Implication and opportunities for sector coupling in Belgium

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About ReInvent

In 2030 and beyond, multiple energy vectors (electricity, gas, heat, green molecules) will play a role in an interconnected energy system. Increased electrification will support sector integration between end user segments. To benefit maximally from the advantages of sector coupling, a fundamental rethinking of market design, business models and financing models is needed. ReInvent will define a roadmap for sector coupling in Belgium. The ReInvent approach is based on **4 pillars** and is a combination of 1) conceptual analysis, 2) sound modelling, 3) proofing of concepts by relevant test cases, and 3) an ambitious impact assessment and replication strategy.

The **first pillar** will analyse the role of different energy vectors (gas, power, heat, and green molecules) in the Belgian energy mix. This includes the impact on infrastructure, market design and business models for different energy end user groups. Based on discussions with project partners and relevant stakeholders, different concepts for both supply-side and demand-side sector integration will be proposed. In addition to the operational implications of sector integration, the financial implications in terms of risk, return, and uncertainty will be analyzed.

The **second pillar** will develop the ReInvent modelling and simulation. This multi-sectoral simulation environment will capture the different dynamics of different vectors in multiple timeframes, for multiple scenarios, for multiple market design options, for multiple services, including different end-use sectors and different layers of the physical networks and their interconnection. Innovations modelled in ReInvent aim at the overarching goal of augmenting and realizing the potential of sector coupling in providing key flexibility, balancing, and adequacy services to the multi-energy system and the electric grid.

The **third pillar** will look at a selection of reference test cases that represent main use cases of sector coupling/integration. These applications will provide real data that allow proofing of the developed models in the second pillar. In addition, the models of the second pillar will provide necessary insights to the test cases about the impact of the ReInvent solutions on the operational and financial stability of the presented solution. The ReInvent test cases address different vectors, end user segments and applications and are selected based on the technologies and applications that will play a central role in a future integrated system but still face barriers today that hinder their expected breakthrough.

The **fourth pillar** will define a roadmap for improved sector coupling and sector integration for Belgium. This includes an impact assessment of a wide roll-out of the solutions for the Belgian energy system, in particular the implications for security of supply and system balancing.

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List of Abbreviations and Acronyms

Acronym	Meaning
ACER	Agency for the Cooperation of Energy Regulators
aFRR	automatic Frequency Restoration Reserve
AFIR	Alternative Fuels Infrastructure Regulation
BRP	Balance Responsible Party
BUC	Business Use Cases
CBAM	Cross-border Adjustment Mechanism
CEC	Citizen Energy Community
DER	Distributed Energy Resources
DSO	Distribution System Operator
EEX	European Energy Exchange
EMD	Electricity Market Directive
ESOM	Energy System Optimization Models
EU	European Union
EV	Electric Vehicle
FCR	Frequency containment reserve
GHG	Greenhouse Gas
IPCEI	Important Project of Common European Interest
mFRR	manual Frequency Restoration Reserve
NBP	British National Balancing Point
NCDR	Network Code Demand Response
NECP	National Energy and Climate Plan
OPEX	Operational expenditure
P2G	Power to Gas
$P2H_2$	Power to Hydrogen
P2L	Power to Liquids
PCI	Project of Common Interest
PEM	Proton Exchange Membrane
PMI	Project of Mutual Interest
Power2X / P2X	Power to X
PtGtP	Power to Gas to Power
PV	Photovoltaics
REC	Renewable Energy Community
RED	Renewable Energy Directive
RES	Renewable energy sources

RFNBO	Renewable Fuels of Non-Biological Origin
SMEs	Small and Medium Enterprise
SO	System Operator
THE	Trading Hub Europe
TIB3R	Times Belgium 3 Regional model
TIMES-BE	TIMES Belgium
TSO	Transmission System Operator
TTF	Dutch Title Transfer Facility
V2G	Vehicle to Grid
ZTP	Zeebrugge Trading Point

Executive Summary

This report provides the basis for analyzing the future of sector-coupling in Belgium. In defining sector coupling (Chapter 2) we found that multiple interpretations of the concept exist. These range from narrow interpretations covering only the electrification of end-use sectors to broad interpretations covering full energy system integration. In ReInvent, we follow an interpretation that places the integration of large-scale renewable electricity via direct and indirect electrification as a central point of departure. We consequently highlight three aspects of sector coupling as central to the project: electrification and demand-side flexibility, power to gas, liquids and heat (Power2X), and community energy.

