

Transcript Lesson 5. Integration

Slide 1

Welcome to Module 5: Integration, part of the course Renewable Energy Integration in the Energy System, developed by The Hague University of Applied Sciences.

Slide 2

In the previous modules of this course you have learned about what energy is, what we currently use it for, and what the challenges of the energy transition are. After that, you learned how the main energy transfer and conversion technologies work, and what the advantages and disadvantages of each of them are. All these lessons were necessary to understand the pieces of the energy system puzzle. In this lesson, we will look at what we need to take into account when we modify the current puzzle by adding more and more renewable energy pieces, while removing the fossil fuel pieces.

Slide 3

The main objective of the energy transition is to switch from the current fossil fuel-based energy system to a 100% renewable energy system.

This is certainly easier said than done. It is a complex transition that will take a long period of time.

It is a gradual transition, with an incremental increase in the share of renewable energy in the total energy system.

There is no golden solution. There is not a single source that can deliver all the energy we use, and there is not a single technology that allows us to transfer or convert this energy into the type we need. Therefore, the total energy system is, and will remain, a mix of energy sources and technologies to transfer and convert energy from source to destination, with a virtually infinite number of possible combinations.

The changes in the energy system have consequences for all aspects of our society: political, economic, social, technological, legal, and environmental. That is why the energy transition is such a complex issue.

Slide 4

Before we look at what we should take into account when integrating more renewable energy into the energy system, it is useful to first discuss what can actually be considered renewable energy.

A renewable energy source is any energy source that replenishes itself fast enough to be considered inexhaustible on a human timescale.

The phrase "on a human timescale" is really important here. Fossil fuels do replenish, but on a geological timescale, which is not compatible with human energy needs.

Biomass also replenishes, and it does so at a considerably faster rate than fossil fuels, but not fast enough given the current pace of human energy consumption. In some countries, biomass is considered renewable by legislation, but strictly speaking it does not meet the definition above.

Nuclear energy, with current technology based on fission, depends on specific materials that are also scarce on Earth, primarily uranium, and therefore cannot be considered inexhaustible.

Slide 5

In this course, you have gained a basic understanding of what energy is, what we use it for, and primarily how we transfer or convert it between different energy forms. This knowledge is necessary to develop a deeper

understanding of the complexities of the energy system. However, when analysing the integration of renewable energy into the energy system, we cannot focus only on technological aspects.

A PESTEL analysis is a practical framework to structure a broader view. It examines the Political, Economic, Social, Technological, Environmental, and Legal aspects of a given situation. We will first go deeper into the technological aspect, as it is the core of this course, and then address the other dimensions at a somewhat higher level. As you will see, all these aspects are deeply interrelated, and that is precisely what makes large-scale system changes so complex.

Slide 6

Let us start with the technological dimension, and specifically with one of the central challenges: integrating renewable energy into the electric grid.

The first challenge is intermittency. Solar and wind energy are only generated when the sun shines or the wind blows. Their output is variable and can only be predicted with limited certainty.

This creates a second challenge: load balancing. On the electrical grid, demand and supply must match at every moment. Any imbalance causes frequency deviations, which can threaten grid stability.

A related problem is the mismatch between when renewables produce energy and when consumers actually need it. Renewable peaks do not always coincide with demand peaks.

To maintain a stable grid frequency of 50 or 60 hertz, fast-responding reserves are needed for what is called frequency regulation.

Distributed renewable generation also creates local voltage fluctuations, which must be actively managed.

Finally, the existing transmission infrastructure was not designed for the bidirectional energy flows that occur when many distributed sources feed energy back into the grid. This leads to grid congestion in many regions.

Slide 7

One approach to addressing these integration challenges is to look beyond the electric grid alone and think in terms of a multi-commodity grid, where electricity, heat, and hydrogen are all considered together.

The electric grid remains the backbone of the energy system. It includes high-voltage transmission lines and medium- and low-voltage distribution networks. It must balance supply and demand in real time.

Heat distribution networks, such as district heating and cooling systems, offer additional flexibility. They can reuse industrial waste heat and, importantly, allow for seasonal thermal energy storage, which helps bridge the gap between summer solar surpluses and winter heating demand.

Hydrogen networks offer yet another option. Surplus renewable electricity can be converted to hydrogen through a process called power-to-gas. This hydrogen can then be stored and transported, even using repurposed natural gas pipelines, and used in industry or transport. Hydrogen is particularly valuable as a seasonal and long-distance energy carrier.

Integrated planning across all three grids, electricity, heat, and hydrogen, is one of the key strategic concepts in the energy transition.

Slide 8

Another critical piece of the integration puzzle is energy storage. Different storage technologies operate on very different timescales, and each serves a specific purpose.

Battery storage systems operate on a timescale of minutes to hours. They are connected at the distribution level, respond in milliseconds, and are used for short-term grid balancing, frequency support, and peak shaving.

Pumped hydro storage operates on a timescale of hours to days. It is a utility-scale technology connected to high-voltage transmission lines. It stores excess energy overnight and releases it during periods of peak demand.

Hydrogen storage can bridge days to months. Power-to-gas plants convert surplus electricity into hydrogen, which can be stored in tanks or injected into the gas grid. It can then be used in fuel cells or reconverted to electricity when needed.

Thermal storage covers a wide range, from hours to entire seasons. It stores excess heat or cold in tanks or underground systems, and is directly coupled to district heating networks and industrial processes.

Each of these storage technologies plays a complementary role. No single technology can cover all needs, which is why an integrated approach to storage planning is essential.

Slide 9

The fourth technological topic is smart grids and digitalization, which are increasingly central to making renewable integration work.

