC(HR)	0.5	4682		10	15
Crop 3 Irrigated	Sugar Cane	CRPSGC(HI)	0.5	4682		80	15
Crop 4 Biofuel	Sunflower	CRPSUN(HR)	0.6	34		10	15

Step 4: Output Activity Ratios

To work out an output activity ratio for any crop we need to know the number of tonnes (**production quantity**) that this much land produced for that crop. For example, in 2019, Zambia cultivated Maize in **841693 ha** of land and produced **2004389 tonnes** of maize from that land in that year.

We now need to convert these units correctly for our model:

$$841693 \text{ ha of land} = 8417 \text{ km}^2 \text{ of land} = 8.417^3 \text{ km}^2$$

2004389 tonnes = **2004** kTon. *(If more than four figures or less than one, consider using different units to kTon- but must be the same for all crops)*

We now need a ratio of what one unit of land (10³km²) can produce. In the example outlined above this would be = 2004/8.4.

So the ratio is = **238 (units of produce):1 (unit of land)** (and thus the output activity ratio for this crop would be: **238**)

Use this technique to find out the output activity ratio for your **biofuel crop (Crop 4)** and input this figure into your table under Output Activity Ratio for Crop 4.

Step 5

This above technique to calculate the ratio of productivity accounts for both rainfed and irrigated arable land into one unit. For our other crops we want to split this average i.e. find out the different output activity ratio of irrigated and rainfed crops.



To work this out we need to do some maths!

First find out how much more efficient irrigated land is at producing crops (in your chosen country) and also how much of your arable land is currently irrigated. These figures are available at [FAO AQUASTAT](#) database under the parameters ‘Ratio between irrigated and rainfed yields’ and “% of the cultivated area equipped for irrigation”.

So, to continue the Zambia maize example let's assume that in Zambia that there is **6 % of the cultivated area equipped for irrigation** and that the **Ratio between irrigated and rainfed yields** is **2.3** i.e. irrigated crops are 2.3 x more productive than rainfed. Thus, if we assume that 6% of all Maize has been irrigated in Zambia, *then rainfed land has instead an efficiency of:*

- **6%** of **8.417³km²** = **0.505³km²** of irrigated land -*update your table with this figure*
- 94% of **8.417³km²** = **7.912³km²** of rainfed land-*update your table with this figure*
- Rainfed yield = Production / ((Irrigated land x **2.3**) + (Rainfed land))
- = **2004** / ((0.505 x **2.3**) + (7.912))
- = **220.8 ktons per 10³km²**
- Irrigated yield = 220.8 x **2.3**
- = **507.8 ktons per 10³km²**

We now have two key output activity ratios for our model Rainfed Maize = 220.8 and Irrigated Maize = 507.8 Ktons per 10³km².

Now using this example as a template, work out the Output Activity Ratio for crops 1-3 in your table, both rainfed and irrigated, and add the relevant figures to your table.

The data in your table should also change based on the maths done, for example crop 1 would look like this:

Zambia	Crop Name	Naming Convention	Area Harvested (10 ³ km ²)	Production quantity (Kton)	Output Activity Ratio (per unit of land)	Capital Costs (Million dollars per 10 ³ km ²)	Operational Life (years)
Crop 1 Rainfed	Maize	CRPMAI(HR)	7.912	1747	220.8	10	15
Crop 1 Irrigated	Maize	CRPMAI(HI)	0.505	257	507.8	80	15

Step 6 Developing the Model

Now the table is complete we will add these crops to our model one at a time, making sure we run the model first, before adding another.

The model structure we will now use and create for our models is:

MINLND → LND → LNDMAIHR/HI → CRPMAI (but use your own crop 1).



In other words we are inserting the row 'crop 1 rainfed' from the table (using the output activity ratio we have worked out and the input activity ratio as '1').

So you need to add a rainfed Crop technology (LND*HR) and a crop commodity (CRP***) to your model**

Step 7

Before you can run your model, we need to add a **demand** for crops. Using the FAO stat website: [FAOSTAT](#), search for the parameters "production" "export" and "imports" alongside your chosen crop in 2019. To work out demand use this formulae:

Demand = production + imports - exports.

Note that the data provided by FAO stats here is presented in Ktons - If you converted to Ktons in the previous steps as advised, then you do not need to adjust figures.

For future demand we will need to make a forecast by considering population increase. Research the population stats for your country and discover the current % increase: [world population review](#).

Now apply this % increase to the 2020 demand figure. Do this continually across all years (for example you might be increasing the 2020 demand by **1.5%** every year until 2050 etc). Use Excel to do this quickly using a formula and then drag the formula across relevant cells (see [Excel % >](#) e.g. =SUM(1+**1.5%**)*[2020 demand]). Once you have done this, input the demand figure into Accumulated Annual Demand in your model for that Crop for all years. Then run your model. **Don't continue until the model has successfully run.**

As with energy demand, you could create a table summarizing this demand for all your different crops across four intervals (2020; 2030; 2040; 2050) and the unit used (i.e. kTon). This may be helpful to monitor data used and if you ever need it for future work.