For each of these aspects, the regulatory contexts have already developed significantly, both at the EU and Belgian levels, as described in Chapter 3. For *electrification and flexibility*, key EU initiatives under, for example, the Clean Energy package lay down the main regulatory framework for flexibility valorization, which has been further implemented at the federal and regional level, although applicable rules regarding flexibility markets and tariff design differ considerably across the regions. For *Power2X*, the EU-level framework includes various targets and ambitions for the uptake of hydrogen (e.g., RePowerEU, REDIII) with a variety of EU policies and directives leveraging on hydrogen supply, infrastructure and demand. EU-level ambitions and strategies are equally reflected in federal visions and policy, in which the ambition to become a clean molecules 'import hub' stands out. For *community energy*, the main EU regulations have defined Renewable and Citizen Energy Communities and mandates member states to support their creation and development. Monitoring the status of implementation in Belgium shows that regional regulatory frameworks differ in terms of support for energy communities and the ease of establishing RECs and CECs.

The report subsequently describes the state-of-the-art in three energy research domains. For the domain of *energy system planning models* (Chapter 4), Belgian models such as TIMES-BE, TIB3R and INTEGRATION are already advanced in modelling end-use sector electrification, demand-side flexibility (e.g., electric vehicles, local battery storage) and Power2X, mainly power to hydrogen and derived gases and liquids. Key research opportunities include better representation of flexibility for heating (thermal heat inertia of buildings, underground heat storage), as well as further multi-model analyses to assess the trade-off between demand-side flexibility options and Power2X. From the domain of *energy markets* (Chapter 5), we describe how current markets are organized, covering two established (electricity, gas) and two emerging markets (heat, hydrogen). Each energy vector is traded under distinct market mechanisms, which are tailored to the specific characteristics of the vector, meaning that potential market synergies are ignored. From the domain of *business models for sector coupling* (Chapter 6), a systematic literature review provides an overview of existing business model concepts such as Energy as a Service, Shared ownership or Cross-sectoral collaboration models. For three end-

user types (industry, residential, energy community), main business model drivers and barriers are described. What is lacking in the literature is an overarching architecture for tailoring business models to specific cases.

The state-of-the-art is complemented by a review of sector coupling implementation barriers (Chapter 7). These are derived from literature – reporting on common EU-level barriers, and specific barriers related to energy markets and business models – and from practical experiences in the ReInvent test cases. We find that a number of barriers remain to be addressed. Economic and financial barriers, include high upfront investment cost, operational costs (also related to taxation asymmetry between electricity and gas). Overall, sector coupling applications often suffer from limited competitiveness compared to conventional technology and difficulties in reaching financial break-even point even with government support. A major issue is financial risk, including (from a supply perspective) the lack of guaranteed off-take. Market barriers include mechanisms that hamper non-discriminatory market access and the lack of alignment and coordination among markets of different vectors. Various technical barriers apply, for example related to technological interoperability or the optimal sizing and operation of decentralized assets. Social barriers, finally, may include a general lack of awareness and engagement leading to limited willingness to pay for sector-coupled solutions, and negative perceptions regarding distributional fairness and safety. On the organizational level, literature points to silo mentality in industry and inherent resistance to change as the main barriers to tackle.

ReInvent research on sector coupling concepts, modelling and impact assessment will address a number of these barriers as follows:

- A main focus is the investigation of new sector-coupled market designs, ranging from isolated to coordinated and fully integrated designs. Such sector-coupled designs are expected to provide flexibility to the electricity market, optimizing resource allocation and improving system efficiency, thereby addressing implementation barriers related to investment and financial risk.
- New local market frameworks for multi-sector communities will be developed to analyze their impact on the long-run business models from end-user perspectives, also addressing fairness of the distribution of the costs and benefits, which is perceived as a barrier.
- Innovative financing solutions will address main barriers related to bankability due to the lower maturity, high risk and the complexity of the solutions.
- Modelling applications at the local level will, to some extent, address technical barriers of sector-coupling. For example, modelling short-term dispatch and cross-sectoral technologies contributes to a more optimal sizing and operation of decentralized assets and creates a better understanding of how optimal community behaviors may help to integrate more renewables and reduce grid stress.
- Research on tailored sector coupling business models typically covers a broad range of barriers going beyond purely economic indicators. New collaboration models, for example, may help spread

investment risk. Also, evaluating different community-based business models in the end-user-oriented modelling applications may show how to unlock sector coupling benefits in energy communities.

