D3.4 - Market design choices for efficient sector integration

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Executive Summary

Electricity is an essential commodity serving very diverse needs. It forms a very peculiar market, since it is expensive to store and needs to be delivered *just-in-time* to a multitude of locations at once with a delicate balance between generation and demand to be maintained at all times. Electricity sector is set to expand, since removing fossil fuels from the other energy sectors has few other scalable low-carbon options than replacing them with fossil-free electricity.

This deliverable examines the interaction between electricity markets and other energy vectors and commodity markets. The main challenges arise when the other sectors have competing needs and rules that can distort participation in the electricity markets. The following aspects are analysed: conversion technologies and their constraints, pricing and regulation, as well as possible options for flexibility. A crucial factor is what alternatives there are for a particular energy service. For example, a building can be heated with electricity, fossil fuels, biofuels, solar heat, district heat or any combination of these. Between these, there are varying mechanisms for equipment purchases, energy trading, distribution tariffs and taxes. Furthermore, in this example, the regulation is heavily affected by energy efficiency targets. All put together, it is an environment where unintended consequences are easy to achieve.

This deliverable analyses several case studies in order to develop a checklist for electricity market design. The case studies include: power to space heating and domestic hot water, power to heat and power with heat (CHP) in district heating, power to heat and power with heat (CHP) in industry, power to hydrogen (H_2) and its fuel derivatives, power to electric vehicles, power from electric vehicles, and power to synthetic transport fuels. Whenever there are two regulatory regimes being connected through a common commodity, there are many options to regulate the interaction between the markets. The checklist will inform the market design and its assessment process in TradeRES WP4 and WP5.

From the case studies, the deliverable distils five main types of energy conversions between energy sectors:

A1. Electricity is the only possible source of energy to fulfil a local demand (e.g., EV)

A2. Other alternative sources of energy besides electricity to fulfil a local demand (e.g., gas heated house with heat pump)

A3. Electricity converted and delivered to other energy networks and/or markets (e.g., gas network)

A4. Other energy vectors are converted to electricity (e.g., fuels to power)

A5. A round-trip of electricity through another energy vector or sector (e.g., $P2H_22P$)

The analysis also identified three levels of flexibility:

B0. No flexibility

B1. Time-shift and other temporally restricted flexibility

B2. Fully controllable demand.

In principle, the goal of the market design is a level playing field where externalities have been appropriately priced in. However, the case studies clearly demonstrated several hurdles in different areas. The choices that may hinder an efficient market outcome include issues in pricing schemes, taxes and/or subsidies as well as technological, environmental, or acceptance related barriers. The consideration of these factors, presented as a checklist, must be carefully evaluated in TradeRES market designs. Among others:

- All energy vectors should be treated equally related CO_2 emissions and other externalities.
- The main market signal should be based on the wholesale market price for an optimal energy conversion interaction. In other words, all end-users should have an undistorted wholesale market access, either directly or through third parties that facilitate market price signals reaching end-users.
- Networks must also signal their flexibility needs to the energy converters, if a market approach is desired. The more a given flexibility is in short-supply, the higher the remuneration from the network.

Given the same energy source and energy destination, a market design should help to avoid costlier routes (which are often also more wasteful). For example, there are several possible routes from electricity to space heating, but the chosen route should have the best cost/benefit for the society and wrong routes should not be picked as winners due to perceived benefits.

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1. Introduction

1.1 Goals of the WP3, Task 3.4 and Deliverable 3.4

[WP3]: *Description of work: Current markets do not sufficiently remunerate the flexibility of small consumers, be it through demand shifting, e.g., in the charging of electric vehicles, or investing in, for instance, home batteries. Therefore, a first challenge is to align the market for small consumers with the wholesale (retail) market. Short-term markets must be (re)designed to integrate and correctly manage flexibility from day-ahead to real-time operation. The market design must provide incentives for investment in, and an optimal mix of VREs, controllable generation, storage, networks and flexibility options at the consumer side. The market design process of this WP will take place iteratively with the model development in WP4 and their application in WP5: if the simulated market performance is not good enough as compared to the benchmark, which is developed in WP2, the iteration cycle will restart, and the market design and modelling tools will be improved. Moreover, there will be close cooperation with WP6, as representative stakeholders will be involved in the market design process. We will build upon the consortium previous work as well as the results of MIT's Utility of the Future project . The outcomes of this work package will contribute to WP4, where tools to simulate new energy-integrated electricity markets will be developed.*

Task 3.4 *will identify how the interaction between different energy vectors (e.g., heat, H2, transport) can be integrated with electricity markets. The key issue is how to set the prices right so the markets should be able to reach a system-wide optimum and foment inter-sector economic integration within a circular economy approach. The prices need to reflect the momentary (system marginal) value of energy, the value of flexibility and the social cost of CO2 emissions.*

Deliverable 3.4 *Market design choices for efficient sector integration*

The TradeRES project plan [1], [2] outlines the content of deliverable 3.4 as "*Report with a proposed design of prices for energy, flexibility and CO2 emissions that allow for efficient sector coupling. Delivery month: M12.*" With that in mind, as well as the other WP3 deliverables (especially D3.5), this report will review market design aspect related to sector integration and propose a framework how to take those into account in further TradeRES analysis.

1.1 Questions, focus and approach of deliverable 3.4

Electricity is an essential commodity serving very diverse needs. It forms a very peculiar market, since it is expensive to store and needs to be delivered just-in-time to a multitude of locations at once. Furthermore, a delicate balance between generation and demand must be maintained at all times. This is made even more difficult by uncertainty in generation, transmission and consumption as well as the possibility of a system-wide collapse of frequency and voltage, better known as a blackout. Consequently, systems of preparatory steps, manual real-time actions, automatic real-time actions, and post-facto clearance have evolved to maintain energy balance and stability. Markets can be involved in all of these steps.

The task of this deliverable is to find out what needs to be considered when the electricity markets interact with other commodity markets and provide energy services with a possibility for active participation in the balancing and stability services. The main challenges arise when the other sectors have competing needs and rules that can distort participation in the electricity markets. The essential questions to study the interactions include but are not limited to:

(i) What kind of products are being supplied, demanded and how are the prices set?

(ii) What is their energy demand and capability to alter the schedules in real time?

(iii) What is the status of competition in the sector (free competition, monopolistic market, distorting taxes or tariffs)?

(iv) How is the integrated sector physically connected to electricity markets and what limitations there may be?

(v) What regulatory interventions can be present?

Hence, the goal of D3.4 is to identify interactions with other energy markets and to give a framework for the market design process in TradeRES WP4 that also considers the other energy sectors. Consequently, this deliverable analyses the ways in which the other energy sectors can add value and enable more efficient operation of the power markets. Meanwhile, electricity and ancillary service markets are explored in more detail in the other deliverables of WP3. Furthermore, the final version of deliverable 3.5 will collect all the findings (including those from this deliverable) and present potential market designs that will be evaluated in the following work packages using performance indicators from the deliverable 3.1.

Whenever there are two regulatory regimes being connected through a common commodity, there are many options to regulate the interaction between the markets. This deliverable selects those that together cover the plausible high-level alternatives so that they can be manageably studied in the TradeRES case studies.

The rest of this report is organized as follows. Chapter 2 will introduce the markets and tariffs that can be present in energy conversion and trade. Chapter 3 presents cases where the electricity markets interact with the other energy sectors. Chapter 4 then presents an analysis framework that defines a manageable set of factors to focus on in the subsequent TradeRES analyses. This presents the integration alternatives that can be included in TradeRES iteration cycles, including discussion on pricing principles for the different integration approaches. Our approach and guideline to contribute for the TradeRES market design process is depicted in detail in Figure 1.

