

REIES – Lesson 5: Integration

Exercise Sheet

Complete the exercises below to practise and integrate the concepts from Lesson 5 and the whole course. Show all working for calculation questions.

Section A – Knowledge Questions

Exercise 1



Knowledge

The lesson introduces the concept of the energy transition and the definition of renewable energy.

- The lesson defines a renewable energy source as ‘any energy source that replenishes itself fast enough to be considered inexhaustible on a human timescale.’ Using this definition, explain why each of the following is or is not considered renewable: (a) solar energy, (b) fossil fuels, (c) biomass, (d) nuclear fission.
- The lesson states there is ‘no golden solution’ to the energy transition. What does this mean in practice? Give two reasons why a single energy source or technology cannot supply all of society’s energy needs.
- The lesson states that changes in the energy system have consequences for ‘all aspects of society’. Name the six dimensions of the PESTEL framework used in the lesson to structure this analysis, and give one specific example of how the energy transition affects each dimension.

Exercise 2



Knowledge

The lesson identifies six key technical challenges for integrating renewable energy into the electric grid.

- Name all six technical challenges described in the lesson. For each one, write one sentence explaining why it arises specifically because of the variable nature of renewable energy sources such as wind and solar.
- The lesson describes the concept of a ‘multi-commodity grid’. Explain what this means and identify the three main energy carriers involved. For each carrier, name one specific advantage it offers for integrating renewable energy.
- Match each energy storage technology from the lesson to its primary operating timescale and its main function by completing the table.

Storage technology	Timescale	Primary function
Battery storage		
Pumped hydro		
Hydrogen (power-to-gas)		
Thermal storage		

Exercise 3

Knowledge

The lesson covers smart grids and digitalization as enabling technologies for renewable integration.

- What is a 'prosumer'? Explain how the rise of prosumers changes the direction of energy flow in the distribution grid, and why this requires infrastructure upgrades.
- The lesson describes demand response and flexibility. Give two concrete examples – one residential and one industrial or commercial – of how a smart grid could shift energy demand to match renewable supply peaks.
- The lesson mentions cybersecurity as a risk introduced by digitalization of the energy system. Explain in 3–4 sentences why a more connected energy grid creates cybersecurity vulnerabilities, and give one real or hypothetical example of the type of risk involved.

Exercise 4

Knowledge

The lesson covers the social and environmental dimensions of the energy transition.

- What is the NIMBY effect and why is it relevant to the energy transition? Give two specific examples of renewable energy or grid infrastructure projects that typically face local opposition, and explain what concerns drive that opposition.
- The lesson emphasises energy equity. Explain what energy equity means in the context of the energy transition. Why are low-income households particularly vulnerable, and what kind of policy measure could protect them?
- The lesson discusses Life Cycle Analysis (LCA) of renewable technologies. What does an LCA measure, and what does the lesson say about when renewable technologies 'break even' environmentally? Name one end-of-life challenge mentioned for renewable energy hardware.

Section B – Calculation Questions

Exercise 5

Calculation

Levelised Cost of Energy (LCOE) – comparing technologies. The LCOE represents the average cost of generating 1 kWh of electricity over a technology's lifetime. It is calculated as: $LCOE = \text{Total lifetime cost (€)} / \text{Total lifetime energy generated (kWh)}$

- A 5 MW onshore wind turbine has a capital cost of €5 000 000, annual operating costs of €80 000/year, and a lifetime of 25 years. It produces electricity at a capacity factor of 30 % (meaning it runs at full power 30 % of the time on average). Calculate the LCOE in €/kWh. (Ignore discounting for simplicity.)
- A gas-fired peaker plant of the same 5 MW capacity has a capital cost of €2 000 000, annual operating costs of €150 000/year, and fuel costs of €0.08/kWh generated. It runs at a capacity factor of 10 %. Calculate its LCOE over 25 years.
- Compare the two LCOEs. Which technology is cheaper per kWh? The lesson states that onshore wind LCOE has fallen 80–90 % in the last decade. If the wind LCOE you calculated represents the current value, what was the approximate LCOE 10 years ago?