Step 7b

We now need to input some additional data to our crop (regarding costs). This is added to the relevant LND***HI/R technology (e.g. LNDMAIHR) in these parameters:

Capital Costs: Rainfed: 10 (million dollars per 1000Km²)

Irrigated: 80 (million dollars per 1000Km²)

Operational life: 15 years (both rainfed and irrigated)

Also include:



Residual Capacity- this figure is the *area harvested* (see the workings out in step 5) in the **first year** of your model, 2020 (use the correct unit/decimal place). You then need to taper/slowly reduce this figure **to zero** over 15 years i.e. in 2035 this figure needs to be 0 (you can apply a linear reduction).

Now run your model. However, on the online cloud platform make sure you select **LARGE Server** (your model is likely too big now to run on the small server - over 28 technologies). Note that if you do not select LARGE server the model may fail to run. This may happen also in a previous step if you have added more data and technologies to your model than we suggested.

Step 8

Save and copy your model. Repeat Steps 6 & 7 for all your other crops (irrigated and rainfed). Run your model regularly to spot data input errors early.

Step 9: Non-agricultural Land-Use

In this activity, you will add four more Land use technologies (and their respective commodity) to include other non-agricultural land cover types: forests, built-up land, water bodies and other land.

Add to your model the new Technologies and Commodities highlighted:

MINLND -> LND -> **LNDFOR-> LFOR**

MINLND -> LND -> **LNDBLT-> LBLT**

MINLND -> LND -> **LNDWAT-> LWAT**

MINLND -> LND -> **LNDOTH-> LOTH**

For **'input'** and **'output activity ratio'** use the unit **'1'** for all the above.

Next, let's add some **Variable Costs** to these four new LND technologies:

LNDFOR = -2 (minus USD million)

LNDBLT = 2 (USD million)

LNDWAT = 2 (USD million)

LNDOTH = 0 (USD million)

Now run your model and look at the Land use graphs.



If you followed the instructions regarding variable costs, it is likely your forests dominated your countries land use.

The model is showing high forest land use because we have made it the most economically lucrative option based on how we entered variable costs. There is also a little agricultural land too because there is a demand for the model to produce crops- however, there is no demand for BLT or WAT and they are expensive to have relative to forests (forests provide income due to the minus number applied in 'variable costs'), thus they are not shown in the graphs.

Remember the model does not produce reality – it produces the most 'economically viable' solution based on the assets (technologies) and data the model has available to use.

Step 10: Adding Constraints

To compensate for this high level of forest land-use, we will now add similar parameters/constraints to our country models as we did with the hands-on exercises . **Save and copy your model first!**

Using 'stats OECD' - [Land cover in countries and regions](#), discover what the rate of change for artificial surfaces (Built up land) is in your country (note that the units in this resource are 10^3km^2). On this website **choose the measure as Square km** (located on the top of the page) then find your country information for the earliest year to the most recent .

For example Zambia's artificial surfaces increased from 0.5 (10^3km^2) in 2005 to 1 in 2019. (a 100% increase in 14 years). Add this information to your model via the parameter '**Accumulated Annual Demand**' for LBLT for all years i.e. project this % increase into the future.

You can use this: [percentage-increase-calculator](#) (then divide by year gap) to work out how much to increase the % by each year.

Step 11

Do the same as above with water bodies (referred to as 'inland water') but keep *the figure stable* throughout your time period in the parameter '**Accumulated Annual Demand**'. Now run your model and compare your land use graphs with the previous.

Step 12

You should also add data to the parameter "**Total Technology Annual Activity Lower Limit**" for forests. Use the tree cover data in 'OECDstat' -**work out the % it is declining or increasing, then multiply the 2020 value to create a projection for the modelling period and add it in here.** This will put a minimum requirement on how much land for forests your model will use.