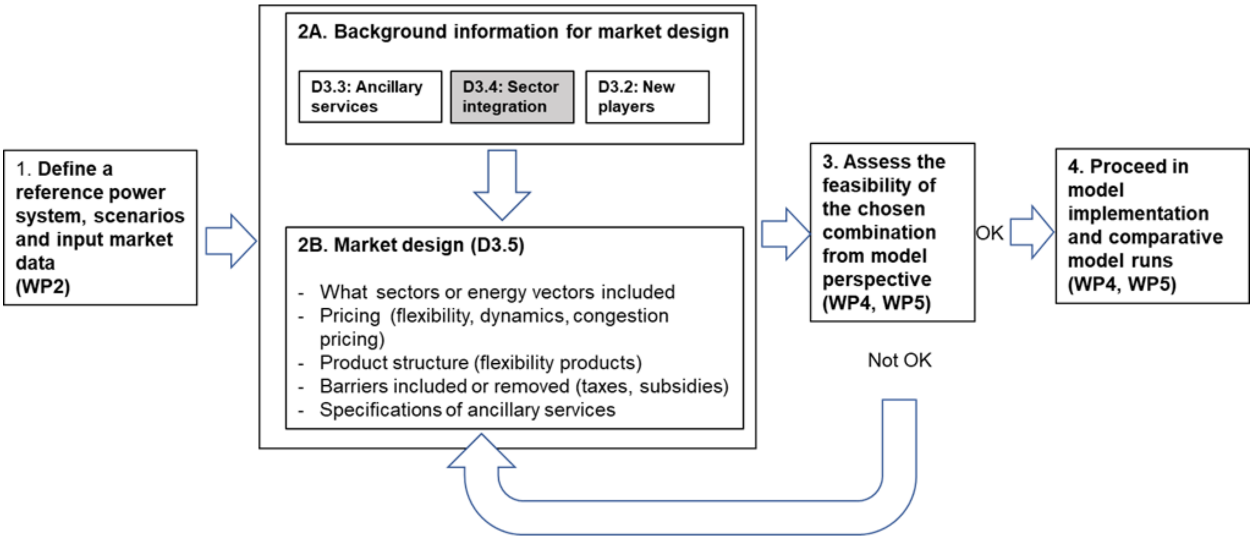

Figure 1: Schematic Iterative loop on market design development in TradeRES and the proposed contribution of D3.4.

2. Aspects to be considered

An efficient market would provide all the needed services while reflecting the real costs, including external costs like those caused by greenhouse gases. In a power grid, the needs can change from moment to moment, and it is far from straightforward to assess what services should be provided by which resource. As a consequence, electricity markets only approximate the services needed and the participation of different resources in the partially overlapping markets. Furthermore, energy is subject to technical and financial regulation that can further introduce distorting elements, such as taxes, levies, or regulatory measures, that may be justified from a societal perspective [3] .

The following chapters will build a framework for including other energy sectors in the design of electricity markets. Before that, this chapter lists the aspects that need to be considered when evaluating those interactions between electricity and other energy markets.

2.1 Technical constraints

Market design needs to consider possible technical and resource related constraints in energy conversion from primary sources to intermediate vectors, between intermediate vectors, and to final use.

- Possibilities for timing the conversion (e.g., wind availability, postponing the processing of raw materials for an industry process)
- Possibilities for storing energy (e.g., heat storages, fuels, intermediate hydrogen storage, batteries)
- Start-up and shut-down sequences
- Part-load efficiencies in the conversion process
- Multiple products from the conversion process (e.g., electricity and heat)
- Minimum loads
- Capabilities for providing ancillary services (including duration and magnitude)
- Inelastic forms of consumption and generation

2.2 Energy transfer related constraints

Electricity markets have considerable limitations when it comes to transferring energy between locations of generation and consumption, but other energy sectors can also have some limits that should be considered. Other sectors may have local grids (district heating), limited geographical scope (gas), or be facilitated by road and rail networks (biomass)

- Limits on energy flow between locations
- Losses in energy transfer
- Limits related to network stability (mostly power grid)
- Step-changes as technology changes due to energy flow volume change (e.g., voltage levels in power grid or vehicle options in delivering liquid fuels)
- Losses when changing the mode of transfer (voltage levels, ships to vehicles)

2.3 Time scales for energy markets

While electricity markets are especially sensitive to the time dimension and power systems require decisions on different time scales, also other energy markets can have important temporal restrictions in their decision making.

- Investment decisions (typically months to years in advance)
- Optimising the use of long-term storages
- Preparation for real-time operation (ensuring sufficient resources in place)
- Real-time operation (mainly concerns power systems)
    - Automatic functions
    - Manual functions
- Post-facto balance settlement (or similar mechanism)

2.4 Current electricity markets and system services

Other TradeRES WP3 deliverables will discuss the electricity markets in more detail, but here we present a compact list considering the interactions between electricity and other energy markets (see [4], [5] for a more thorough discussion).

- Various capacity mechanisms (discussed more in D3.5)
- Contract markets for futures and forwards
- Market structures for short-term energy balancing

"Traditional"	**Real-time**	**Power pool**
Day-ahead	Continuous trading real time market	Costs and constraints submitted to central optimization
(Intra-day market)		
Balancing market		

- Ancillary services (based on [6])
    - Frequency containment
    - Frequency restoration
    - Replacement reserve
    - (Fast frequency response)
    - (Ramping margin)
    - Voltage control
    - System restoration
- The markets can be zonal or locational (nodal). The transfer limits can be set by capacity limits or by a flow-based calculation.
- Power to district or industrial heat, hydrogen etc. actors, although operating directly on the market, are subject to transmission or distribution network tariffs, unless they use electricity produced at site behind the meter.

2.5 Markets at the retail level

Retail customers (electricity or otherwise) are not necessarily direct participants of the 'whole-sale' energy markets. Retail customers have often been isolated from the immediate fluctuations in energy prices. However, retail customers form the biggest block of energy consumption and TradeRES needs to consider how retail customers could be more price sensitive especially when they have energy-intensive applications. Pricing options for retail customers:

- Flat price contracts
- Contracts that reflect dynamic prices (from energy markets to ancillary services)
- Energy service contracts (e.g., certain level of comfort)

Sometimes the cost of energy and the cost of transferring the energy to the final customer are separated. In this case, transfer pricing has also similar options:

- Flat price based on e.g., transfer capacity (for example fuse size in electricity retail)
- Pricing that reflects the scarcity of energy transfer capacity (pricing set by peak load, critical peak pricing, day/night tariffs, real-time prices, etc.)
- Pricing that reflects the costs caused by the location of the customer (oil truck delivery costs, connection costs for electricity grids)
- Dynamic pricing that follows changes in electricity market prices

2.6 Energy sector interaction types

Here we build a list of potential types of interactions between electricity and other energy sectors. The list is a product of the next chapter – the examples from Chapter 3 produced an extensive list of possible specific interactions, but the list below is an end-product of a trimming down process where the specific interactions are represented by generic interaction types.

The list is divided into two parts. List A is about the various kinds of conversion processes there can be between electricity and other sectors. List B is about the constraints of the flexibility of the conversion process. A single interaction between electricity and some other energy sector can contain both: an item from the list A and an item from the list B.

A. Energy conversion and its alternatives

A1. Electricity is the only possible source of energy to fulfil a local demand (EV can be charged only with electricity; case dependent: local space heating, H2)

A2. Other alternative sources of energy besides electricity to fulfil a local demand (e.g., gas heated house with heat pump, hot water boiler with both fuel furnace and electric resistors). Could be a full or a partial supplement.

A3. Electricity converted and delivered to other energy networks and/or markets (H2 network, gas network, fuel markets)

A3.1. Local markets with a local market price (significant import/export costs) (H2)

A3.2. Pan-European type of markets (gas network, fuel delivery)

A4. Other energy vectors are converted to electricity

A4.1. Electricity-only generation (e.g., CCGT)

A4.2. Electricity is produced together with another vector (e.g., DH CHP, micro-CHP)

A4.2. Electricity coming from other networks (e.g., Gas)

A5. A round-trip of electricity through another energy vector or sector (e.g., EV V2G, H2)

B. Constraints on flexibility

B0. No flexibility

B1. Time-shift and other temporally restricted flexibility

B1.1 Short-term flexibility for ancillary service markets (e.g., air-to-air heat pump)

B1.2 Flexibility for balancing time scales from storage (e.g., building heat storage)

B2. Fully controllable demand

Energy conversion can be arbitrarily curtailed or switched off if the price is right (e.g., an alternative conversion is available or a process that can be shut down, also a very long-term energy storage appears as fully controllable from the electricity market perspective)

For markets to reach near-optimal solutions in given circumstances, there are several aspects to be considered:

- Each energy vector should include in their tariffs those aspects that are necessary to give the actors appropriate incentives both in operational and in investment time scales.
- When DSOs, TSO and actors with an imbalance compete for flexibility, there are many kinds of technical constraints as well as cost structures that should be properly reflected in the final prices. Flexibility should be used where it has the highest value.
- If the physical distance is essential, it should be reflected in the final prices (e.g., including losses) as well as in connection costs.
- Network bottlenecks (congestion), and lack thereof, should be reflected in the prices of energy and ancillary services.

