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**title: Mini-Lecture 3.1 -- Energy demands in energy systems modelling**

**keywords:**

- Energy demand

- Energy systems models

authors:

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To begin lecture 3, this mini-lecture provides an overview of energy demands within an energy system. We will cover differences in energy demands by sector, time and population classes. We will also begin to explore why these differences are important within energy models. Lecture 3 will take you through the basics for modelling energy demand in MUSE, the different options available to do so, and some specific examples

# Learning objectives

- Learn what energy demands are in an energy modelling context

- Understand how demands can change based on different variables

# Introduction

Everyone needs energy for many different purposes. The form in which this energy should be delivered is dependent on the specific application. These demands for energy come from all sectors of society such as:

- The residential sector (rural and urban)

- Cooking

- Heating

- Cooling

- Lighting

- Appliances

- Industry

- Chemical processes

- Steam production

- Heating

- Commerce

- Lighting

- Heating

- Cooling buildings

- Keeping products at low temperatures

- Transport

- Cars

- Trucks

- Buses

- Aviation

- Shipping

- Trains

- Agriculture

- Tractors

- Machinery

- Pumping water

## Variations in daily energy demand

These energy demands can vary on hourly, daily, weekly and monthly timescales. This mainly reflects the schedule of consumers' activities. For example, on a monthly timescale more cooling will be used in summer and more heating in winter. However, these energy demands can also vary by sector, as shown by Figure 3.1.1.

![](assets/Figure\_3.1.1.png){width=100%}

\*\*Figure 3.1.1:\*\* Variations of energy demand by sector in a hypothetical example [@Taliotis2018].

Figure 3.1.1 shows us that the magnitude of demand varies by sector, with agricultural demand significantly lower than residential and commercial demand, in this example. The reason that the commercial and residential sectors consume more is because their activities are more energy intensive or they are simply larger.

We can also see that the daily profile of demand varies by sector. For example, in Figure 3.1.1 we can see that there is a clear evening peak in residential demand, whereas agricultural and industrial demand remains flat throughout the day. This is because agricultural and industrial demands are consistent throughout the day. This is likely because the industrial and agricultural sector operate constantly, whereas energy use in homes peaks in the evening when consumers use more electricity for cooking, lighting and appliances when they return from work or other business.

## Sector specific demands

The differences between sectors means that it can sometimes be important to model demands separately by each sector. This feature allows the models to consider the specific characteristics of each demand.

Within each of these sectors, the energy demand varies over time and across different types of consumers. For example, within the residential sector, demands can differ between rural and urban households, as shown in Figure 3.1.2. This can also be true between grid-connected and off-grid areas. Energy planners must ensure that energy demand is always met for all types of consumers. Therefore, it is important that the key characteristics of different demands are represented in energy models.

![](assets/Figure\_3.1.2.png){width=100%}

\*\*Figure 3.1.2:\*\* Variations of energy demand for the residential sector by population types [@Olaniyan2018]

## Long-term variations in energy demands

A major challenge in energy planning is that energy demands can change over time. This could be due to population growth or the creation of new industries. Figure 3.1.3 displays historical variations in energy demands. It is likely that these demands are correlated to changes in society. For example, increases in energy demand likely reflect increased industrial activity. For energy planning, we must also think about how energy demands are likely to change in the future.

We can often forecast energy demand, such as with future projections as shown in Figure 3.1.3. These forecasts can be created using estimates of the key influencers of energy demand, such as population growth and economic activity. Future projections are often based on how energy demands have changed historically.

![](assets/Figure\_3.1.3.png){width=100%}

\*\*Figure 3.1.3:\*\* Long-term energy consumption by source

## Capacity expansion planning

One of the key purposes of MUSE is for capacity expansion. Figure 3.1.4 displays this key issue which MUSE can address. Essentially, if total demand increases (green line) and existing system capacities are retired (blue line), how can we invest to meet the energy capacity needed to supply demand (red line)?

![](assets/Figure\_3.1.4.png){width=100%}

\*\*Figure 3.1.4:\*\* Capacity expansion [@Taliotis2018]

You may notice that the red line is higher than the green line at all points. This is due to losses due to lower generating efficiencies. The gap between the red and blue lines demonstrates the required capacity expansion over time. MUSE enables us to plan such a capacity expansion whilst considering technical, economic and environmental constraints.