Exercise 6

Calculation

Grid frequency and power balance. The electric grid must maintain a frequency of exactly 50 Hz (in Europe). Any mismatch between generation and demand causes the frequency to deviate.

- A regional grid has a total generation capacity of 2 000 MW and a current demand of 1 800 MW. A large offshore wind farm of 500 MW suddenly comes fully online (from 0 to 500 MW within seconds, due to a sudden strong gust). By what percentage does generation now exceed demand? Why is this a problem for grid frequency?
- The grid operator has a fast-responding battery storage system of 200 MW / 400 MWh. If the battery absorbs the surplus generation from part (a), how long (in minutes) can it continue absorbing at full power before it is full? Is this enough time for slower dispatchable plant to ramp down?
- An alternative response is 'curtailment': reducing the wind farm's output. If the wind farm is curtailed from 500 MW to 300 MW, what is the new generation-demand balance? Calculate the annual energy lost to curtailment (in GWh/year) if curtailment at this level occurs for 200 hours per year. What is the economic cost if the LCOE of wind is €0.04/kWh?

Exercise 7

Calculation

Multi-commodity grid – power-to-gas and seasonal storage. A coastal region has surplus wind electricity in winter and high gas heating demand in winter, but also summer solar surplus. A power-to-gas (P2G) system converts surplus electricity to hydrogen.

- The P2G system has an electrolyser efficiency of 70 % (electricity to hydrogen, HHV basis) and a fuel cell reconversion efficiency of 60 %. Over a year, 500 GWh of surplus renewable electricity is available for P2G. How many GWh of hydrogen energy is produced? If this hydrogen is later reconverted to electricity, how many GWh are recovered? What is the round-trip efficiency?
- Instead of reconverting to electricity, the hydrogen is blended into the natural gas grid at 20 % by volume. The heating value of hydrogen is 3.0 kWh/m³ (at standard conditions) and natural gas is 10.0 kWh/m³. If 1 000 m³ of the blend is delivered to homes, how many kWh of heat does it deliver? How does this compare to 1 000 m³ of pure natural gas?
- A district heating network is fed by a large underground seasonal thermal store. In summer, 800 MWh of excess solar heat is stored at 85 % overall efficiency (charging + discharging losses). How much heat (MWh) is available for heating in winter? If a neighbourhood of 500 homes each needs 8 MWh of heat per winter, is the stored energy sufficient?

Exercise 8

Calculation

Carbon emissions and lifecycle analysis. The lesson states that wind and solar have lifecycle emissions 10–50 times lower than natural gas per kWh.

- A natural gas power plant emits 450 g CO₂ per kWh of electricity generated (lifecycle, including upstream emissions). An onshore wind turbine emits 11 g CO₂ per kWh (lifecycle). A country generates 200 TWh of electricity per year from natural gas. If 50 % of this is replaced by wind power, how many tonnes of CO₂ are avoided per year?
- A 3 MW wind turbine has a lifecycle carbon footprint of 1 500 tonnes of CO₂ equivalent (including manufacturing, installation, operation, and decommissioning). At a capacity factor of 30 %, how many kWh does it generate in one year? Using the 11 g CO₂/kWh lifecycle emission factor, calculate the energy payback time: the number of years until the wind turbine's own carbon footprint is 'paid back' by the avoided gas emissions (using 450 g CO₂/kWh as the reference).
- The lesson mentions that end-of-life solar panels create waste. A solar panel has a mass of 20 kg and a lifetime of 30 years. It generates 400 kWh/year. If 10 million panels reach end-of-life in one year in Europe, calculate: (a) the total mass of panel waste in tonnes, and (b) the total electricity those panels generated over their lifetime (in TWh). What recycling challenge does this scale suggest?

Exercise 9

Calculation

Energy equity – transition costs and household impact. A government introduces a renewable energy levy of €0.05/kWh on all electricity consumed to fund grid upgrades and storage investment.

