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**title: Mini-Lecture 5.1 -- Energy technologies**

keywords:

- Energy technologies

- Technoeconomic data

authors:

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This lecture will introduce the various technologies and how we can represent them within MUSE. We will also learn about the supply chains in which these technologies exist. Finally, we will learn about the key characteristics of the different technologies in the context of MUSE.

# Learning objectives

- Understand the concepts of technologies and supply chains

- Learn how to represent technologies in MUSE

- Understand the key characteristics of technologies

# Introduction

A technology in MUSE represents a process, or a group of processes, that:

- Converts energy from one form into another. For example, the conversion of crude oil to oil products, oil products to electricity or electricity to heat.

- Transfers, transmits or distributes a form of energy, for example electricity transmission technologies.

- Supplies or produces a form of energy, for example oil imports or extraction, or a hydropower plant generating electricity.

## Technology examples

Now we will discuss specific technologies and their role in the energy system.

Within the energy system there exists natural gas for the generation of electricity. However, we have to represent a technology which extracts natural gas in the system. We can call this technology "gas extraction", which outputs natural gas. This technology does not have any input fuel as it is a primary energy supply technology.

A coal power plant, on the other hand, has an input of coal and an output commodity of electricity. This technology is an energy conversion technology and converts the energy in coal to electricity.

Similarly, an oil power plant converts the energy in oil to electricity. It therefore has an input fuel of oil and an output commodity of electricity.

It must be noted that some technologies can have more than one input or output fuel, such as a refinery with oil as the input fuel, producing both gasoline and heavy fuel oil as output fuels.

## Parameters that define technologies

There are three main groups of parameters that are used to define technologies. These can be seen in Figure 5.1.1 below. These include input commodities, which refer to the fuel supply to the technology. For instance, what is the input fuel, what is the price of this, and what is the availability? Crucially, it can also contain the greenhouse gas emissions associated with the fuel.

Secondly, there is techno-economic and environmental characteristics of technologies. These include technology costs, efficiency, lifetime and availability.

Finally, we need to define each technology's output commodity. This is the commodity which it produces, such as electricity from solar PV. Important data on output commodities includes their demand, impacts and when it is needed.

![](assets/Figure\_5.1.1.png){width=100%}

\*\*Figure 5.1.1:\*\* Technology definitions by example parameters [@Taliotis2018]

## Representing technologies in MUSE

Since models are abstractions of reality, we can define technologies at different levels of abstraction depending on the nature of our energy model. Within MUSE, for instance, a single technology can represent a single power plant, or a group of similar power plants (for example, a technology could represent all coal power plants in a region if they had similar characteristics). The information provided can create a model with more or less granular data based upon the requirements of the user. It must be noted, that with increased granularity, an increase in computation time will be observed.

It is possible within MUSE to represent all power plants as a single technology. This is appropriate when technologies do not change significantly between power plants or extraction plants.

## Key characteristics of technologies

There are a number of different important technology characteristics that should be considered in capacity expansion planning. MUSE allows for several of these characteristics to be included. Such as:

- Variation in the availability, efficiency and costs of a technology over short and long timescales. For example, it may be the case that solar power reduces in costs over the next 30 years. If this happens, we would like to model this process and see the long-term effect on the market.

- MUSE can consider the limits on production by technology and capacity constraints. For example, there may only be a certain amount of hydro resources in a particular country, based on the number of rivers etc. It is important that MUSE takes this into account to ensure that the results are aligned to the reality in a region or country.

- Finally, the emissions associated with technologies can be captured. For example, we may want to reduce the carbon dioxide emissions of an entire system. This would allow us to compare scenarios and enable us to understand how we can reduce these emissions to reduce the impact of climate change. MUSE is also able to impose a limit on emissions through a constraint.

# Summary

In this mini-lecture we have learned the importance of technologies within MUSE. We learnt that a technology can refer to a single power plant, to all coal power plants, for example. This is largely based on the requirements of individual case studies. We also learnt that technologies can also be processes, such as the extraction of natural gas. All of these different technologies come together to build an entire energy system, which MUSE is able to model.

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**title: Mini-Lecture 5.2 -- Technoeconomic characteristics**

keywords:

- Technoeconomic data

- Parametrisation

authors:

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This mini-lecture will describe the techno-economic data that defines technologies in MUSE. These technoeconomics are fundamental to the functioning of a good MUSE model. Most technologies can be characterised by their efficiencies, technoeconomics and inputs and outputs. This is because the technologies must be competitive against each other in an economic sense.