- Energy planning models are suited to analyze the long-term economic viability of sector coupling options under a range of possible future conditions. A main focus is to understand the trade-offs between demand-side flexibility and Power2X, and study how flexibility should be leveraged for different purposes (e.g. day-ahead arbitrage or balancing provision).
- The impact analysis based on the energy planning models aims to enrich modelled energy scenarios at different levels of sector coupling with insights on the main barriers and enablers on sector-coupled pathways. The work on business models, market designs and financing can provide tangible pathways for overcoming key barriers and realizing the potential of sector coupling. This will set the basis for the development of policy recommendations and a roadmap for sector integration in Belgium.

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1 Introduction

Sector coupling is generally recognized as an important enabler for the energy transition towards climate neutrality. Sector coupling has various dimensions, including the integration across energy vectors, such as power and clean molecules, the coupling of supply and demand, such as in the provision of demand-side flexibility, and the coupling of different end-use sectors, for example in multi-sector energy communities. The flexibility that sector coupling provides allows significant energy system benefits, resulting in a highly efficient energy system with reduced energy system costs. Realizing a highly sector-coupled system, however, is not easy. Its rollout is still subject to different challenges, such as those associated with the development of new market designs and business models. The ReInvent project, therefore, brings together knowledge from energy research and sector coupling applications to address these challenges and ensure the success of sector coupling.

1.1 Objectives of the Work Reported in this Deliverable

This deliverable reports on Task 1.1 of the ReInvent project: Implications and opportunities for sector coupling in Belgium. As such, it aims to provide an overall framework for the ReInvent project as a stepping-stone for further ReInvent research. To this end, it defines the concept of sector coupling more clearly and reviews its current regulatory context in the EU and Belgium. Moreover, it aims to create a better understanding of how ReInvent research can best contribute to overcoming the main challenges to sector coupling implementation. Therefore, the report brings together insights on state-of-the-art and research opportunities from three energy research domains (energy system planning models, sector coupling business models, and market design) along with a review of implementation barriers, both from the literature and from the experiences of the ReInvent test cases.

1.2 Outline of the Deliverable

The report starts with a review of different sector coupling definitions, describing how sector coupling is conceptualized in the scope of the ReInvent project (Chapter 2). It highlights three main aspects of sector coupling, namely electrification and demand-side flexibility, power2X, and community energy. For each aspect, the regulatory context for sector coupling at the EU and Belgian levels is described (Chapter 3). Consequently, the report reviews the state-of-the-art from three energy research perspectives: long-term energy system modelling (Chapter 4), new business models (Chapter 5), and market designs (Chapter 6). The implementation barriers from the literature and from the experiences of the ReInvent test cases are described in Chapter 7. The report concludes with an outlook for ReInvent research on sector coupling concepts, modelling and impact, reflecting on how the identified barriers are addressed (Chapter 8).

2 What is sector coupling?

The term *sector coupling* in the context of energy systems broadly refers to the integration and coordination of different energy and end-use sectors and vectors to improve efficiency and flexibility, and promote renewable energy usage (IEA, 2020; Ramsebner et al., 2021; Van Nuffel, 2018). The key notion is well represented by the archetypical visualization on the web portal[1] of the EU Strategy for Energy System Integration. Whereas the 'traditional' energy system is organized linearly with supply operating to meet demand in one direction only, the 'new' integrated energy system is one with ample bi-directional interactions between demand and supply (e.g., prosumers, flexibility) and energy vectors (e.g., electricity, heat, fuels).

Although it is broadly clear what the concept of sector-coupling means, it is difficult to define the term unambiguously. As pointed out by (Ramsebner et al., 2021), multiple interpretations of the concept exist, and discussion remains on what is included and what is not. Without attempting to contribute further to this conceptual discussion, this chapter aims to provide clarity on how the concept is defined and conceptualized in the scope of the ReInvent project.