- A low-income household consumes 2 000 kWh/year of electricity. A high-income household consumes 6 000 kWh/year. Calculate the annual levy payment for each household. Express the levy as a percentage of a typical annual energy bill: assume €800 for the low-income household and €2 400 for the high-income household.
- The government introduces a ‘social tariff’ that exempts the first 1 200 kWh/year from the levy for low-income households. Recalculate the levy for the low-income household under this exemption. By how much does the social tariff reduce their levy payment, and what percentage of their annual bill does the reduced levy represent?
- The total fund raised by the levy is €5 billion per year (across 100 million households). The grid upgrade needed costs €200 billion. How many years of levy collection are needed to fund the grid upgrade? The lesson notes that ‘additional trillions of dollars’ will be needed globally by 2050. If the global need is €3 trillion and there are 25 years to 2050, what annual global investment is needed? How does this compare to the ‘500 billion euros per year’ currently invested in renewables?

Exercise 10

Calculation

Whole-course integration: designing a small renewable energy system. A small island community has the following annual energy needs: 2 000 MWh of electricity and 3 000 MWh of heat. The island has good wind and solar resources. Use the knowledge from across the whole course to answer the following.

- The island installs 2 MW of wind turbines (capacity factor 35 %) and 1 MW of solar PV (capacity factor 12 % for the island’s latitude). Calculate the total annual electricity generation from wind and solar in MWh. Is this enough to cover the 2 000 MWh electricity demand? If there is a surplus or deficit, state how large it is.
- The island also installs a heat pump (COP = 3.5) powered by the surplus electricity to cover part of the heat demand. If 500 MWh of surplus electricity is available for the heat pump, how much heat does it deliver? How much of the 3 000 MWh heat demand remains unmet after the heat pump contribution?
- The remaining heat demand is met by a solar thermal system with an efficiency of 60 % and an average irradiance of 150 W/m² (annual average, accounting for night and cloud). Calculate the solar thermal collector area needed to supply the remaining heat demand. (Assume 8 760 hours/year.) Based on all three technologies – wind, solar PV, and solar thermal – list one advantage and one disadvantage of this island energy system, drawing on the PESTEL framework from Lesson 5.

Section C – Internet Exploration Questions

Exercise 11



Internet Exploration

Explore the IEA's World Energy Outlook (<https://www.iea.org/reports/world-energy-outlook-2023>) or the IRENA World Energy Transitions Outlook (<https://www.irena.org/Publications/2023/Jun/World-Energy-Transitions-Outlook-2023>).

- Find the current global share of renewable energy in total electricity generation (in %). How does this compare to the share in 2010? Which renewable source has grown fastest in the last decade, and what share of global electricity does it now supply?
- Find one specific country or region that has achieved a very high share of renewable electricity (above 70 %). Describe how they achieved it: which technologies dominate, what storage or grid management tools do they use, and what challenges remain. Write 3–5 sentences.
- The lesson identifies permitting and planning as a key legal barrier to renewable deployment in Europe. Find one specific example from the IEA, IRENA, or a European Commission source of how long permitting takes for a wind or solar project in Europe, and what reforms are being proposed. Write 3–5 sentences connecting this to the legal dimension of the PESTEL framework.

Exercise 12



Internet Exploration

Explore ENTSO-E (<https://www.entsoe.eu>) – the European Network of Transmission System Operators for Electricity – or the EU REPowerEU plan (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repower-eu-affordable-clean-and-secure-energy-europe_en).

- Find the current level of cross-border electricity interconnection between EU member states, or a specific planned interconnection project. Describe what it connects, its capacity (in GW), and how it contributes to the multi-commodity grid concept from the lesson.
- The lesson mentions that 'energy diplomacy is increasingly important for hydrogen trade.' Find one real or planned international hydrogen trade agreement or project involving Europe. Describe the countries involved, the type of hydrogen (green, blue, etc.), and the expected volumes or timeline. Write 3–5 sentences.
- Find one example of a community energy project or energy cooperative in Europe (for example in Germany, Denmark, or the Netherlands). Describe how it works, how many households or members it involves, and how it contributes to the social dimension of the energy transition described in the lesson.

Section D – Home Activities

Exercise 13



Home Activity – Conduct a Personal PESTEL Analysis of Your Home Energy

In this activity you will apply the PESTEL framework from Lesson 5 to your own home's energy situation. This is a reflection and analysis exercise that requires no equipment – just observation, your energy bill (if available), and some online research.