# Learning objectives

- Understand the main technoeconomic parameters

- Understand how these parameters can impact investment decisions

# Technology costs

In this mini-lecture we will describe the different techno-economic parameters that MUSE defines, primarily in the `Technoeconomic.csv` file found in the different sector folders.

Figure 5.2.1 displays the different cost types as defined in MUSE. The total costs are largely split into capital costs and annual costs. Capital costs, as shown by the figure, are the costs of depreciation, return on investment and other one-time fixed charges. This can include the initial costs of the technology such as construction.

Then there are annual costs, which are split into variable and fixed costs. There is a distinction between these two types of costs, where fixed costs depend on the capacity of the power plant, whereas variable costs depend on the amount of energy output in a year. For instance, if a power plant does not output any electricity, it will not have to pay for fuel. However, it will still have to pay for salaries to look after the plant.

![](assets/Figure\_5.2.1.png){width=100%}

\*\*Figure 5.2.1:\*\* Cost types [@Taliotis2018]

In MUSE, these are defined in the `cap\_par`, `cap\_exp`, `fix\_par`, `fix\_exp`, `var\_par`, and `var\_exp` variables where:

-- `cap\_par` is the capital costs, and `cap\_exp` is the exponential component of this. Effectively, the `cap\_exp` defines the reduction in cost due to economies of scale as the investment into this technology and its capacity increases. This should be a number between 0 and 1.

-- `fix\_par` is the fixed costs, and `fix\_exp` is the exponential component similar to the exponential component in `cap\_exp`.

-- `var\_par` is the fixed costs, and `var\_exp` is the exponential component.

The exponential component can be chosen from relevant data, but can often by difficult to find. In that case it is okay to use a number such as 1 or 0.95 as a rough indication.

## Growth constraints

As previously mentioned, it is important to place realistic constraints on the growth of technologies. For instance, there is only so much resource or land potential for renewable energy resources, such as offshore wind. If a country or region does not have any access to land offshore, the limit for offshore wind should be zero. On top of this, it may not be possible to grow and install technologies faster than a certain rate. For instance, there may not be enough resources, such as steel and labour, to double the capacity of wind in a certain country.

The parameters which set these can be found in the `Technodata.csv` file and are called:

- `MaxCapacityGrowth`

- `MaxCapacityAddition`

- `TotalCapacityLimit`

## Other technoeconomic parameters

Other technoeconomic parameters include the lifetime of a technology, scaling size and interest rate. A technology may become much more attractive if we are able to use it for a longer amount of time. For instance, the economics of nuclear power plants can be very sensitive to the length of time they can be used for due to their high capital costs. It is therefore important that we have good data on the lifetime of the plant. This is set by the `TechnicalLife` parameter.

The scaling size defines how small a single unit can be. For instance, a single nuclear power plant outputs a lot more energy than a single solar photovoltaic panel. This detail can be set by the `ScalingSize` parameter.

The interest rate is the parameter which defines the discount rate. For instance, a technology may have a 2% return on investment, which may seem good. But it could also be possible to put the money required to build a technology into a high interest savings account and have a 4% investment. Thus the 2% return would actually reflect a loss relative to the rate of interest. This opportunity cost is the interest rate defined in the `InterestRate` parameter.

## Inputs and outputs

Finally, there are the input and output parameters. For a gas power plant, the input is gas and the end use is electricity. This can be set in the `Fuel` and `EndUse` parameters respectively.

# Summary

In this mini-lecture we have discovered the main components which make up the Technodata sheet. We discovered the importance of properly defining the costs, lifetime and other characteristics which have a large impact on the final investment decisions.

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**title: Mini-Lecture 5.3 -- Input and output commodities**

keywords:

- Technology efficiency

- Input commodities

- Output commodities

authors:

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In this mini-lecture we will learn about the input and output commodities within MUSE. Specifically we will learn what the `CommIn.csv` and `CommOut.csv` files do and how these relate to the energy system.

# Learning objectives

- To learn the importance of input and output commodities

- To learn how we can modify these commodities in MUSE

# Introducing commodities

Input commodities are the commodities consumed by each technology. This could be coal for a coal power plant, uranium for a nuclear power plant or electricity for an electric heater. This is dependent on the technology, and some technologies can have multiple inputs.

Output commodities are similar, but are the outputs of technologies. For example the output of any power plant will be electricity, and for heaters the output will be heat. Again, this is dependent on the technology, and some technologies can have multiple outputs such as combined heat and power plants.

The ratio between these two parameters is very important in MUSE and in energy modelling in general. This is because it defines the efficiency of the technology. For instance, if a coal power plant requires 1 PJ of energy stored in coal to output 0.8 PJ of electricity, the coal power plant has an efficiency of 0.8. The higher the efficiency the more economical the power plant is and the more competitive it will be when compared to different technologies.