# Summary

In this mini-lecture we covered the differences between energy demands in different population types, sectors and timescales. We learnt why it is important to model these differences in demand in energy systems models. We also explored how energy systems models can be used to meet a changing demand profile in the future.

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**title: Mini-Lecture 3.2 -- Energy demands in modelling**

**keywords:**

- Energy demands

- Scenario analysis

authors:

- Alexander J. M. Kell

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Mini-lecture 3.2 outlines the general requirements for defining energy demands and how modelling different scenarios can help assess potential future energy demand.

# Learning objectives

- Understand how to define energy demands

- Understand why we need scenario analysis

# Introduction

Within modelling we can break up the previously defined energy demands by sector. Electricity comes from the power sector and can be used to fulfil demand from each of the final service sectors. For example, the residential, commercial or industrial sector.

These sectors can have different electricity demands and needs and which can evolve over time as was seen in the last mini-lecture. We will now explore how these energy demands can be defined.

## Defining energy demands

When defining an energy demand for energy systems models, it is important to identify the following:

- The energy carrier which the demand arises for. For example, electricity, gasoline for transportation or biomass for cooking.

- The sector the demand arises from. For example, residential (urban and/or rural, off- or on-grid), industrial or commercial.

- The average variability of the demand within a year. This is usually expressed using average demand profiles, which are explained in more detail later in this lecture.

- The current and expected future annual average demand.

However, it is very difficult to predict future demand, and there will always be uncertainty in our predictions. Due to this it is important to model different scenarios.

## Defining our own energy demand

As has just been seen, when we want to define our own energy demand, we need to identify a number of different features. Let's say, for example, that we want to define the demand for electricity in urban homes. To do this, we need to define:

- The energy carrier for which the demand arises for. In this case it is electricity.

- The sector the demand arises from. In this example it is the residential sector, or the urban residential sector if you would like to be more specific.

- The average variability of the demand over the year. In this example we can look at daily and yearly electricity demand profiles for a residential urban area. This will tell us how the demand varies on a daily and seasonal scale.

- Current and predicted future demand. For this, we can look at an energy balance (covered in more detail later) to get data for the current and historical residential electricity demand. We can use these data as a baseline, and we could combine it with an estimate of population growth to create a future projection for the demand.

## Scenario analysis

Within energy systems modelling, we must explore different possibilities of what could happen in the future. This is known as scenario analysis. We do this as the future is uncertain, particularly over the long-term horizon. We therefore might want to consider multiple scenarios to assess how demand could vary in the future.

For example, for different scenarios, key predictors of energy demand, such as population growth, economic development and energy policy can be varied across the scenarios. This would mean that each scenario has a different energy demand projection.

Since we can not be certain of the scenario which will be the best predictor of the future, it is useful to model several scenarios and consider the implications of each of them to give useful insights for policymaking. This allows policy makers to assess which of the different policies and mixes suit their needs based upon likelihoods and risk tolerances.

# Summary

Mini-lecture 3.2 provided an overview of energy demands, how we can define them and the details which make them up. We also explored how we can perform scenario analysis with energy demands, to understand what could happen in the future.

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**title: Mini-Lecture 3.3 -- Energy demand in MUSE**

keywords:

- Energy demand

- MUSE

authors:

- Alexander J. M. Kell

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## Short description

Following mini-lecture 3.2, this mini-lecture provides an insight into how to model service demand within MUSE. There are two possible methods to model service demand in MUSE, from user input and by correlation. In this mini-lecture we will learn what the difference is between these.

## Learning objectives

- Understand how to input exogenous service demand

- Understand what service demand by correlation is

# Lecture content

## Service Demand

A service demand is a term used to describe the consumption of energy by human activity. This could be, for instance, energy for lighting or cooking in the residential sector, personal vehicles in the transportation sector or machine usage in the industrial sector. The service demand drives the entire energy system, and it influences the total amount of energy used, the location of use and the types of fuels used in the energy supply system. It also includes the characteristics of the end-use technologies that consume energy.

## Exogenous service demand

Within MUSE we must set the energy demand exogenously. That means that the model does not calculate how much the service demand is. Effectively, this means that the user must make an assumption on how much electricity is consumed in, for example, the residential sector for a particular region in the model.