2.1 From sector coupling to energy systems integration

The concept of *sector coupling* emerged about a decade ago mostly in the context of power system research (Ramsebner et al., 2021). It originally referred to the electrification of end-use sectors (e.g., heating and transport) to provide power sector balancing services and enable higher integration of variable renewable energy sources. Over the years, the concept evolved to include further aspects of supply-side integration, such as the integration of power and gas sectors through technologies like power-to-gas (Van Nuffel, 2018).

The drawback of this evolution of the term sector coupling is that multiple interpretations currently exist (Ramsebner et al., 2021). On the extreme ends, the concept is used either in a narrow sense, exclusively considering the use of excess renewable electricity in consumption sectors currently not yet electrified, or in a wide sense referring to the integrated optimization of the entire energy system including, for example, cross-energy-carrier integration with the use of excess heat and biomass energy. The latter interpretation lies close to the concept of *energy system integration* as adopted in the EU's energy strategy (EC, 2020b). A range of possible definitions of sector coupling and the related concept of energy system integration can be found in Box 1.

(Ramsebner et al., 2021) propose an interpretation that stays close to its original roots related to the integration of large-scale renewable electricity in the energy system. Their sector coupling definition consequently includes both direct and indirect forms of electrification (Table 2.1). Direct electrification refers to

[1] https://energy.ec.europa.eu/topics/energy-systems-integration/eu-strategy-energy-system-integration_en

the electrification of end-use sectors that traditionally relied on fossil fuels, while indirect electrification ('Power2X') refers to the transformation to another vector (heat, gas, liquids) ultimately devoted to an end-use sector as well. In addition, a distinction is made between centralized and de-centralized applications referring to the typical scale of application and the proximity to local consumption. Importantly, this interpretation excludes energy flows between sectors that do not include electricity as a main input (e.g., waste heat, biofuels) as a main aspect of sector coupling.

Table 2.1: Categorization of sector coupling applications into direct/indirect electrification and centralized (C)/decentralized (D) forms. Source: (Ramsebner et al., 2021)

Sectors and applications	Traditional	Direct electrification	C/D	Indirect electrification (P2X)	C/D	Alternative options[a]
Transport						
Cars and small trucks	Gasoline and diesel Natural gas	Batteries	C, D	Hydrogen, methane Liquid electrofuels	C	Biofuels, biogas, trucks: purified biogas
Large trucks	Diesel, natural gas	Overhead lines on highways Batteries	C	Hydrogen, methane Liquid electrofuels	C	Biofuels, trucks: purified biogas
Railway	Electric drive, diesel	Electrification of nonelectrified sections	C	Hydrogen, methane Liquid electrofuels	C	Biodiesel
Air	Turbines (kerosene)	No solutions expected	–	Liquid electrofuels (kerosene) Hydrogen	C	Bio-kerosene
Maritime	Heavy fuel oil, diesel LNG	No solutions expected	–	Hydrogen, methane, liquid electrofuels (diesel/kerosene)	C	Biodiesel, purified biogas
Residential/industry/trade: Low temperature heat for households, industry and trade/services						
Low temperature heat	Oil or gas heating, DH	Heat pumps Resistance heating	C, D	Hydrogen/methane	C, D	Biomass, biogas
Industry						
Industrial process heat	Gas engine, steam	Electrode boiler, induction heating, plasma process, resistance heating	D	Liquid electrofuels	C	Biomass, biogas
Iron (primary route)	Coke	Not applicable	–	Hydrogen	C	Biomass, biogas
Refinery	H_2 (side product and from natural gas)	Not applicable	–	Hydrogen	C	Biomass, biogas
Chemicals		Not applicable	–	Hydrogen, liquid electrofuels	C	Biomass, biogas

Source: Adapted from Ausfelder and Dura (2018).
Abbreviations: C, centralized; D, decentralized.
[a]Not depending on electricity input.