## Editing the CommIn and CommOut files

Within MUSE there are two files which one should change to edit these parameters: the `CommIn.csv` and `CommOut.csv` files. These files are found within the sector folders of the case study. For instance, in the `power/CommIn.csv` or `gas/CommOut.csv` directories.

In this example we will look at the residential sectors `CommIn.csv` and `CommOut.csv` files. An example `CommIn.csv` file can be seen in the figure below:

![](assets/Figure\_5.3.1.png){width=100%}

\*\*Figure 5.3.1:\*\* CommIn file for the residential sector

Here we see two technologies: `gasboiler` and `heatpump`. They are both in region R1 and we are specifying the characteristics for the year 2020. The `gasboiler` only requires gas, but requires 1.16 PJ, whereas the `heatpump` requires only 0.4 PJ to produce some energy.

However, it is important to note that these figures are meaningless without the `CommOut.csv` file. We need to know how much energy does the 1.16 PJ of energy produce in the `gasboiler`? As can be seen in the figure below showing an example `CommOut.csv` file, it is convention to select an output of 1. That way we only have to vary the `CommIn.csv` to change the efficiencies consistently.

![](assets/Figure\_5.3.2.png){width=100%}

\*\*Figure 5.3.1:\*\* CommOut file for the residential sector

Therefore, we can now conclude that the `heatpump` is much more efficient than the `gasboiler` as only 0.4 PJ are required to output 1 PJ of heat. If we divide 1 by 0.4, we get the efficiency of the `heatpump`, where 1/0.4= 2.5. Notice that the `gasboiler` also outputs carbon dioxide. It is important to take these emissions into account to have a complete understanding of the energy system. MUSE calculates these emissions endogenously.

# Summary

This mini-lecture has explored the input and output commodities in MUSE. We have learnt that the `CommIn.csv` and `CommOut.csv` files relate to efficiencies when brought together in a ratio.

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**title: Mini-Lecture 5.4 -- Interpolation and future years**

keywords:

- Interpolation

- Energy technologies

authors:

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MUSE is flexible in its approach. It requires inputs for at least the base year, but does not necessarily need more than that to project forward. In this mini-lecture we will cover how MUSE deals with missing data and how to model future years

# Learning objectives

- Learn how to model costs in multiple years

- Understand how MUSE deals with missing data

- Understand interpolation

# Introduction

Within the input sheets you may have noticed the `Time` column. In the default example this is set to 2020. However, what happens beyond these years if we do not specify a cost, for example? Also, what happens in 2030 if we only specify a cost in 2020 and 2040?

Within MUSE, we make some assumptions. We assume that if there are no costs input into a model beyond a certain year, that the costs remain the same. This is known as a flat-forward extension. If, for example, we input costs in 2020 and 2040, we will interpolate the values in between these years linearly.

An example of this is, say that the capital costs for a gas boiler is set to be 4 for a gas boiler in 2020 and 2 in 2040. We have not explicitly defined 2025, 2030 or 2035. Based on linear interpolation, MUSE will assume a value of 2.5 for 2025, 3 for 2030 (halfway between the year 2020 and 2040) and 3.5 for 2035.

It must be noted, however, that MUSE does not allow a user to just update a single technology. For instance, if we want to specify the technology costs in 2035 for a coal power plant, we must also define the technology costs for every other technology in 2035 – although this cost need not be changed from the original value. We also do not need to define every year, however, as interpolation and a flat-forward extension can still be used.

## Practical example

The figure below shows a snippet of the technodata file for the residential sector. We can see that we have data parametrising the technologies in 2020.

![](assets/Figure\_5.4.1.png){width=100%}

\*\*Figure 5.4.1:\*\* Technodata for residential sector

Let's say that we want to update the capital costs (`cap\_par`) for heat pumps in 2040, but do not want to update the prices for gasboilers. This is how we do it:

![](assets/Figure\_5.4.2.png){width=100%}

\*\*Figure 5.4.2:\*\* Updated technodata for residential sector

Notice that we need separate rows for both `heatpump` and `gasboiler` even though we are only making a change in the `heatpump` capital cost. If we do not do this we will encounter an error. In between 2020 and 2040 we will get interpolation.

# Summary

In this mini-lecture we learned how to update costs in the time domain, and the assumptions MUSE makes if we do not give costs for every year. Namely, flat-forward extension and interpolation. We also learnt how to practically input these values in MUSE with the `Technodata.csv` file.