We can change this per scenario, but these values will not change during a simulation run, even if the price for all fuels increases significantly, for instance. We are able to define the exogenous service demand by year, sector, region and timeslice.

## Service demand by correlation.

In the previous section we learnt about the exogenous service demand. That is, we can explicitly specify what the demand would be per year, sector, region and timeslice. However, it may be the case that we do not know what the electricity demand is per year, especially in the future. We may instead conclude that our electricity demand is a function of the GDP and population of a particular region, as previously discussed.

To accommodate such a scenario, MUSE enables us to choose a regression function that estimates service demands from GDP and population projections, which may be more predictable or have more accessible data in your case. A regression function is simply a mathematical model which fits a linear model to your data to predict what may happen in the future.

## Sources for energy demand data

We can get publicly available energy balance data and/or demand projections from the following sources:

- International Energy Agency

- International Renewable Energy Agency

- United Nations Statistics

- Asia-Pacific Economic Cooperation

Energy balances tell us the amount that each energy commodity is used in a country or region in a given year. This is usually broken down by sector.

## Summary

In this mini-lecture we introduced service demands, and the way we can input these into MUSE. The two ways we can input service demands are:

- Exogenous service demand

- Service demand by correlation

We also learned where we can get energy data from for various countries.

In the hands-on we will see how we can actually do this within MUSE.

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**title: "Mini-Lecture 3.4 -- Demand examples and units"**

keywords:

- Infrastructure performance

authors:

- Alexander J. M. Kell

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# Short description

Mini-lecture 3.4 explains how we can use timeslices to approximate the real-world demand profile. We will look into the difference between power and energy. Finally, we will learn how to convert units to ensure we are consistent within MUSE.

# Learning objectives

- Understand how timeslices can be used in the context of demand

- Understand the difference between power and energy

- Know the units to use within MUSE and how to convert these

# Demand profile

Figure 3.1.5 shown an example demand profile for electricity that could be used in MUSE. In this demand profile there are 96 bars: one for each of the timeslices used in MUSE. These timeslices are split into 16 different sections – seasonal and into day and night. This is because there are four different seasons, which are split into day and night (twice). The demand profile is used to represent the proportion of demand occurring in each timeslice.

![](assets/Figure\_3.1.5.png){width=100%}

\*\*Figure 3.4.1:\*\* Example demand profile for MUSE

The chart shows us that electricity demand, in this example, is highest during the day in winter, while it is lowest during the night in spring. However, it is important to note that this is a simplification: in reality demand varies in the season and with each hour of the day. This simplification means that we model one representative day for each season, and we assume equal demand within days and nights of those seasons.

Whilst this is a simplification, it allows us to consider the variation in demand across seasons and days without having an incredibly complex model structure. This reduces the amount of time required to run a full model relative to having timeslices for each hour and day of the year, as well as reducing the data input requirements.

## Units

We must ensure that during our data input process we are consistent with our units. Usually we will use the petajoules unit as this is the unit for energy for different sectors. If you were just modelling the power sector, you could use megawatt hours.

## Power vs. Energy

When using energy modelling tools it is important to remember the difference between power and energy. Sometimes these terms are used interchangeably. However, there is an important difference between the two:

- Energy is the total amount of work done or the total capacity for doing work

- Power is the rate at which this energy is supplied or used.

Therefore, energy and power have different units. For example, energy is often measured in Joules, while power is often measured in Joules per Second (or Watts).

For example, providing the weight stays the same, lifting a weight requires the exact same amount of energy no matter how quickly we lift it. However, if we lift the weight more quickly, the power has increased. We used the same amount of energy, but over a shorter amount of time.

## Units for demand

It is important that we convert our data from different sources to petajoules (PJ) when we include it in MUSE.

Here are some example conversion factors:

- 1 Petajoule (PJ) = 1000 Terajoules (TJ)

- 1 Petajoule (PJ) = 1,000,000 Gigajoules (GJ)

- 3.6 Petajoules (PJ) = 1 Terawatt hour (TWh)

- 0.0036 Petajoules (PJ) = 1 Gigawatt hour (GWh)

We must ensure that we are consistent with the units we use within MUSE.

# Summary

In this lecture we have learnt the difference between power and energy. We have also learnt how to use timeslicing to speed up our model and reduce complexity. Finally, we learnt that we must use consistent units.