2.7 Taxes and subsidies

Energy markets are subject to various taxes, external costs, and subsidies. Taxes can be fiscal (main purpose is revenue for the government) or related to externalities (e.g., emission taxes). There can be tax breaks to protect business interests. Subsidies can be used to assist technologies that are not yet mature, but they can also be reminiscent of the past with vested interests protecting those subsidies. Both taxes and subsidies are most often levied on the energy content, but there are alternatives:

- Energy or emission content (e.g., EU ETS)
- Percentage of the price (VAT typically)
- Ceilings and floors in conjunction with the above alternatives
- Flat fees (e.g., per customer using the service)

3. Examples of interactions between electricity and other energy sectors

This chapter reviews several different examples of interactions between electricity and other energy sectors. The examples highlight what types of interactions need to be considered in electricity market design.

Figure 2 contains examples of the energy flows in an energy system with partial electrification of the other energy sectors. We can observe that in addition to the traditional power system there are three kinds of interactions with the other energy systems. 1) Energy incoming to the power system also has alternative uses for the rest of the energy system. 2) Energy outgoing from the power system has alternative sources of energy. 3) The energy outgoing from the power system can return to the power system (i.e., storage). In addition, there are multiple possibilities for storages that can influence the temporal challenges the power system in particular has.

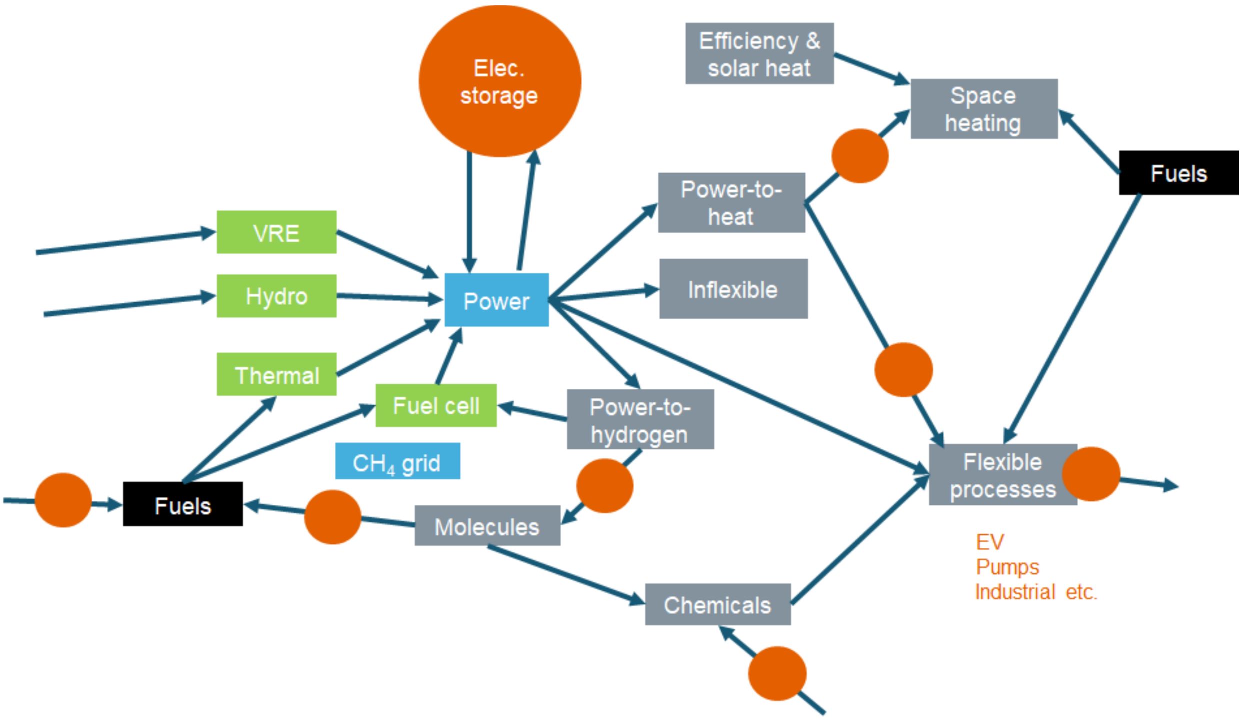

Figure 2. Potential energy flows (arrows), energy vectors and/or energy conversions (boxes), and energy storages (circles) in a partially electrified energy system.

The following sub-chapters review interactions between electricity and specific energy processes in order to give background for the framework that will be presented in the next chapter.

3.1 Electricity and gas end-user prices today

Electricity and gas are two important energy sectors in EU today. Electricity and gas end-user prices, as already noted, differ. If we look at the end-user prices of medium sized households, including all taxes, levies and network fees, we can note that the difference is very country dependent, see Figure 3.

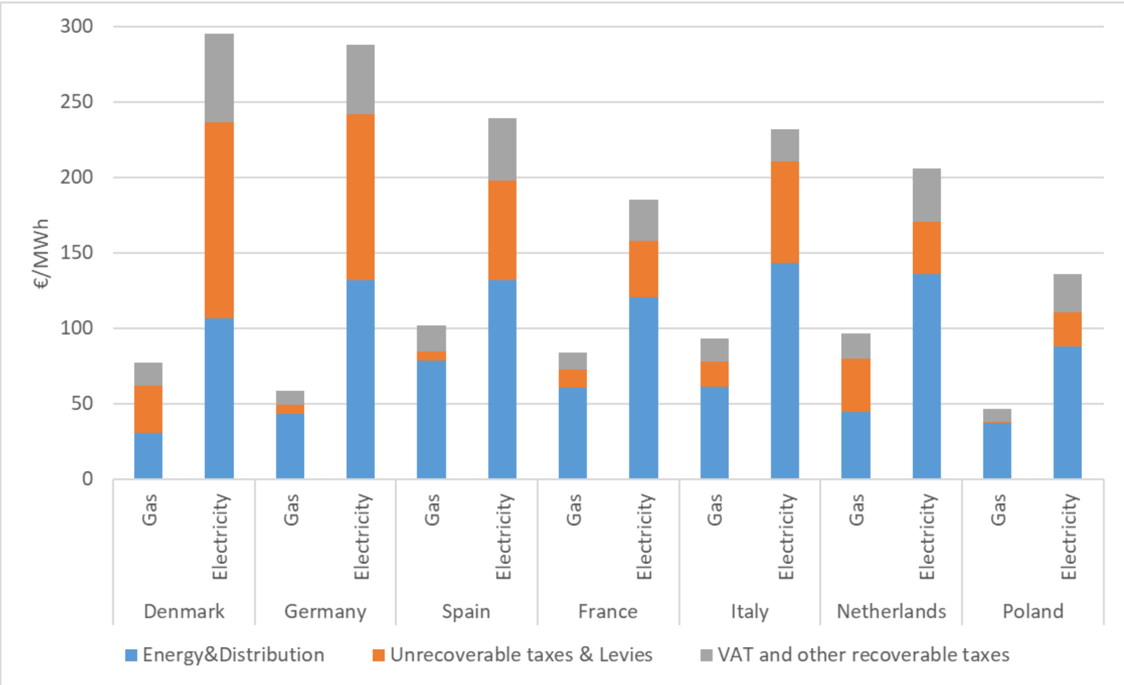

Figure 3. End-user prices of electricity and gas in 2019 for medium size household consumers[1] (Data source: [7])

As can be seen, gas prices are more competitive than power prices. Overall electricity prices are two to almost five (Germany) times higher. The difference can be found in all cost components (Energy&Distribution, Taxes and levies (excl. VAT), and VAT in all countries except for the taxes and levies category in the Netherlands. Eurostat has a more detailed classification for the taxes and levies of electricity. The largest taxes and levies are the ones classified as Renewable Taxes and the Environmental taxes. For example, the German EEG surcharge is classified under Renewable taxes. Please note that the EU Allowances (EUA) for emissions are already included in the market price of electricity, we can make the observation that electricity is heavily burdened with costs related to climate change mitigation while gas itself is not.

However, these average prices are not the whole truth. In Germany, end-users are able to contract "Wärmepumpenstrom"-electricity for the heat pumps, which require that the heating electricity is measured separately and that the heating load can be controlled by the network for a few hours per day. The network fee is clearly lower and, in addition, does not

[1] For gas: Consumption Band D2 with annual consumption between 20 and 200 GJ (GCV); For electricity: Consumption Band Dc with annual consumption between 2500 and 5000 kWh

necessarily include the local concession levy. Other countries also have arrangements for electric (storage) heating, e.g., time-of-use tariffs with low nighttime fares.

To really understand end-user decisions, we need to look at the individual tariff components they experience, not annual averages based on all costs. For example, network tariffs are expected, to better reflect their cost structure, to decreasingly rely on energy-use based tariff components and more and more on peak load/capacity-based components.