A key shift is the emergence of prosumers: consumers who also produce energy, for example through rooftop solar panels. This creates bidirectional energy flows, which the traditional one-way grid infrastructure was not designed to handle. Upgrades are needed for electricity, heat, and hydrogen flows alike.

Smart meters and Internet of Things devices enable demand response and flexibility. They allow consumers, and even industrial processes, electric vehicles, and heat pumps, to shift their energy use to times when renewable supply is high. In this way, demand becomes an active tool for grid management.

Digital platforms can integrate and optimise across electricity, heat, and gas networks simultaneously. Artificial intelligence and predictive algorithms play a growing role in this coordination.

However, increased connectivity also brings new risks. Real-time data exchange requires robust communication protocols, and the expanded digital infrastructure creates cybersecurity vulnerabilities that must be actively managed.

Slide 10

Moving to the economic dimension of the PESTEL framework, there are four key factors to consider.

First, the Levelised Cost of Energy, or LCOE, measures the average cost of generating one unit of energy over a technology's lifetime. Solar and onshore wind are now the cheapest sources of new electricity generation in most markets. Their costs have fallen by 80 to 90 percent over the past decade, making them fully cost-competitive with fossil fuels.

Second, while renewable generation itself has become cheap, the investment required in grid infrastructure and storage remains enormous. Global renewable energy investment has exceeded 500 billion euros per year in recent years, but additional trillions of dollars will be needed for grid upgrades and storage by 2050.

Third, the renewable energy sector is a significant and growing source of employment, with over 13 million jobs globally according to the International Energy Agency. However, the transition also requires reskilling workers from fossil fuel industries.

Fourth, renewables offer stable long-run costs because their fuel, wind and sunlight, is free. But wholesale electricity prices become more volatile as the share of variable renewables grows, which creates new challenges for energy market design.

Slide 11

The political dimension of the PESTEL analysis is equally important in shaping the energy transition.

International agreements set the overarching direction. The European Union aims for climate neutrality by 2050 and a 55% reduction in emissions by 2030 under the EU Green Deal, which builds on the Paris Agreement. National governments must translate these targets into binding energy and infrastructure plans.

Policy tools such as feed-in tariffs and renewable portfolio standards have been essential in driving renewable deployment. Many of these are now shifting toward more market-based mechanisms as renewable costs have fallen.

The energy crisis of 2022 added a new urgency to renewable expansion in Europe, with energy independence and security becoming major political drivers alongside climate goals.

At the international level, cross-border grid interconnections require political agreements, and energy diplomacy is increasingly important for topics such as hydrogen trade and offshore wind development.

Slide 12

The legal dimension shapes how and how quickly the energy transition can actually be implemented.

Permitting and planning frameworks are a major bottleneck. Slow and complex approval processes for wind farms, solar parks, and grid upgrades are one of the biggest barriers to renewable deployment in Europe. Streamlining these processes is a key priority of the European Union's REPowerEU plan.

Grid access rules are another important area. Third-party access regulations require grid operators to provide non-discriminatory access to all producers. Rules also govern connection costs and priority dispatch for renewables.

International energy trade requires harmonised legal frameworks. Bilateral and multilateral agreements are needed to govern the use of interconnectors and to assign balancing responsibilities between countries.

Finally, as energy systems become more complex and interconnected, legal frameworks around liability, insurance, and technical standards must evolve. Standards such as those from the International Electrotechnical Commission and the IEEE carry legal weight and are essential for safe and interoperable systems.

Slide 13

The social dimension reminds us that the energy transition is not only a technical or economic challenge, but also a deeply human one.

While renewables enjoy broad public support in general, local opposition to wind farms, solar parks, and new grid infrastructure remains common. Concerns about visual impact, noise, and property values can lead to the so-called NIMBY effect, meaning "Not In My Back Yard", and slow down projects significantly.

Energy equity is another crucial issue. The costs and benefits of the energy transition must be distributed fairly. Low-income households are particularly vulnerable to energy poverty, especially if transition costs are passed on to consumers without adequate protection measures.

Consumer behaviour and awareness play a growing role as well. Making the transition work requires active participation from households and businesses, as prosumers, members of energy communities, or participants in demand response programmes. Digital tools and public education are key enablers here.

Community energy projects, such as cooperatives and local energy communities, allow citizens to invest in and benefit directly from local renewable projects. These models increase social acceptance and help distribute the economic value of the transition more broadly.

Slide 14

The final dimension of the PESTEL analysis is the environmental one, which is, of course, the reason we are making this transition in the first place.

Replacing fossil fuels with renewables is the most powerful single lever for reducing carbon emissions from the energy system. Wind and solar have lifecycle emissions that are 10 to 50 times lower than natural gas per unit of electricity generated.

However, large solar farms and wind installations require significant land areas, and site selection must carefully account for ecological sensitivity, habitat disruption, and visual landscape impacts.

Life Cycle Analysis, or LCA, looks at the full environmental footprint of a technology, from manufacturing to end of life. The energy and materials used to produce solar panels, wind turbines, and batteries are not negligible, but full lifecycle assessments consistently show that renewables become net positive within one to four years of operation.

Finally, the end-of-life phase of solar panels, wind turbine blades, and batteries creates new waste streams that need to be managed carefully. Developing recycling infrastructure and designing products for disassembly and reuse are becoming increasingly urgent priorities in the circular economy.

Slide 15

This brings us to the end of this lesson on the integration of renewable energy in the energy system. We have covered the key technological challenges, from grid integration and multi-commodity networks to storage and smart grids. We have also looked at the broader context through the PESTEL framework, touching on economic, political, legal, social, and environmental dimensions.

The references listed on this slide include the main sources used to develop the content of this lesson.