In their report on the role of sector coupling in EU decarbonization, (Van Nuffel, 2018) also refers to the different possible interpretations of sector coupling, ranging from narrow (end-use electrification and balancing) to broad (energy system integration). They point out that both the electrification of end-use sectors and the integration of the energy supply sectors can contribute to decarbonization while providing additional flexibility. Therefore, two main sector coupling types are distinguished: *end-use sector coupling* reflecting the coupling of end-use sectors with the energy supply sector (mainly electricity), and *cross-vector integration* referring to the coupling of different supply sectors, mainly electricity and gas. See Figure 2.1 for illustration.

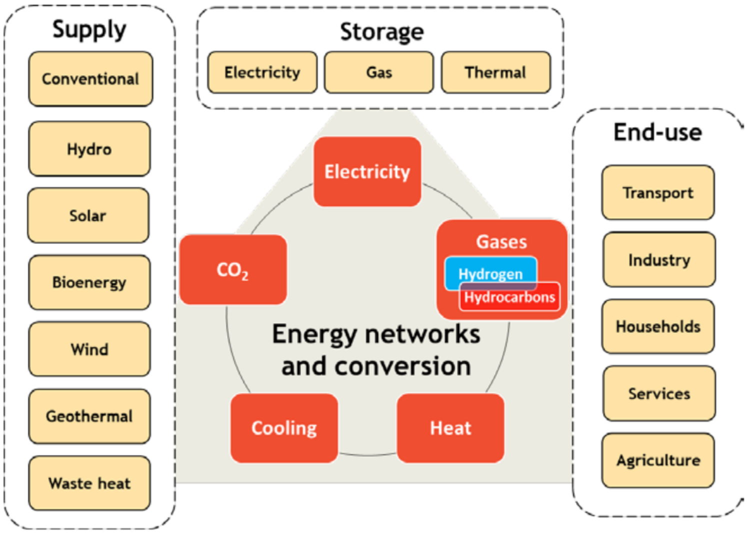

Figure 2.1: Conceptualization of energy sector coupling. Source: (Van Nuffel, 2018), based on (Hanna et al., 2018)

This broad distinction between direct electrification on the one hand and Power2X on the other can also be found in other sources:

- The International Energy Agency (IEA, 2020) highlights the 'intelligent linkage' between the power sector and other energy-consuming sectors (e.g., industry, mobility and buildings), acknowledging the role of demand-side flexibility and Power2X via electrolysis and synthesis. Moreover, sector coupling involves a feedback to electricity supply, for example, via Vehicle to Grid (V2G) and power production from synthetic gasses and fuels.
- In the recent draft scenarios report for the EU network operators' Ten-Year Network Development Plans (TYNDP2024) (ENTSO-E & ENTSOG, 2024), sector coupling (also referred to as 'sector integration') is mainly perceived as Power2X. This includes Power to Gas (P2G), further detailed into Power to Hydrogen and its derivatives Power to Methane and Ammonia, and Power to Liquids (P2L) through a combination of hydrogen with Fischer-Tropsch processes. Yet, also direct electrification, as well as prosumers and hybrid heating technologies[2] are considered part of sector coupling (see TYNDP2024 methodology report (ENTSO-E & ENTSOG, 2024)).
- (Thellufsen et al., 2023) point out that current EU energy system models like Euro-Calliope, PyPSA-Eur-Sec and PRIMES represent sector-coupling to a more or lesser extent via direct electrification

[2] Hybrid heating technologies are a combination of different heat supply sources on a closed network aiming to optimize heat pump operation.

(transport, heat, industry) and Power2X (e.g., synthetic fuel production). However, reasoning from their concept of ‘smart energy systems’, there is potential to better represent synergies from waste heat from electrified industry processes and Power2X to heating supply via district heating networks.

The term *energy system integration* is generally used in a broader sense to reflect an optimized energy system planning and operation with minimal waste and impact on the environment (e.g., Hanna et al., 2018; O’Malley et al., 2016). The EU strategy on energy system integration (EC, 2020b) decomposes this broader concept into a number of complementary and mutually reinforcing concepts: first, a more ‘circular’ and energy efficient system; second, a greater direct electrification of end-use sectors; and third, the use of renewable and low-carbon fuels where direct heating or electrification are not feasible. System integration also implies a more ‘multi-directional’ system in which consumers play an active role in energy supply, both ‘vertically’ (decentralized production and flexibility) and ‘horizontally’ (exchanges between consuming sectors, for example through energy communities).