For electricity consumed, it matters where it is used, as

- network tariffs differ for transmission and distribution networks.
- small-scale end-users have different retail pricing structures than large-scale end-users, although in the future, more and more will be based on the spot market directly.
- an EV can buy electricity from alternative locations and sellers.

For electricity produced, it matters where it is produced and consumed, as

- networks may have input tariffs and connection charges
- use of own production at site does not generally incur a network fee nor taxes, only production costs.
- if own production is used at site, it can replace bought end-user electricity
- if own production is delivered to the market, the remuneration is different than for electricity use and, in addition, it runs the risk of getting curtailed, depending on location.

If real-time pricing is introduced, more and more consumers will consume at the same time (in times of low spot prices), which can lead to network congestion on one hand or can also alleviate network surplus production areas on the other hand, depending on the consumers' location in respect to VRE production. To alleviate, real-time network prices should get high when there is a congestion.

The gas network offers short term storage (linepack) and relatively cost-effective longer term gas storages. Both of these reduce the need for dynamic prices. On the other hand, increasing amounts of P2G could make gas prices also more volatile.

Prices of electricity and district heat (mostly with the exception of very small plants and networks) include greenhouse gas costs as they are part of EU emission trade system, but gas or oil heating does not, giving them an unfair advantage. Individual countries, e.g., Finland, have taken remedial steps by inserting CO_2-based taxes on these fuels for years. The EU Commission has also expressed plans of extending the emission trade scheme to heating and transport [8]. In 2019, Germany took a big step towards decarbonizing the heating sector and decided to implement a carbon tax for non-EU ETS sectors in the Climate Action Programme 2030. It starts at 25 Euro/tCO_2 in 2021 and will increase steadily each year, and after 2025 the price will be determined by a tendering process and will be within 55-65 of EUR/tCO_2 [9].

3.2 Heat in general

Heat, from space heating to industrial process heat, is one of the dominant end-uses of energy in EU. Heat can be locally generated with boilers and other such equipment or bought from heat networks, see Figure 4. Heat can also be produced in combined heat and power (CHP) plants that may serve buildings, industrial sites or heat networks.

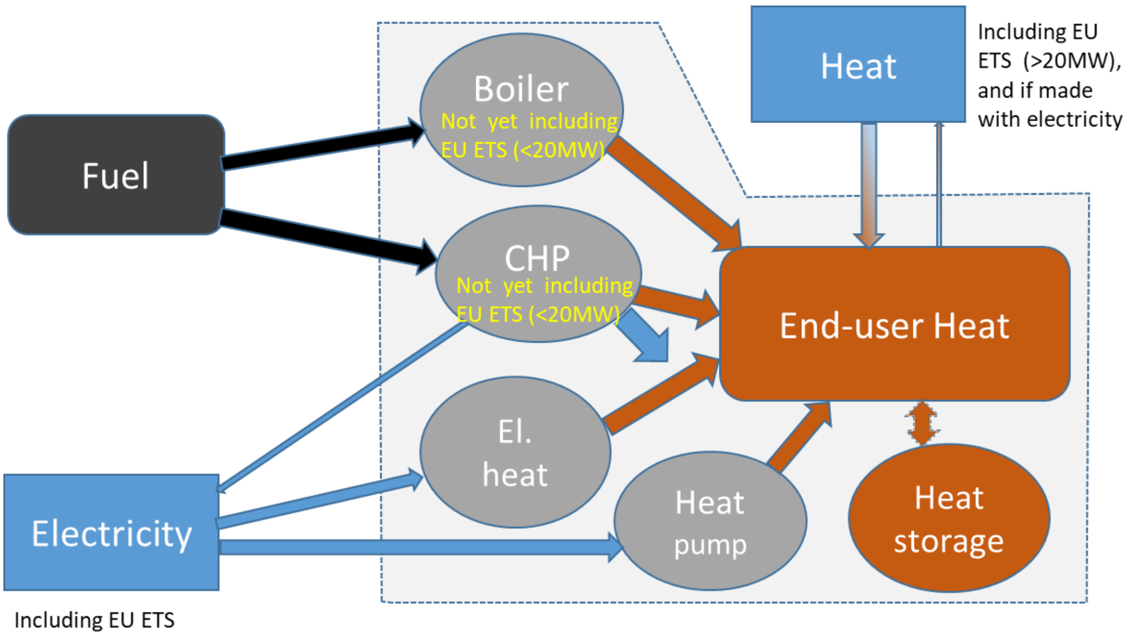

Figure 4. The concept of end-user heat. Grey area forms the boundary for the end-user.

District heating (DH) can have several price components. Energy use-based components might have seasonal variations. The energy use-based components usually depend on heat production costs, which in turn depend on fuel market prices and taxes. For example, so far in Finland, fossil fuels used for district heating have a carbon tax component while they are also part of the EU emission trade system. However, they get part of their Emission Unit Allowances for free, clearly giving DH an unfair disadvantage compared to gas or oil heating.

Heat can be seen as a demand that may have a degree of flexibility itself due to heat storage and other demand response (Flexibility type B1, see Chapter 2.6). Heat storages are decisively less expensive than same sized electricity storages. For electric heat, the heat demand forms the upper bound of the production and the lower bound is dependent on the availability of alternative heating sources at the site. Curtailing heat demand is not usually a practical option, although it could be possible at the cost of occupant discomfort. In industrial process heat, especially in energy-intensive processes, curtailing the whole manufacturing process might be an option at high energy prices.

Combined heat and power (CHP) forms a special case of energy conversion as two energy vectors are produced, electricity and heat. The flexibility of CHP depends on the type of CHP: Electricity can be generated with fixed power-to-heat ratio (e.g., for steam cycle: backpressure unit) or more independently from heat production (e.g., for steam cycle:

extraction unit). CHP can be used, for example, in buildings (micro-CHP), for DH or in the industry. There are also tri-generation options, which are not widespread at least for now.

3.3 Heating of buildings and domestic hot water

Heating systems and demands show a large variety, and with future near zero emission or passive houses, even more so. The general set-up alternatives are shown in Figure 5 (here excluding CHP). Although heating of buildings and domestic hot water are stacked together here, they are separate functions and can well have separate heat sources (and heat storages). Heating demand is large at higher latitudes. For example, in Germany, residential final energy consumption for space heating was 410 TWh (66% of overall household energy use) and for domestic hot water (DHW) 113 TWh (18%) in 2015 compared to electricity use of 76 TWh (12%) for appliances and lighting and energy use for cooking 24 TWh (4%) [10]. In EU-28, electricity (including electric heating) formed only 25% of overall household energy use in 2018 [11], with energy use comprising mainly heating, cooling, domestic hot water, electric appliances and cooking. Closer to the equator, the potential heating season becomes shorter and is increasingly supplemented by cooling needs.

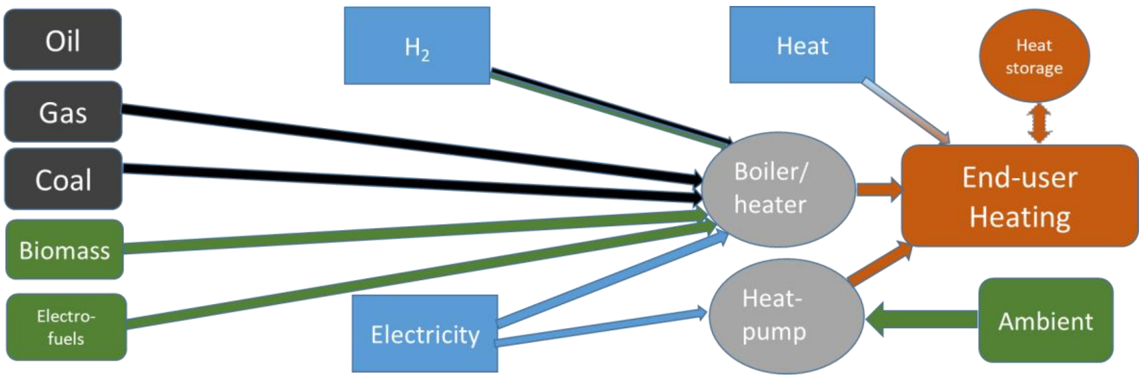

Figure 5. Heating alternatives of buildings and domestic hot water

3.3.1 Markets and competition

Electrical heating is not uncommon, see Table 1, although gas (western and central Europe) or district heating (northern or eastern Europe) have dominant positions. Electrical space heating is common in countries with a relatively low end-user price of electricity and less common in more expensive countries, which can be seen in Table 1. The Nordics are a good example. Finland, Sweden and Norway have relatively low end-user prices for electricity. In addition, Finland and Sweden, with large nuclear power investments in the 70's and 80's, promoted night-time chargeable electric storage heating. Denmark, with gas reserves in the North Sea, has had strict area heating regulations, either gas or district heating, depending on which network was present. The price of electricity for end-users is relatively high in Denmark and in Germany, affecting the competitive position of electric heating.