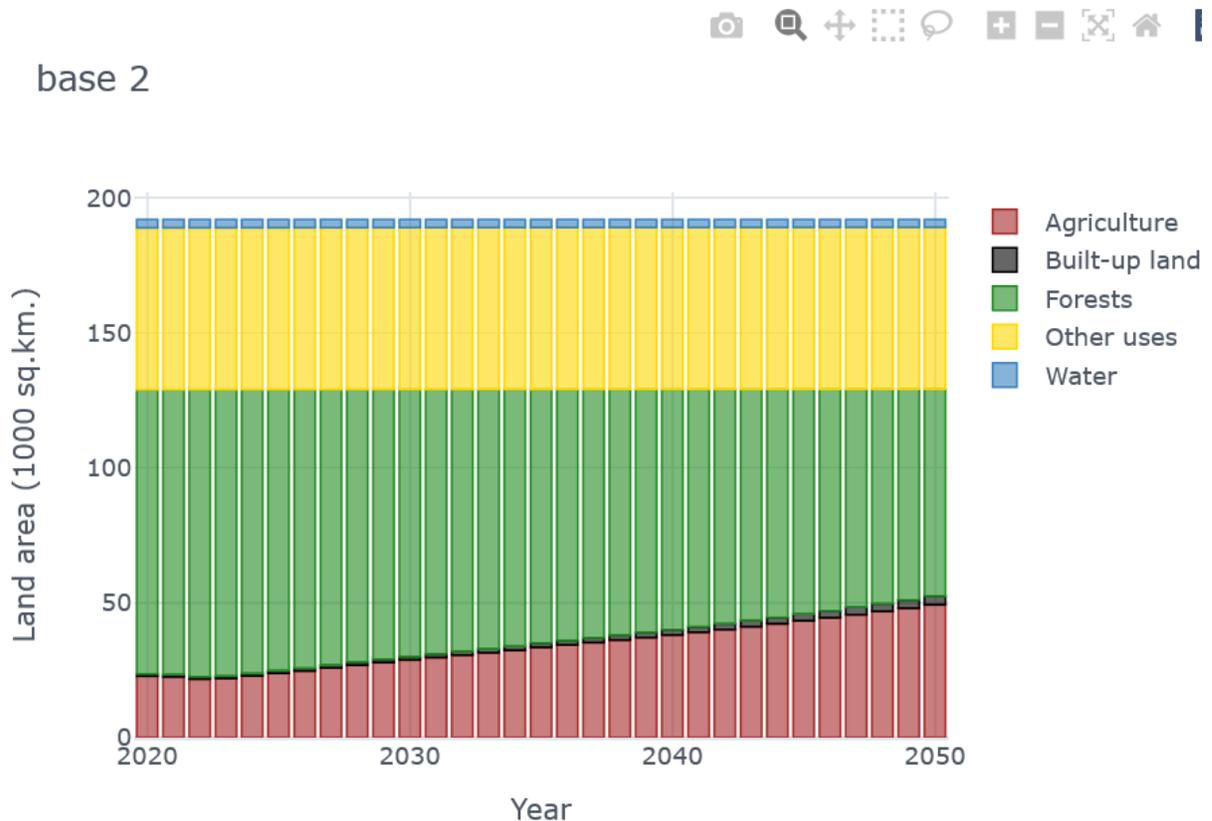
Step 13

We will now put in some data for LNDOTH. Go back to this resource: 'stats OECD' - [Land cover in countries and regions](#) (it takes a while to load) and change the top field to "square kilometres". Find your country and the data for 2019 (or the latest year available). Add together the data for **Grassland, Wetland, Shrubland & Sparse Vegetation, Bare area** and use this figure for "LNDOTH- Total Technology Annual Activity Lower Limit".

The 'Area by Land Cover Type' graph should appear 'full' - there should be a flat line across the top and it should correspond to the value you first inputted for MINLND.

The model in this graph (i.e. the models solution) implies that as crop demand increases, the more economically viable forest land has to give way to agricultural land.

Area By Land Cover Type



Check the rest of your graphs are showing and are not erratic; now save your model (using the 'backup model' tool) and then copy it before proceeding further.



Water

In this part, you will include elements of the water system and water cycle. Since the water cycle passes through land (via precipitation that falls on land and evapotranspiration, groundwater recharge and water runoff that goes through the land), the water system model will be tightly connected to the land technologies you have already created.

Crucial data for your country can be found here: [AQUASTAT database](#). It is a very slow website so let's use it now to find all the relevant data for this session in one sweep:

You need to find the data for these listed variables for the most recent year for your country:

- Long-term average annual precipitation in volume
- Area equipped for full control irrigation: total (1000 ha)
- Irrigation water requirement
- Irrigation water withdrawal
- Industrial water withdrawal
- Municipal water withdrawal
- Irrigation Potential
- % of irrigation potential equipped for irrigation
- Total renewable surface water
- Total renewable ground water
- Total water withdrawal

Now click **'show data'** (top right)

Now click **'download'** - so you have a copy and a semi ready-made table for your future reference.

NOTE: sometimes there is missing data for countries, if so let us know on the [google group](#) and we will try to help you work around it.

Step 1: Adding Water Technologies and Commodities

Add five new commodities (WTRPRC, AGRWAT, WTREVT, WTRGWT, WTRSUR) and one new technology (MINPRC).

In the Technology tab:

- Ensure you have MINPRC producing WTRPRC as an output
- and WTRPRC as an input for all technologies beginning "LND".



- The output, for all the technologies beginning with LND, are the three water commodities WTREVT, WTRGWT, WTRSUR.

(The definition and description for all these Commodities & Techs can be found in [HOZ](#) page 7+)

Now complete this parameter in your model:

Technology	Commodity	Value	Parameter
MINPRC	WTRPRC	1	Output Activity Ratio

Step 2

Now we need to work out the two key water input activity ratios for your country. The first refers to rain or the precipitation volume for your country per unit of land. Use the FAO AQUASTAT link provided to find '**Long-term average annual precipitation in volume**' for the latest year in your country's data set.

[AQUASTAT database](#) (The unit 'volume' used in this database is 10^9m^3)

Divide this digit by your total land area - for Zambia approximately $767.66 (10^9\text{m}^3) / 743(10^3\text{km}^2) = 1.0$ **(rounded to significant figure)**

Note: If your unit is smaller than 0.1, convert the rainfall to 10^6m^3 **throughout your model.**

This number will now be referred to as '**X**' and is now your input activity ratio water commodity (WTRPRC) value.

Insert this value '**X**' as the input activity ratio for all WTRPRC to all LND technologies.