This conception of energy system integration strongly resonates with sector coupling. However, it is not rooted in power systems and departs from a more holistic perspective. It consequently goes beyond sector coupling in at least the following additional focus points:

- General energy efficiency, for example through building retrofit
- Renewable biofuels supply, for example extracting bioenergy from wastewater
- Properly reflecting the life cycle energy use and footprint of the different energy vectors
- Carbon capture, utilization and storage (CCUS) to support deep decarbonisation, including but not limited to synthetic fuel production

Box 1: Some definitions and interpretations of sector-coupling and energy system integration from the literature

Sector-coupling

Sector coupling […] is defined as the intelligent linkage between the power sector and other energy-consuming sectors (e.g., industry, mobility and buildings), often through advanced sensing, communication and control technologies, that can flexibly use demand to integrate VRE and lower power system operational costs (IEA, 2020)

Sector coupling accelerates power generation development to meet the rising demand from direct electrification and the production of renewable fuels via electrolysis (ENTSO-E & ENTSOG, 2024).

Originally, *sector coupling* referred primarily to the electrification of end-use sectors like heating and transport, with the aim of increasing the share of renewable energy in these sectors […] and providing balancing services to the power sector. More recently, the concept of sector coupling has broadened to include supply-side sector coupling [that] focuses on the integration of the power and gas sectors, through technologies such as power-to-gas (Van Nuffel, 2018).

We […] suggest considering *sector coupling* as a concept to promote the integration of large-scale renewable electricity by increasing its direct use or indirect application through transformation into a suitable energy carrier, such as heat, gas, and liquids. Consequently, we do not consider renewable energy, which does not include electricity as a main input, such as waste heat or biofuels, as a main aspect of the sector-coupling concept but rather of multi-energy systems (Ramsebner et al., 2021).

Energy system integration

Energy Systems Integration […] refers to the connecting and combining of a wide range of energy services and systems in order to maximise energy use and minimise waste and carbon emissions (Hanna et al., 2018)

Energy Systems Integration is the process of coordinating the operation and planning of energy systems across multiple pathways and/or geographical scales to deliver reliable, cost-effective energy services with minimal impact on the environment (O'Malley et al., 2016)

Energy system integration refers to the planning and operating of the energy system "as a whole", across multiple energy carriers, infrastructures, and consumption sectors, by creating stronger links between them with the objective of delivering low-carbon, reliable and resource-efficient energy services, at the least possible cost for society (EC, 2020).

2.2 Conceptualization

A conceptualization of sector-coupling requires a view on ‘sectors’ and on ‘coupling’. Together with a set of coupling interfaces, these aspects make up the broad sector coupling concept illustrated in Figure 2.2.

2.2.1 Sectors

There are different ways sectors are defined in the literature (Ramsebner et al., 2021). One typically distinguishes *end-use sectors* where energy is consumed to meet energy service demands, and *energy sectors* (or *supply sectors* or *energy industry*[3]) in which energy commodities are mined, transformed, generated[4], traded and transported. Main examples of end-use sectors are passenger and cargo transport, residential and commercial buildings (mainly important for heating and cooling), agriculture and industry. Energy sectors are traditionally defined based on the different types of energy commodities they deliver. For example, by distinguishing the power, natural gas, fossil fuel, or heat sectors. Yet, this distinction is becoming increasingly blurred with traditional fossil fuel companies investing in renewable power[5]. Moreover, with the rise of individual and collective prosumers, energy production is clearly no longer the exclusive domain of the energy sector. Nonetheless, a broad distinction between end-use and energy sectors remains relevant.

2.2.2 Coupling

Coupling refers to the way these different sectors relate. The simplest ‘one-way’ relationship can be referred to as ‘energy delivery’ from an energy to an end-use sector. As the main pillar of the traditional fossil-based energy system, this relationship is <u>not</u> considered part of sector coupling[6]. What is considered sector coupling is the feedback from the end-user to the energy sectors reflecting the multi-directionality of the system. This can be referred to as *end-use ↔ energy sector coupling*. Electrification in combination with demand flexibility, as described above, clearly falls under this category. It may also include decentralized production (prosumers) where energy production is shifted from the energy to an end-use sector.