E.g., heavy surcharges related to the *German Energiewende* clearly distorts the competitiveness of electricity for end-users – the surcharges are higher than the price of electric energy itself.

Table 1. Electricity's share of household space heating and domestic hot water markets in 2015 (Data: [10])

	Space %	Domestic hot water %
Finland	21 %	28 %
Germany	3 %	16 %
Denmark	4 %	N/A
Sweden	29 %	32 %
Italy	0 %	14 %

Electricity based domestic hot water has larger shares than space heating in all the countries in Table 1 except for Denmark, where the number is not available.

3.3.2 Interaction types

Electric heating competes against other alternatives mainly on a long-term base, i.e., what heating system to install. If there is electric heating, the main target is to fulfil the space heating and/or domestic hot water heat demand (Interaction type (IAT) A1, see Chapter 2.6). Nevertheless, as buildings often have multiple heating sources, electricity competes against other sources also in the short term (IAT 2). Micro-CHP's can be used for the heat demand (IAT 4.2).

In Germany, where the price of end-user electricity is relatively high, a lot of gas fuelled end-user CHP, based on fuel cells or reciprocating engines is already being piloted for heating demand (IAT A4.2).

Electricity based domestic hot water systems are in practice always based on a storage, and they form the basis for time-shift flexibility (IAT A1). The smaller the storage, the lower the flexibility.

3.3.3 Electricity based heating systems

In its simplest form, electric space heating is by room-wise heaters with no storage capacity. An alternative would be to have room-wise storage heaters, floor heating with partial storage or a hydronic distribution with a heat storage (hot water tank). Any sort of storage usually increases the investment costs, but allows for the use of cheaper (e.g., night-time) electricity and provides much sought-after flexibility. Whereas traditionally night-time storage heaters are controlled either by timers or by the DSO, modern Home Energy Management Systems allow for widespread flexibility both regarding charging and discharging heat storages and heating demand.

One of the fastest growing new electric heating solutions are heat pumps, which use electricity for their operations. End-user heat pumps come in different forms:

Air-air heat pumps (AAHP) use ambient heat from the outside air. They are mainly used as an auxiliary heat source (IAT A2). The heating capacity of the AAHP diminishes with dropping temperatures in step with the drop in coefficient of performance (COP, i.e., the heat output per electricity input).

Air-water heat pumps deliver the heat to a hydronic system, so it can, and usually does, cover domestic hot water needs. Air-water heat pumps can be auxiliary heating sources or they can cover the whole demand, but in that case the investment cost will rise steeply.

Exhaust air heat pumps are similar to air-water heat pumps in that they mainly target domestic hot water demands. A requisite is to have mechanical exhaust ventilation installed. As exhaust air flows are restricted, the heat capacity is not very high, and the heat storage should be large enough so it covers the daily demand for domestic hot water.

Ground source heat pumps use ambient heat sources via collectors. These collectors can be buried in the field, lie in the sea or in hundreds of meters deep geothermal boreholes. Ground source heat pumps have the highest investment costs due to the collector system. The capacity of the ground source heat pump system can match the peak demand or be lower. For example, in the Nordics 90% of the heating energy can be covered by a system dimensioned to 60% of peak demand. In such a system, the peak heat is produced by direct electric heating, i.e., coils. Ground source heat pumps are based upon hydronic heat distribution and usually have a small heat storage connected to them.

E.g, as PV's are already very popular, the use of surplus PV power for a heat pump makes the heat pump much more profitable compared to using purchased electricity, especially in high electricity cost countries such as Germany or Denmark. But not only there, for example Keiner et al [12] study the complexities of self-consumption of PV prosumers with stationary batteries, heat pumps, thermal energy storage and electric vehicles across the world up to 2050.

3.3.4 Flexibility types

Heat can be seen as a demand that itself may have a degree of flexibility due to heat storage and other demand response (Flexibility type (FT) B1, see Chapter 2.6). For electric heat, this flexible demand forms the upper bound of the production and the lower bound is dependent on availability of alternative heating sources at the site. If there are no alternative heat sources, the only flexibility available is the one from the electric heating system.

There can be a separate heat storage for heating in addition to the virtual storage formed by building heat inertia. Electric space heating has several heat storage alternatives aside from hot water tanks. E.g., floor heating can be combined with a larger, well isolated floor mass that lets heat diffuse through the floor "uncontrollably". Room wise brick-filled electric storage heaters are also a common form of electric heating in some countries, e.g., in Ireland and the UK. Heat is controllably dispersed with the use of a fan. Domestic hot water is usually also associated with a heat storage, especially electric water heating. The heat storages for space heating and domestic hot water can be separate as they have different requirements and have separate (hydronic) distributions.

3.4 District heat network

District heat (DH) or district cooling networks form a natural local market place for different heat (or cooling) production alternatives, as can be seen in the modelled options presented in Figure 6.

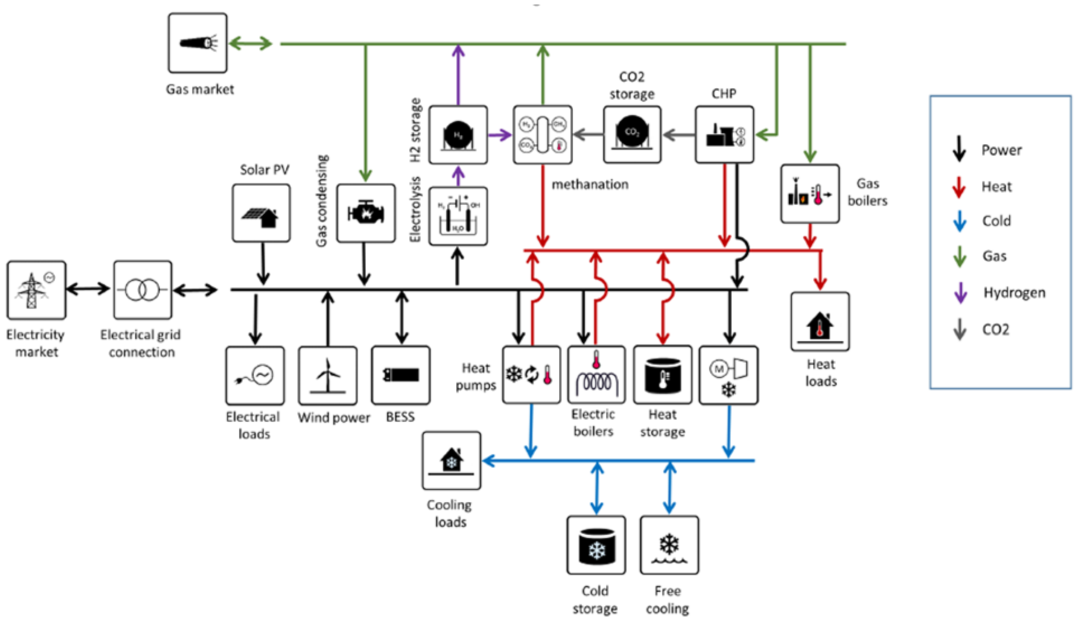

Figure 6. Possibilities of a future district heating and cooling system with its connections to a power system and a gas market [13]

The district heating schema is very much like what is presented in Figure 4, although produced electricity is not used on site, and a lot more heat sources could be available, for example the methanation process. In larger DH networks this multitude of heat sources is used according to merit order to fulfil the heat demand. Heat sources are notably heat-only boilers or CHP plants working on coal, gas, biomass, waste etc., heat pumps utilising waste or ambient heat sources (waste heat, wastewater, sea water, ground sources, ambient air), solar heat collectors, electric boilers and heat storages. As decarbonisation is advancing, fossil fuel solutions are more and more shunned, but biomass availability does also form restrictions.

CHP plants and heat-only boilers have technical restrictions concerning minimum and maximum output, start-up and shut-down sequences, ramp rates etc. In addition, CHP plants can have a fixed power to heat ratio (e.g., backpressure units), or can variate more freely (e.g., for steam cycles: extraction units). CHP has a strong foothold, for example, in Finland, with a market share of 75% of DH heat generation, but it will decrease in the coming years as fossil fuel CHP's are being phased out. In Denmark, old coal-fired extraction CHP's have in recent decades been converted to pellets, straw, wood chips, etc., or shut down, reducing the power production capability.