Note: This step means that you are assuming precipitation falls uniformly (same quantity per unit of area) on all land areas/types in the whole country. Of course, this is only an approximation and in a more detailed model you may have to change it.

The second water input is used for irrigation (AGRWAT). Add this as an input for all your irrigated crops using the technology tab.

For the input activity ratio number:



1. Turn the number for “**Area equipped for full control irrigation: total (1000 ha)**” from 1000 ha unit to 1000 km² unit.
2. Divide the “**Irrigation water withdrawal**” (in 10⁹ m³, or in 10⁶ m³ if you set this as the water unit) by “**Area equipped for full control irrigation: total**” (in 1000 km²).

For example, in Zambia the area equipped for full control irrigation is 55.39 (1000 ha) = 0.5539 (1000 km²). The irrigation water withdrawal is: 1.15 (10⁹ m³). So the input activity ratio is: 1.15 / 0.5539 = is figure is: **2.08 (Y)**.

Note: with this, you are assuming that every irrigated crop requires the same amount of water, equal to the average water need for irrigation in the country. With more detailed data, you could differentiate the irrigation water need by crop.

Input water commodities			(LND****)
WTRPRC	AG RWAT	TOTAL (not for UI)	
X (1)		1	Crop 1 Rain-fed
X (1)	Y 2.08	3.08	Crop 1, Irrigated
x		1	Crop 2, Rainfed
x	2.08	3.08	Crop 2, Irrigated
x		1	Crop 3, Rain-fed



x	2.08	3.08	Crop 3, Irrigated
x		1	Crop 4, biofuel
x		1	LFOR
x		1	LBLT
x		1	LWAT
x		1	LOTH

Step 3

Now we need to add the Output activity ratio value for WTREVT, WTRGWT, WTRSUR for crop type. In reality this value will be quite different for each crop type and land use. For simplification, however, we will use the averages shown in the table; work out the correct Output Activity Ratios *as a percentage of value X or (X + Y) for irrigated crops*).

(For slightly more precise figures, we may have the global average for some of your crops on this document: [Water Use Averages for Crops](#) for you to use instead.)

Feel free to round figures up and down to make the maths easier, however make sure WTREVT, WTRGWT and WTRSUR all add up to X (100%) in total (or X + Y for irrigated crops).

(If you are maths impaired- use this: <https://percentagecalculator.net/>)

For example:



Zambia	Output activity ration for water commodities		
	WTREVT (Evapotranspiration)	WTRGWT (Groundwater recharge)	WTRSUR (Surface Runoff)
Rainfed crops	42% of X (which in Zambia's case is 42 % of 1 so: 0.42)	6% (of X): ?	52% (of X): ?
Irrigated crops	42% of X+ Y (which is 42 % of 3.08 in Zambia's case): 1.3	6% of (X +Y): ?	52% (of X + Y): ?
(Forests)	1% (of x)7:	2.5%(of x): ?	26.5%(of x): ?
(Built-up land)	63%(of x): ?	3%(of x): ?	34%(of x): ?
(Water bodies)	33%(of x): ?	7%(of x): ?	60%(of x): ?
(Other Land)	71%(of x): ?	2%(of x): ?	27%(of x): ?

Create this table and do the sums for your own data so you can keep track.

Note: that these % are blunt averages - in 'real' CLEWs models you would have to research the specific % for each country and crop (even the same crops in different countries have very different %).

Step 4

In this next step we include one new commodity PUBWAT, this represents our water demand.

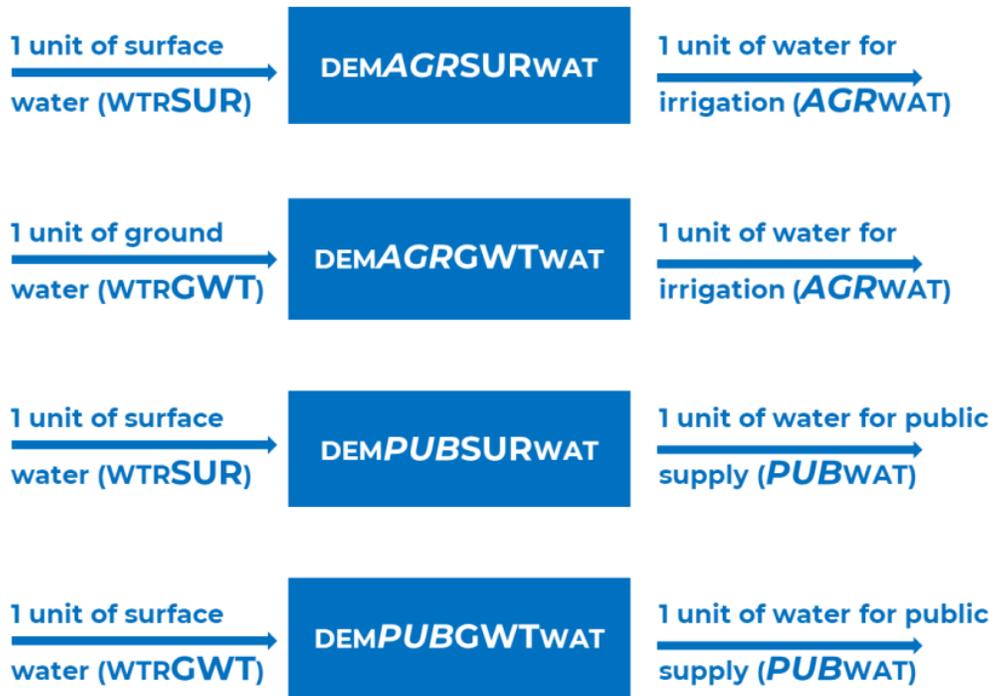
Use the FAO [AQUASTAT database](#) to find this figure out (e.g. add together *industrial water withdrawal* and *municipal water withdrawal* to get your demand figure (enter this into **Accumulated Annual Demand for PUBWAT**)).