Part A – Your home energy audit (observation):

- Walk through your home and list all energy-consuming devices and systems (heating, hot water, cooking, lighting, appliances, electronics). Estimate whether each uses electricity, gas, or another fuel.
- If you have access to an energy bill or smart meter app, find your household's monthly or annual electricity and gas consumption in kWh. If not, use the Dutch average: approximately 2 800 kWh/year of electricity and 1 300 m³/year of natural gas (approximately 13 000 kWh of gas energy).
- Identify which of your energy uses could realistically be electrified or made more efficient (e.g. replacing a gas boiler with a heat pump, switching to LED lighting, adding roof insulation). For each, estimate whether the change would increase or decrease your electricity demand.

Part B – PESTEL analysis of your home energy transition:

For each of the six PESTEL dimensions, write 2–3 sentences describing a factor that affects your personal ability to make your home more sustainable. Use the table below as a guide.

PESTEL dimension	Factor affecting your home energy transition	Your observation (2–3 sentences)
Political	e.g. government subsidies for heat pumps, solar panels	
Economic	e.g. upfront cost of a heat pump or solar system vs. payback time	
Social	e.g. peer influence, energy community, landlord-tenant dynamics	
Technological	e.g. availability of smart meters, home batteries, EV charging	
Environmental	e.g. impact of your current energy use; LCA of upgrades	
Legal	e.g. planning permission for solar panels, rental regulations	

Part C – Reflection:

- Which PESTEL dimension is the biggest barrier to your personal energy transition? Which is the biggest enabler? Write a short paragraph (5–8 sentences) summarising your analysis.
- Based on your audit, what single change would have the biggest impact on reducing your household's carbon footprint? Estimate the CO₂ reduction in kg/year. (Hint: burning 1 m³ of natural gas emits approximately 1.9 kg CO₂; 1 kWh of Dutch grid electricity emits approximately 0.3 kg CO₂ in 2024.)

Exercise 14



Home Activity – Map Your Local Energy Infrastructure

In this activity you will explore the real energy infrastructure in your local area using freely available online tools. This connects to the lesson's discussion of the electric grid, multi-commodity networks, and smart grid upgrades.

Tools you will need:

- Google Maps or OpenStreetMap (<https://www.openstreetmap.org>) – satellite and map view
- The Netherlands: Netkaart (<https://www.netkaart.nl>) – shows electricity grid infrastructure
- Europe: ENTSO-E Transmission System Map (<https://www.entsoe.eu/data/map>)
- Optional: your local grid operator's website (e.g. Eneco, Vattenfall, Liander for the Netherlands)

Part A – Identify local energy infrastructure:

- Using Google Maps or OpenStreetMap, identify at least three of the following energy infrastructure elements within 5 km of your home or school: (a) electricity substation or transformer station, (b) high-voltage transmission tower or line, (c) solar farm or rooftop solar installation, (d) wind turbine, (e) district heating pipe or plant, (f) EV charging station, (g) gas pressure station.
- For each element you find, note: what it is, approximately where it is (street or area), and what role it plays in the energy system based on what you learned in the course. (For example: 'A distribution transformer at [location] steps down voltage from 10 kV to 230 V for local homes – this is the last step in the electricity delivery chain from Lesson 4c.')

Part B – Grid integration challenge:

- Using Netkaart or the ENTSO-E map, identify the nearest high-voltage transmission line or substation to your home. What voltage level does it operate at? From Lesson 4c, what does this voltage level tell you about where it sits in the electricity delivery chain (transmission vs. distribution)?
- Look at the satellite view of your neighbourhood. Estimate the percentage of rooftops that appear to have solar panels installed. Based on the lesson's content on grid congestion and bidirectional flows: what grid challenge might arise in your neighbourhood as more households add solar panels?

Part C – Reflection:

- Write a short paragraph (5–8 sentences) summarising what you found. Which energy technologies from the course are already present near you? Which are missing? What infrastructure upgrade would you expect to see in your area in the next 10 years, based on the lesson content on smart grids and the multi-commodity grid?