Heat pumps are becoming more and more popular in DH networks. The main concern is the availability of suitable (waste) heat sources such as data centres, wastewater, district cooling network, industrial waste heat, ambient heat. Sea water can be used, but it has to remain a high enough temperature during the winter to be useful. The more elaborate the heat collector pipes, the more expensive the solution will be. In Finland, sea water heat pumps are not a solution as the water gets too cold to be used during the direst demand in winter. Heat pumps can be used to produce cooling and heating at the same time, which greatly improves the COP. Large heat pumps in Helsinki operated this way have a combined COP of around 5.

Electric boilers were common in the 80's, for example, in Sweden and Finland as there was an overproduction of low short term marginal cost electricity, mainly from nuclear power plants. Electric boilers have lately again become more popular in DH networks in Europe (usually in combination with heat storages) as the amounts of VRE have increased, and they are inexpensive investments.

Heat storages (large water tanks) are often in use for intraday cycles, although they cover only a small share of the load (e.g., ~500 MWh). Larger heat storages depend on geographical circumstances, for example on the availability of large (salt) water aquifers. Large cave-based storages are being developed in Helsinki, but the energy content is still restricted (320 000 m3, 11600 MWh/120 MW; 300 000 m3, 4500 MWh/1.5 MW, local use seasonal storage) when compared to normal loads of 2000 MW in the winter.

District heating networks are not per se part of the EU Emissions Trading System (EU ETS), only emitters, i.a., boilers with a fuel capacity above 20 MW are, but this can be extended to DH networks. For example, in Finland in DH networks with a peak load above 20 MW all boilers are part of the EU ETS even if no single boiler is above limit.

Fossil fuels used for heating can be subject both to energy and CO2 taxes. As large networks are part of the EU Emissions trade system, production in those networks could even pay for CO2 twice. In Finland, for example, heat producers in district heating networks have to pay for CO2 emissions first through taxes and then through their emission allowances. However, at the moment they are receiving a substantial part of their emission allowances for free, but the share is constantly diminishing. For CHP's, there is an additional question concerning the allocation of fuels between electricity and heat generation, as these are treated differently taxation wise. In Finland, generated useful heat in a CHP is factored with 0.9 (this is subject to change in coming years) to define the fuel use relating to it. This approximately matches the benefit allocation method in most cases, giving equal benefit of the CHP to power and heat.

3.5 Industrial heat

Industries are using heat for specific purposes, and the used heat has strict qualifications (usually steam at certain pressure and temperature). The schema is very much like what is presented in Figure 4. For electricity related heat production, the competition is mainly against alternative local heat sources at the industry or industry area. The heat can also be outsourced, which has an impact on flexibility. If the heat delivery is in other parties' hands, usually long-term contracts apply and then price setting might be more regulated and even unflexing.

As for providing flexibility to the electricity market, the electricity market price is the main key. Large industry sites may already be purchasing their electricity need directly from the spot market, providing valuable price flexibility. They might also be connected directly to the transmission grid. The provided flexibility is of course specific to individual sites, as heat source alternatives depend on availabilities (IAT A2) and specific heat demands. Even the production process might be halted at very high electricity prices. For industrial heat, the alternative of stopping the production forms the lower bound (IAT A2). As that decision is dependent on the profit margin of manufactured products versus the additional electricity cost of the heat, it is a case-by-case decision. Today, e.g., the Norwegian aluminium production provides a notable sensitivity to electricity market price signals, new sulphate pulp mills are large net power producers, iron mills are taking baby steps towards the use of (electricity derived) hydrogen instead of coke etc.

Industrial heat systems might include heat recovery. One barrier is the low temperature of the available "waste" heat, but this barrier might well be overcome with heat pumps or added electric heaters.

From a modelling perspective, the difficulty with industrial heat is that each site has its own specific business case and heat specifications. There is no generic "market price" for industrial heat.

3.6 H2

H2 is currently produced by natural gas reformation or as a side product from industrial processes. H2 can also be produced with electrolysis, and electrolysers are becoming increasingly attractive, although the current projects are still pre-commercial. Although conversion losses are considerable, the investment cost of electrolysers also forms an important barrier. E.g., Thema et al. [14] estimate in a market review the average costs of PEM and alkaline electrolysers at 1200 €/kW and 900 €/kW, respectively. Those prices are not yet competitive, but the costs are expected to drop considerable, to around 400 €/kW by 2050.

To use electrolysers only at times of surplus VRE severely restricts their ability to pay off the investments and does not form the basis of a successful business case. Some fuel cell -based electrolysers (e.g., reversible solid oxide fuel cell) might, on the other hand, provide additional flexibility during high electricity prices or ancillary service prices, as the H2 process can be reversed. H2 can also be used in some gas turbines already and the European gas turbine industry is targeting a 100% H2 compatibility for all new turbines by 2030 [17]. Hydrogen is versatile as it can be used in different sectors, e.g., electricity production, transport and industry, and further refined to synthetic natural gas (SNG) or liquid fuels, see Figure 7.

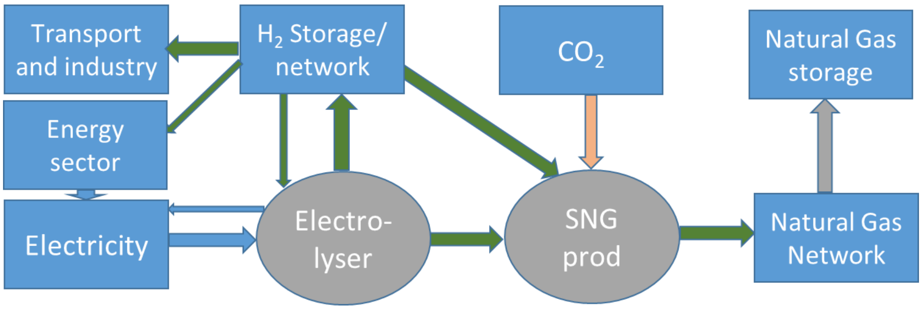

Figure 7. Hydrogen production and usage possibilities

3.6.1 Synthetic natural gas and natural gas network

H2 can in small amounts be added to existing gas networks. The allowed amounts depend on the country in question. For example, the permissible level of H2 currently allowed in EU range from a minimal amount of 0.1%vol (UK, Latvia and Sweden) to a 'high' concentration of up to 10% vol. (Germany) [15] .

There are other barriers. For example, Figure 8 shows the barrier severity of gas quality issues for hydrogen injection and transport in the low-pressure DSO local gas grid, including gas quality monitoring and metering in relation to payment terms and responsibilities for monitoring and metering, according to [16] .

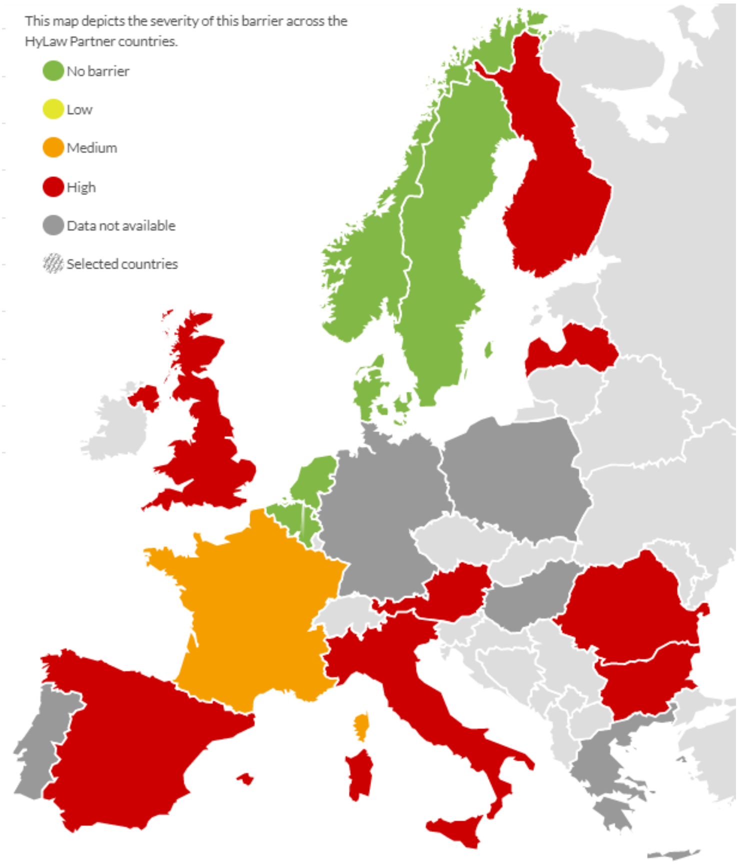

Figure 8. Barriers related to gas quality issues for hydrogen injection and transport in DSO local gas grid [16]

There are constantly new tests being performed on what amounts could be allowed, but these tests do not always give generic answers. The big obstacle is end-user restrictions. For example, gas motors might be highly sensitive to the presence of H2, so networks with gas motors present might have stricter guidelines than networks without. Also gas furnaces and gas boilers would need to be retrofitted to be H2-compatible.