For demand in future years, increase this figure by the rate of GDP growth. Use [statista.com '\(GDP\) growth rate Statista'](https://www.statista.com/statistics/1000000/gdp-growth-rate-statista/) and the projected 'stable' figure (for example Zambia = 1.45%).

Step 5

Now add four new technologies DEMAGRSURWAT, DEMAGRGWTWAT, DEMPUBSURWAT, DEMPUBGWTWAT. Add the correct inputs (WTRSUR/WTRGWT) and outputs (AGRWAT/PUBWAT) with these new techs accordingly:



As highlighted by the image above, the input/output ratios are 1.

Now run your model. If it's successful, copy it before proceeding (this is a good habit to have whilst modelling using the UI).

Step 6a: Adding constraints

To make the model reflect reality with more precision/detail it is useful to add constraints. Currently the model assumes that all crop land has the potential to be irrigated. However, in reality, this is not possible. Thus, we need to add a suitable constraint:

Find the variable 'Irrigation potential' in [AQUASTAT database](#) for your country and divide this figure by the number of irrigated crops you have. Then put this divided figure as a land restriction (using the correct



units) in your model via the parameter 'Total Technology Annual Activity Upper Limit' for all the relevant land technologies (all your *irrigated* crops).

Note: It's worth also keeping in mind the figure for “% of irrigation potential equipped for irrigation” – which might be relevant for future scenario purposes.

Now try a model run and compare the land-use graphs with the previous.

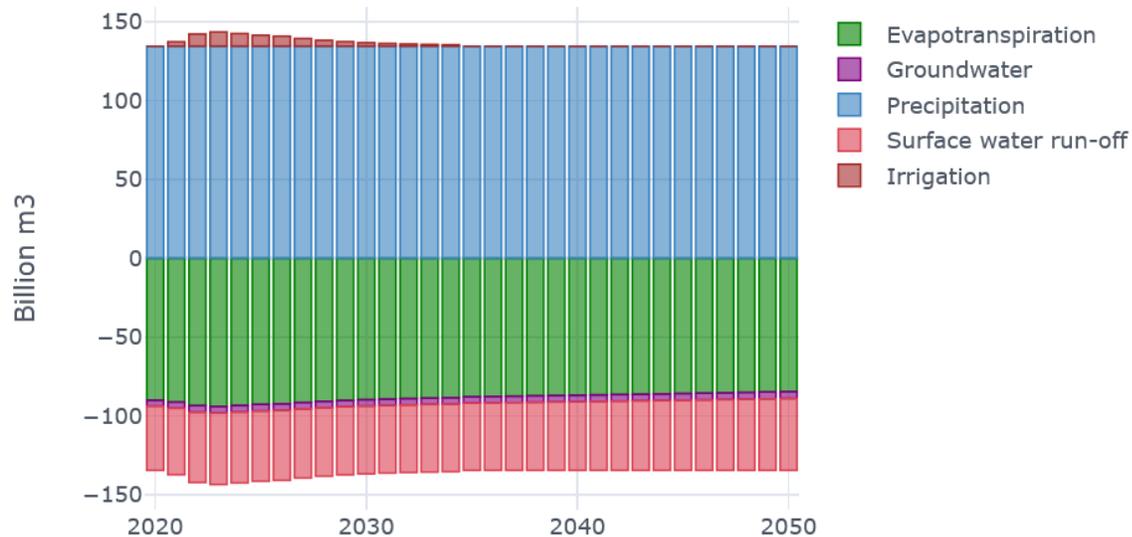
Step 6b

Another constraint we can use is in relation to 'renewable water'. Find the variable “Total renewable surface water” and half this figure to place a limit on the annual activity of DEMAGRSURWAT, and DEMPUBSURWAT by using the parameter “Total Technology Annual Activity Upper Limit”

Repeat this process again with “Total renewable groundwater” (Halved) and the technologies DEMPUBGWTWAT, DEMAGRGWTWAT.

Run your model, save and copy it if it runs successfully.

The graph for Water Balance should be beautifully symmetrical either side of 0 throughout all years i.e. the water going into the system (Precipitation and Irrigation), is equal to the water going out (Evapotranspiration, Groundwater and Surface Water Run Off).



From this graph, water for irrigation is only needed up to 2034 (peaking in 2023).



Interlinkages

We will now add linkages between the different systems to our model. This section generally follows the processes discussed in CLEW's hands-on exercises 'HO8' with some minor adjustments.