Another form of sector coupling can be referred to as *energy sector internal coupling*. This denotes energy conversions from power to other suitable energy carriers within the energy sector. Power2X is a main example of this type of coupling. Being located within the energy sector, this form of coupling typically requires relatively large scale, centralized infrastructures and wholesale level markets. Yet a third form of sector coupling is *end-use sector internal coupling*. This denotes coupling between end-use sectors like industry, commercial and

[3] https://en.wikipedia.org/wiki/Energy_industry

[4] Although technically speaking energy cannot be generated (only transformed), ‘generation’ here refers to renewable power generation where a sustainable energy resource (like solar or wind energy) is transformed into a useable energy commodity (electricity).

[5] https://www.shell.com/what-we-do/renewable-power/wind/our-wind-projects.html

[6] In that sense, it can be debated whether electrification as such is sufficient to be denoted sector-coupling. It only becomes sector-coupling when the relationship is two-way, i.e., when demand-side flexibility is ‘delivered’ back to the energy sector...

residential buildings. This form of sector-coupling is typically realized on a decentralized level, with (multi-sector) energy communities as a key example.

2.2.3 Coupling interfaces

To describe the sector coupling applications in more detail, the conceptual framework defines four key elements at the 'interface' between sectors:

Energy vectors: these are the energy commodities at play in the sector-coupling application. These include traditional energy commodities, such as, electricity, natural gas and heat/cold, as well as more innovative commodities, notably clean molecules like hydrogen, ammonia, e-methane and sustainable fuels.

Energy and end-use technologies: the technologies in the sector-coupling application's value chain may be diverse, including technologies for energy production, conversion, distribution and end-use. It is tempting to allocate different types of technologies to either the energy (production, conversion, distribution) or end-use (end-use technologies) sectors. Yet, with prosumption as a main example, it is more useful to neutrally position technologies at the sector interface.

Markets: market mechanisms and regulations are needed to facilitate sector coupling. Traditionally, markets are organized at the wholesale level with dedicated mechanisms for each energy vector specifically (see Chapter 6). Sector coupling requires new market designs, like multi-carrier markets to optimize the synergies between energy vectors, local markets to facilitate decentralized forms of sector-coupling, and flexibility markets to put a value on flexibility services.

Facilitation: These refer to mechanisms other than markets that are needed to make sector-coupling a success. The main examples addressed in ReInvent are new business models (Chapter 5) putting a value on sector coupling benefits, innovative financing methods to enable investment in sector-coupling technologies and automated financial transactions to implement sector-coupling in practice.

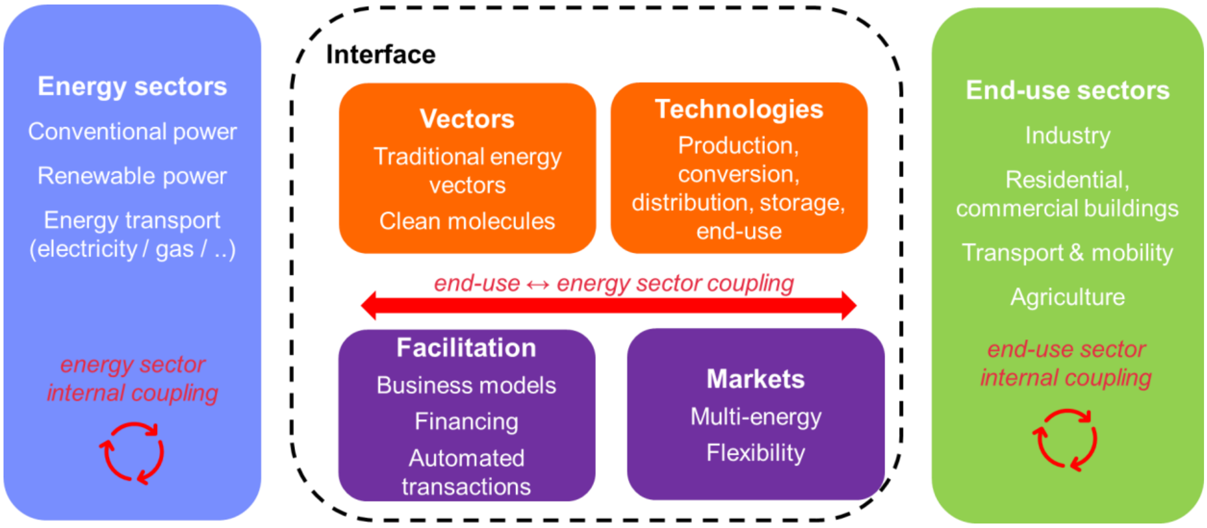

Figure 2.2: Conceptual framework for sector coupling distinguishing energy and end-use sectors, three main forms of coupling, and four elements at the sector coupling interface.