For the nearest future, the NG price forms the reference price for H2. As H2 production is an end-use and taxed as such, the competitive situation is not good for any actor just planning to operate an arbitrage unit between the electricity and the NG vector. The electricity wholesale price includes the use of EUA's, the end-user has to pay for all taxes and surcharges and, of course, for the distribution. The input value of H2 to the NG grid might also be associated with a gas network fee and a price rebate.

H2 can further be refined to synthetic natural gas (SNG) with CO2 and additional energy. SNG is rather expensive to produce and will need to compete against natural gas, which will remain competitive until CO2 emissions are quite costly. However, if EU wants to achieve a CO2 neutral future, natural gas (NG) will be used only to a very limited extent, so biogas, which has a limited potential, and SNG would have to be the of the current gas network. Electricity wholesale price is expected to be cheaper than SNG, as SNG is made from electricity and includes considerable investment costs as well as conversion losses.

Thanks to the available storage capacity of gas networks, both short term line packing and long-term storage caves etc., the integration between SNG and electricity is expected to be a two-way street. During high prices, SNG can be used to generate much demanded electricity. The stored SNG will also be used in the gas network to provide end-users. The less gas storage capacity there is, the more SNG prices will follow electricity prices. However, the amplitude of price swings could be smaller due to the significant conversion losses.

3.6.2 H2 networks and end-use

There are already H2 network pilots in progress. It could also be possible to convert redundant NG networks to H2 networks and preliminary tests show promise [17]. However, this may be difficult, since H2 is a much lighter and more explosive gas and has much smaller molecules than NG. The costs of new H2 networks are also likely to be higher than for NG - especially the distribution to small end-users.

Some industrial processes require H2. Other processes could be converted to H2. These industries can either reform NG to H2, electrolyze H2, or buy H2 from the market (tanker truck delivery). Electrolysis must compete against the alternative H2 procurement costs. In countries such as Germany where the end-user electricity has a lot of taxes and surcharges included, it can be hard to compete against NG with smaller taxes and lower distribution costs. Even after the tax structure is equalized, the CO2 costs need to be high before H2 from electrolysis can compete with H2 from reformed NG. There can also be sites that are not connected to the NG grid and would therefore have higher NG procurement costs.

3.6.3 P2H2P

One alternative is to locally store the hydrogen and use it for electricity in a reversible fuel cell or in a gas turbine/engine that can run on H2, see lower left loop in Figure 7. The storage cost, as well as the conversion losses back and forth have to be covered for a successful business case. If the facility is seen as an end-user, it has to pay for taxes, surcharges and network distribution costs of the consumed electricity. As in some parts in EU, e.g., Finland, separate electricity storages are or will be seen as production units and will not have to pay end-user taxes, one might assume that $P2H_22P$ in the future will be categorised similarly. Otherwise, conversion losses back and forth will amplify the impact of electricity taxes and levies.

3.7 Transport

Transport sector consists of different segments with varying level of interest for sector coupling. Rail transport is already highly electrified, and it is a relatively small energy consumer. Long-distance sea transport is likely to remain fuel-based but could move to synthetic fuels at some point. Short-range sea transport as well as short-distance air transport could use either synthetic fuels or even be battery-based, although technological development is still very young. Long-distance air transport could start using synthetic fuels although it will have a considerable cost impact on the flights. The biggest consumer in the transport sector is road transport and it has alternatives arising both from direct as well as indirect electrification.

Heavy-duty long-distance cargo transport may be most difficult to electrify, but even this could happen if charging of batteries becomes sufficiently fast. The gains due to better efficiency are high due to the high utilization of these trucks. Delivery trucks are already moving towards battery-electric vehicles as they have a high utilization and more opportunities for charging. A break-even price between battery-electric vs. gasoline vehicles for personal use could be reached in couple of years given the current battery technology development.

Road transport requires a whole chain of technology, from energy conversion technologies to distribution infrastructure and to the vehicles themselves. Systemic changes can be expensive. When comparing different alternatives, it is important to consider also the distribution infrastructure. As already noted above, H2 infrastructure might prove to be difficult. For gas (e.g., SNG) and electricity vehicles, reasonable network may exist, although charging posts or SNG fueling stations are needed. H2 can also be produced locally where-ever there is a power network. Electricity can also be converted to gasoline in order to utilise the current gas station infrastructure. The higher the level of fuel refinement, the higher production costs and losses can be expected.

3.7.1 Electric vehicles

Electric vehicles (EV) could potentially offer a sizable source of flexibility. Controllable charging in grid-to-vehicle (G2V) can offer high capacity although energy quantities are limited by the consumption by the vehicles. Controlled discharging in vehicöle-to-grid (V2G) can also be helpful, although studies so far have shown a limited impact. It is burdened by wear and tear costs related to the batteries. Both types of interaction can be good sources of ancillary services.

3.7.2 Synthetic transport fuels

As noted above, there are several potential fuels made with electricity and each of them require their own infrastructure. It is unclear which pathways would be the wisest.

Power to gasoline has the advantage of an existing infrastructure. Biofuels are also an important alternative that already complement existing road transport fuels and could similarly complement power to gasoline. At the same time, there are regional limitations in the potential biomass supply as well as concerns over the climate impacts of bioenergy. Synthetic hydrogen and natural gas would require expensive new infrastructure, but at the same time they would offer better efficiency. Ammonia based transport can also be interesting, especially for heavy transport, shipping and air transport, as it requires careful handling due to mild toxicity and low gasification temperature. Ammonia does not require carbon and can therefore be carbon neutral without carbon capture.

For now, the market price of transport fuels is set by fossil and biofuels. With more stringent climate targets, the competition may shift more towards biofuels and synthetic fuels. These fuels can also be used in the power sector which can complicate the analysis. Security of supply is also an important, but non-trivial, aspect to be considered when comparing the alternatives.

The transport sector has an interesting advantage compared to other uses, since the end-user can come to the fuel, as opposed to the fuel having to be transported to the end-user. Among other things, this opens the opportunity for a distributed small-scale P2X generation, especially P2H2 for transport purposes.

4. A framework for power and energy market interactions

4.1 Suggestion on prices for energy, flexibility and CO2 emissions that allow for efficient sector coupling

It could be argued that an efficient market design is also simple: it should provide a level playing field with no distorting elements while accounting for externalities in a fair manner. However, the examples in Chapter 3 clearly demonstrate that transforming the energy systems towards this target includes several detailed choices, including issues in pricing schemes.

The main part of new electricity use in the future is from areas currently served mainly by fuels: heating and cooling of buildings, domestic hot water, industrial process heat as well as the transport sector. As noted in the TradeRES project plan [1], the market design must provide incentives for investment in an optimal mix of VREs, controllable generation, storage, networks, and flexibility options for all market actors.

To ensure that market design is not hindering efficient sector integration, the correct price signals should reach all market participants, including the final end-users that should choose what energy sources to use and when (or more appropriately what equipment to acquire that can do all the choosing for them in an efficient manner). One important prerequisite is that automated meter reading is needed to verify actual consumption or generation. It should offer sufficient time resolution (currently looks like 5 to 15 minutes may be appropriate). Furthermore, a near real-time communication to the grid operators would improve the observability of the power grid and allow more secure and stable operation of the grid. Provision of ancillary services may require additional capabilities either from the meters or directly from the devices providing the service – it remains unclear at what consumption levels those capabilities are worth the investment and transaction costs.

The correct price signal should contain information about real-time bottlenecks in the power grid – only then the flexibility from other sectors can be activated at a right time. This could be as simple as alternative sources of heating: a water boiler that can either use electricity or fuel (e.g., SNG or ethanol produced with electricity). The prices should also send the signals for new investments: e.g., this distribution grid cannot take more PV without expensive upgrades or that better voltage control would be highly appreciated in that corner of the grid. On the other hand, the information systems have a cost impact and potential reliability issues. A careful consideration is needed to understand what is worthwhile. This can only be understood when all reasonable opportunities are evaluated at once. With increasing electrification this means proper account of the other energy sectors.