Step 1: Adding Crop Imports

Before adding these linkages, we should create import technologies **for every crop** you have (IMP***). This is because when using our model to run scenarios, we might put our models under stress i.e., there may not be enough land to produce the crops to meet demand.

When adding this technology there is no 'input' and the output is the relevant crop i.e., 'IMPMAI' would have the output of 'CRPMAI'. Don't forget to add an output ratio figure (which is '1') also!

We should also set a high **Variable cost and Capital Cost** for each crop import technologies we only want our model to import crops in extreme circumstances as a last resort. So input the figure 99999 (five '9's).

Also change '**TotalTechnologyModelPeriodActivityUpperLimit**' to 99999 (five '9's) for all crop import technologies so the model can use these technologies as often as necessary.

Step 2: Water for Energy

This activity will introduce the necessary links to capture the water needed for cooling in thermal power plants. You will introduce the following two new technologies and commodities to capture the amount of water that is to be used by the gas and coal power plants.

Name	Entity	Description
DEMPWRSURWAT	Technology	Technology to account for cooling water from surface sources



DEMPWRGWTWAT	Technology	Technology to account for cooling water from underground sources
PWRWAT	Commodity	Water for cooling in thermal power plants

The input and output connections between the different technologies are specified below. It is noticeable that in this example coal power plants will consume more water for cooling to generate a unit of electricity than gas plants. Once all the connections are made, rerun the model, and visualize the results using the online platform. The focus of this activity is on the results related to the water demand for the power sector.

Technology	Description	Parameters
DEMPWRSURWAT	Water supply technology that uses 1 unit of WTRSUR to produce 1 unit of PWRWAT	Input Activity Ratio & Output Activity Ratio
DEMPWRGWTWAT	Water supply technology that uses 1 unit of WTRGWT to produce 1 unit of PWRWAT	Input Activity Ratio & Output Activity Ratio
PWRGAS (add extra input to technology using the tech tab)	1 unit of activity of the gas powerplant requires 0.03 BCM of PWRWAT for cooling	Input Activity Ratio



<p>PWRCOA</p> <p>(add extra input to tech using the tech tab)</p>	<p>1 unit of activity of the coal powerplant requires 0.05 BCM of PWRWAT for cooling</p>	<p>Input Activity Ratio</p>
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Note: If you have a fossil fuel power plant in your model that is neither GAS nor COAL use the value **0.04**

Complete a successful run before moving on.

Step 3: Energy for Water

This activity will introduce the necessary links to capture the energy (electricity: **ELC002**) needs for different activities in the water system. Energy is needed for pumping water from surface and groundwater sources for irrigation, thermal power plant cooling, and public water supply.

It is essential to notice that the energy input is actually the electricity produced by the power plants. This creates a loop in the model that is essential for capturing the energy links. In this activity, no new technologies and commodities will be added. The following table details the necessary linkages and ratios that need to be established.

Technology	Description	Parameters
DEMAGRSURWAT	1 unit of activity of the water technology requires 0.1 PJ of ELC002 for pumping	Input Activity Ratio
DEMAGRGWTWAT	1 unit of activity of the water technology requires 0.2 PJ of ELC002 for pumping	Input Activity Ratio



DEMPUBSURWAT	1 unit of activity of the water technology requires 0.1 PJ of ELC002 for pumping	Input Activity Ratio
DEMPUBGWTWAT	1 unit of activity of the water technology requires 0.2 PJ of ELC002 for pumping	Input Activity Ratio
DEMPWRSURWAT	1 unit of activity of the water technology requires 0.1 PJ of ELC002 for pumping	Input Activity Ratio
DEMPWRGWTWAT	1 unit of activity of the water technology requires 0.2 PJ of ELC002 for pumping	Input Activity Ratio

Once the data entry is complete, **rerun the model and visualize the results using the online platform**. The focus should be on the increase in electricity demand due to the internal links. It shows that investment / development / policy decisions in one sector can have implications for another and cross-sectoral discussions need to happen!

Step 4: Energy for Land

This activity will introduce the necessary links to capture the energy needs for different activities in the land system. Energy (diesel) is used for operating agricultural equipment in the land used for crop cultivation. To represent the need for diesel inputs, you will need to create two new technologies (MINDSL and DEMAGRDSL) and two new commodities (DSL and AGRDSL) - Units in PJ.

The new diesel commodity will be consumed by the LND technology that represents crops. Note that the irrigated land cover types consume more diesel as they use more equipment to manage higher harvests.

Technology	Description	Parameter
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MINDSL	1 unit of activity produces 1 unit of DSL	Output Activity Ratio
DEMAGRDSL	1 unit of the agricultural diesel tech requires 1 unit of DSL 1 unit of activity produces 1 unit of AGRDSL	Input Activity Ratio Output Activity Ratio
DEMAGRDSL	1 unit of activity produces 0.0698 million tonnes of CO2eq	Emissions Activity Ratio
<u>Rainfed Crops</u> E.g., LNDMAIHR	E.g., 1 unit of rainfed Crop uses 0.08 units of diesel (AGRDSL) Use this figure for all rainfed crops	Input Activity Ratio
<u>Irrigated Crops</u> E.g., LNDMAIHI	1 unit of irrigated maize cropland uses 0.12 units of diesel (AGRDSL) Use this figure for all irrigated crops	Input Activity Ratio

Once the data entry is complete, **rerun the model and visualize the results using the online platform**. The focus should be on the diesel consumption in the agricultural sector.

Step 5: Land for Energy

This activity will introduce the necessary links to capture the land area needs for energy-related activities. Use **Crop 4** from the Land section table. We will take the example of using Maize to produce biofuel for consumption in the transport sector. If you don't have Maize use one of these crops

- Rapeseed/Canola
- Sugarcane
- Palm Oil



- Jatropha
- Soybeans
- Cottonseed
- Sunflowers
- Wheat
- Switchgrass
- Sorghum

The actual process of producing biofuel from food crops has many intermediate steps. Therefore, a simplistic representation of a complex biofuel chain is employed to explain the systemic inter-linkages.

In this activity, you will add a new technology (DEMTRABIO) to represent the simplified step that converts Maize (or ‘crop 4’ the one you want to use as biofuel) to a new biofuel commodity which we will call: (TRABIO) . In the model, there will now be competition for land to grow Maize (biocrop) for the purpose of food and biofuel production.

Note: This structure assumes the crop has competing uses; in reality it could be the case that the crop residues are used for biofuel production, i.e., by-products. In that case we would model the chain a bit differently because the production of biofuel would not be in parallel to the one of food, but rather in series with it.

To ‘find’ a suitable demand figure for your biofuel crop use this resource (look for the most recent year): <https://www.iea.org/regions/africa>. Remember to convert from TJ to PJ and then grow the demand the same as population increase throughout the entire model period. **Add this as an Accumulated Annual Demand for TRABIO.**

The table below details the different inputs and outputs relevant for the representation of this biofuel chain.

Technology	Commodity	Description	Parameter
DEMTRABIO	Biofuel E.g., CRPMAI	1 million tonnes of “Maize” (CRPMAI)....	Input Activity Ratio



	TRABIO	...is used to produce 6 PJ of biofuel (for TRABIO) - (use this figure for any type of biofuel crop)	Output Activity Ratio
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The demand we have used for biofuels is an accumulation of demand for all biofuel crops in your country. So, in essence your biofuel crop, in terms of TRABIO, is a symbol/signifier for all biofuel crops needed for your country.

Once the data entry is complete, please update '**TotalTechnologyModelPeriodActivityUpperLimit**' to 99999 (five 9's) for the tech DEMTRABIO.

Now, rerun the model and visualize the results using the OSeMOSYS cloud. The focus should be on the land allocated for bio crop cultivation to meet the demands for food and biofuel.

Once completed, **run your model**. Check the graphs look smooth too.

Step 7: Saving your model

A successful run now means that you have created a baseline CLEWs model for your chosen country.

Make sure you save and 'back-up' the model, so that you have that baseline model ready should you ever need it again.

If the model fails to run or the graphs look erratic, please upload the data file here for data input troubleshooting: <http://lee2d2.pythonanywhere.com/>



What Next?

- Scenarios
 - Similarly, to the Open University course section on ‘scenario testing’, you can now begin to run scenarios within the model. This model you have created will be your ‘baseline’ or ‘business as usual’, then you create new versions of it depending on the scenario.
 - There will be further worksheets available that provide instruction on how to build scenarios with your CLEWs baseline model.
- Improve data
 - See the Appendix for instructions on how you might update Energy data. For Land and Water, another useful resource is GAEZ: <https://gaez.fao.org/>
- Report/paper/article writing.
 - This model you have now built has the potential to form the basis of a research paper (etc.). For example, masters’ students at Loughborough University are building CLEWs model and running scenarios as a basis for their dissertation.
 - A more developed model with scenarios could allow you to provide useful insight for a country, which can then be presented within a research paper.
 - When the student papers are published, we will update this document references accordingly
- Summer schools
 - In completing this worksheet, you have also completed a CCG summer schools worth of work without the scenarios. However, if you wish to learn more please visit the CCG website and/or LinkedIn page. There are many other modelling tools you can learn to build on your experience.
 - Climate Compatible Growth: <https://climatecompatiblegrowth.com>
 - LinkedIn: <https://www.linkedin.com/company/climate-compatible-growth-ccg>



Key References

Please use the following citation for this resource:

- Martindale, L., Alexander, K., Gardumi, F., Shivakumar, A. (July, 2023) **My First CLEWs Country Model**. *Zenodo*. 10.5281/zenodo.7916224

An introduction to the value of CLEWs modelling:

- Howells, M., Hermann, S., Welsch, M., Bazilian, M., Segerström, R., Alfstad, T., ... & Ramma, I. (2013). **Integrated analysis of climate change, land-use, energy and water strategies**. *Nature Climate Change*, 3(7), 621-626.

The pedagogical value of CLEWs modelling in an era of wicked problems.