As noted in the schemes presented in Chapter 3, there is a multitude of energy conversion alternatives – including circularities in the energy flows. Market design choices will have a strong influence on the selected pathways. For example, heating can be done using electricity directly, but there is an alternative route where H2 or SNG is produced with the electricity and delivered through the gas grid to the end-user. Whenever the end-user electricity tariffs and taxes are high, the alternate route might become more tempting, even though it would be more costly overall and would require more power generation to be built. On the other hand, SNG could offer an easy way to store energy for couple of days – a time scale of flexibility that will be in short supply in energy systems relying heavily on VRE. How then to design markets and regulations that result in the adoption of best overall solutions?

4.2 Framework for interaction

When other energy sectors interact with electricity markets, the task of finding the optimal market design becomes more complicated. TradeRES aims to find market design structures that minimize the impacts of market distortions under future scenarios where the power generation is dominated by VRE and electrification of other energy sectors is widespread. To be able to address these aspects, conceptual flowcharts in Chapter 3 present alternatives for sector integration in respect of different electricity use and flexibility types.

Summarizing the relevant sector interactions of Chapter 3, a framework with the building blocks that characterize them is presented in Table 2. Particularly, out of many alternatives, an analysis framework defines a concentrated set of factors to focus on in the subsequent TradeRES analyses, including the flexibility types and key technologies. Furthermore, the framework highlights the key areas, "interaction hotspots" between electricity and other sectors that should be considered when new market designs are under scrutiny. The hotspots are classified according to the types of energy conversions classified in Ch. 2.6: electricity used locally, electricity converted to another energy vector with a marketplace, another energy vector converted to electricity, and a round-trip of electricity back to electricity.

Additionally, model characteristics and country-specific details must be considered in any applications of the framework.

Table 2. Overview of building blocks considered in the different TradeRES interaction cases studied.

	Interaction option (A1&A2 "Vector used by end-user")	*Interaction option (A3 "Delivery to other market")*	*Interaction option (A4&A5:B2e "Delivery to power system")*
Heating	*Heat pump, electric boiler, radiator (A1:B1, A2: B1, B2)*	*Micro-CHP heat to DH (B2)* *DH-CHP heat to DH (B2)*	*Micro-CHP (A4.2)* *DH-CHP (A4.2)*
Transport	*EV G2V (B1)*	*P2fuel (B2), P2H2 (B2)*	*EV V2G (A5)*
Industry	*Electric boiler, heat pump, P2H2 (A1:B1, A2: B1, B2)*	*Ind-CHP heat (B1, B2)*	*Ind-CHP (A4.2)*
H2	*P2H2 part of the P2H22P (B2)*	*P2H2 to H2/NG market (B2)* *H22SNG to NG market (B2)* *H22Fuel to Fuel market (B2)*	*H22P of the P2H22P (A5)* *H22P (A4)* *Fuel to Power (A4)*

4.3 Checklist for barriers for integration

Several barriers for the realisation of interaction alternatives have been identified. These barriers should be taken into account in forthcoming TradeRES cases and analyses. However, they are often of a highly country-specific/locational nature. Hence, the list below is meant to serve as a checklist.

- Taxes and/or subsidies distorting competition
    - In short-term, production subsidies or taxes can have an effect on economic dispatch.
    - In long-term, the capacity mix can be affected.
    - Are EU ETS costs included in the energy tariffs for energy conversion or in alternative sources for the energy vector?
    - Are other decarbonisation costs (e.g., renewable taxes) included in the energy tariffs for energy conversion or in alternative sources for the energy vector?
- Pricing questions
    - The type of network and energy pricing mechanisms available (fixed, time-of-use, dynamic) for the different sectors. For example, inconsistent time resolution between electricity and interacting sector can prevent efficient use of resources.
    - Correct pricing for the use of networks during network congestions as well as during no congestion. High energy or ancillary service prices should not lead to overloaded networks – this can be avoided by dynamic network prices that would offset energy prices when the local network is constrained. On the other hand, when there is no congestion, the use of most networks causes costs that are almost solely related to losses. At the same time, network owners need to be able to recover investment and other fixed costs (through e.g., annual tariffs).
    - Imperfections and inconsistencies in pricing and taxation schemes, e.g., "double billing" of energy storages in both charging and discharging.
    - Not internalizing CO_2 prices equally in all energy vectors.
    - Fixed end-user prices do not give market-based incentives to time-shift operations. In what cases would the system benefits outweigh the costs including the end-user risk increase.
    - Locational prices would send the right price signals, but they are not easy to implement, have some transaction costs, and increase the risk of market power.
- Technological barriers
    - Insufficient technology diffusion to, e.g., limited roll-out of smart meters to allow dynamic pricing. Smart meters with insufficient capabilities.
    - Lack of controllability of resources; high cost of control; communication security and risks related to cyber-attacks.
    - Lack of necessary infrastructure for a conversion technology, e.g., H2 gas stations for H2 vehicles or a H2 grid. Can be a chicken and an egg problem.
    - Conversion losses that decrease the attractiveness of the interaction

- Site-specific feasibility barriers, e.g., availability of suitable (waste/ambient) heat sources for heat pumps.
- Economic barriers
  - Uncertain or highly variable investment cost of a conversion alternative that may need case-specific consideration.
  - Costs related to infrastructures that will serve multiple actors at once – who pays and how the costs are recovered.
  - Allocation of externalities when there are multiple products. For example, heat and electricity are not directly comparable products, and it is not possible to unambiguously divide emissions between them.
  - Electricity related conversions often compete against other alternatives. The price setting of the alternatives can form a barrier, especially if there is tax or subsidy differences.
- Risks related to long-term prices (also an economic barrier)
  - Investments need to be recovered from future market prices. Risks related to long-term prices mean that investors want higher expected profits to negate the risks.
  - Long-term price risks are increased by inter-annual fluctuations in weather driven energy demand and production.
  - Short-term price fluctuations are not nearly as important – they are just part of normal operation where the actor sometimes wins a bid and sometimes not – they mostly cancel each other over time
  - Regulatory uncertainty can be a major source of long-term risks – solutions that are not likely to change can be better. Market based and cost-reflective designs may be more likely to remain in place.
- Environmental barriers
  - Environmental impacts that may limit the potential of a conversion alternative when local circumstances are considered (e.g., environmental permits).
- Barriers in (social) acceptance of a solution limiting the techno-economic potential

5. Summary and conclusions

This deliverable outlines a framework to efficiently enable sector integration with other energy vectors for TradeRES market design on electricity. Whereas the details in TradeRES market design will be determined in an iterative process in the project, certain key principles for the task are identified:

- Market design to enable efficient interaction must target a level playing field for all energy vectors with no distorting elements.
- The market design process should consider different kinds of energy conversion situations between electricity and other energy sectors: 1) Electricity is the only possible source of energy to fulfil a local demand. 2) There are other alternative sources of energy besides electricity to fulfil a local demand. 3) Electricity converted and delivered to other energy networks and/or markets. 4) Other energy vectors are converted to electricity. 5) A round-trip of electricity through another energy vector or sector.
- It is also important to identify what kind of flexibility constraints there can be: 1) no flexibility. 2) Time-shift and other temporally restricted flexibility. 3) Fully controllable demand.

It could be argued that an efficient market design is also simple: it should provide a level playing field with no distorting elements while accounting for externalities in a fair manner. However, the examples in Chapter 3 clearly demonstrate that transforming the energy systems towards this target includes several detailed choices, including issues in pricing schemes. The choices that may hinder the interaction include issues in pricing schemes, taxes and/or subsidies distorting competition as well as technological, environmental, or acceptance related barriers. The consideration of these factors, many of which are highly case-specific, must be carefully evaluated in the iteration cycles of TradeRES market design.

With regards to pricing and incentives, the key principles include:

  - All energy vectors should be treated equally in relation to CO_2 emissions and other externalities.
  - The main market signal should be based on the wholesale market price for an optimal energy conversion interaction. In other words, all end-users should have an undistorted wholesale market access, either directly or through third parties that facilitate market price signals reaching end-users.
  - Networks must also signal their flexibility needs to the energy converters if a market approach is desired. The more a given flexibility is in short-supply, the higher the remuneration from the network.

Given the same energy source and energy destination, a market design should help to avoid costlier routes (which are often also more wasteful). For example, there are several possible routes from electricity to space heating, but the chosen route should have the best cost/benefit for the society and wrong routes should not be picked as winners due to perceived benefits.

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