- Martindale, L.; Cannone, C.; Niet, T.; Hodgkins, R.; Alexander, K.; Howells, M. **Empowering Tomorrow's Problem Solvers: Nexus Thinking and CLEWs Modelling as a Pedagogical Approach to Wicked Problems**. *Energies* 2023, 16, 5539. <https://doi.org/10.3390/en16145539>

How to use OSeMOSYS-CLEWs in teaching, training and open science

- Ramos, E. P., Sridharan, V., Alfstad, T., Niet, T., Shivakumar, A., Howells, M. I., ... & Gardumi, F. (2022). **Climate, Land, Energy and Water systems interactions—From key concepts to model implementation with OSeMOSYS**. *Environmental Science & Policy*, 136, 696-716.

A discussion of how CLEWs can be applied and used in different case studies (countries) and at different spatial and temporal scales.

- Ramos, E. P., Howells, M., Sridharan, V., Engström, R. E., Taliotis, C., Mentis, D., ... & Rogner, H. (2021). **The climate, land, energy, and water systems (CLEWs) framework: a retrospective of activities and advances to 2019**. *Environmental Research Letters*, 16(3), 033003.

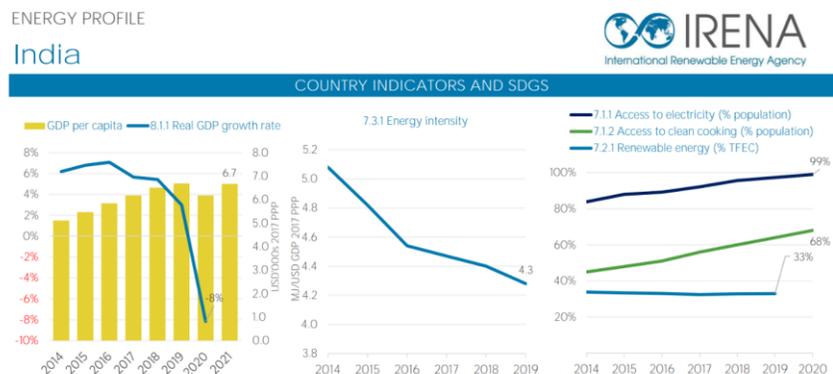
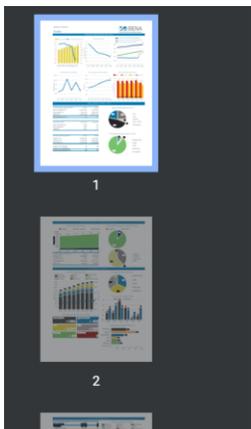
An explanation of the Starter Data Kits used for energy data in this resource.

- Allington, L., Cannone, C., Pappis, I., Barron, K. C., Usher, W., Pye, S., ... & To, L. S. (2022). **Selected 'Starter kit' energy system modelling data for selected countries in Africa, East Asia, and South America (# CCG, 2021)**. *Data in Brief*, 42, 108021. <https://doi.org/10.1016/j.dib.2022.108021>

Appendix

Alternative data to the Starter Data Kits

- The starter data kits are extremely useful in that they provide an open access set of data for a country.
- However, some of the data may now be *out-of-date or inaccurate*. But they are designed in a way, where (hopefully) participants of summer schools and Master's students (etc.) may use them and add new data, thereby actively supporting the open modelling community with their expertise.
- For parameters such as output activity ratio, input activity ratio and capacity to activity unit (to name but a few), the data is adequate.
- A key parameter for updating data (as well as helping you to select the power plants you want in your model) is **residual capacity**.
- This parameter represents the current installed capacity of power plants, so the minimum amount of capacity for a given power plant before the model decides to find the least cost solution. Whilst also considering the retirements of plants (through the use of operational life- how long a plant stays open before it must be retired).
- The first step would be to research the installed capacity of the energy mix within your country.
- You can do this through government websites, international organisations like IRENA or other sources that you may find.
- For example, in the image below, which is taken from **IRENA's document on India's Energy Profile**, this is what will appear when you download it.





- Also, you may be able to access government websites that provide consistent sets of accurate data. For example, for India, the Ministry of Power provides information on total installed capacity (<https://powermin.gov.in/en/content/power-sector-glance-all-india>). So you could use this kind of data to update residual (installed) capacity.
 - This process will however require some calculations. You can simply take the values (e.g. India in 2023 has 205,235 MW- which is 205.235 GW of coal power) and replace the values in the starter data kit, whilst keeping the same retirements (note: you will see the residual capacity get smaller and maybe going to 0 in the starter data kit, this is accounting for plant closures). *Or you could decide to keep the residual capacity as the new value you have set for the whole modelling period.*
 - The furthest step is to research planned projects and closures, which means you can then edit the residual capacity further to account for these.
 - Secondly, you can update the specified annual demand. This can be done easily by researching the energy demand for your country (e.g. in 2023) and then multiplying it by GDP/population growth to project for the modelling period. Alternatively, you could also find, and use demand projections presented by other studies, especially where these were dedicated specifically to studying demands and used detailed models to calculate them.
 - Finally, you can update data such as capital costs, fixed costs and variable costs by using reports such as the Renewable Power Generation Costs by IRENA.
 - Any other questions on this can be asked in the CLEWs google group [linked here](#).
 - Another key resource on updating the Sand Data Kits can be found [here](#)
-