2.3 Sector coupling in ReInvent

In the ReInvent project, the interpretation of sector coupling lies in between the narrow and wide interpretations mentioned above. It goes beyond the narrow definition (usage of excess renewable electricity), for example by including multi-sector energy communities (Test Cases 3, 4 and 6) in the project's scope. Yet, it is not as broad as the wide definition of energy system integration. For example, renewable biofuels and CCUS (although import elements for renewable energy systems and as such included in the energy system planning models) are not foreseen to be studied in-depth.

Concretely, we follow the definition of (Ramsebner et al., 2021) (Box 1), placing the integration of large-scale renewable electricity via direct and indirect electrification as the central point of departure. This implies aspects of energy system integration that do not involve renewable electricity are considered out of scope. From this starting point, we identify three central aspects of sector coupling as follows:

- Electrification and demand-side flexibility: This aspect closely links to 'direct electrification' as described in (Ramsebner et al., 2021) and 'end-use sector coupling' in (Van Nuffel, 2018). This corresponds to *end-use ↔ energy sector coupling* in the conceptual framework of Figure 2.3. We highlight demand-side flexibility as a key element of this aspect of sector coupling. Demand-side flexibility is needed to create 'multi-directionality' as indicated, for example, by the EU strategy on energy system integration. Demand side flexibility, which can be defined as the ability of demand to adjust their electricity consumption patterns in response to external signals, such as price changes or incentives (European Smart Grids Task Force & Expert Group 3, 2019), includes the provision of grid services by means of demand-side flexibility and the shifting of energy demand to periods of high energy availability.

- Power2X: This aspect closely links to the concept of 'indirect electrification' (Ramsebner et al., 2021) and 'cross-vector integration' in (Van Nuffel, 2018). Power2X is a form of *energy sector internal coupling* in the conceptual framework of Figure 2.2. The X can denote a variety of synthetic fuels and gases or heat[7], with Power to Hydrogen and Power to Heat (via district heating systems) as a main research focus in ReInvent. Hydrogen or derivatives can be used in different ways: energy end-use (for example, in high-temperature heating processes), feedstock end-use (for example, ammonia production), and as a storage solution (for example, back-up electricity generation).
- Community energy: Community energy can be considered a main organizational principle of sector coupling (among other possibilities). In particular, it can enable the integration of end-use sectors via multi-sector energy communities. As such, it facilitates *end-use sector internal coupling* in the conceptual framework of Figure 2.3. Moreover, community energy can be a vehicle to enable collective prosumption (Horstink et al., 2020), community-based demand-side flexibility (Wieczorek et al., 2024), and community wind energy (Kirkegaard et al., 2023).

[7] Power to heat may be considered both as electrification and as Power2X. In this report, we consider the uptake of heat pumps in buildings as a form of electrification, and centralized heat pumps feeding into district heating systems as Power2X.

3 Regulatory context

This chapter describes the regulatory context for sector coupling at the EU and Belgian levels. It focusses on the three main sector coupling aspects defined in the previous chapter: electrification and demand-side flexibility, power2X, and community energy.

3.1 Electrification and demand-side flexibility

3.1.1 EU-level context

The revised Renewable Energy Directive[8] (RED) sets the legal framework for advancing clean energy in all sectors of the EU economy. It establishes a binding EU renewable energy target of at least 42.5% by 2030. It stresses the role of direct electrification of end-use sectors (including the transport sector) to help integrate these large shares of variable renewable energy generation. The EU Strategy on Energy System Integration (EC, 2020b) advocates for a more interconnected energy system. Similarly, as in the RED, the proposed measures include, amongst others, the electrification of heating, cooling, industry and transportation, and the introduction of smart, bidirectional charging and vehicle-to-grid services. To meet the aforementioned renewable energy targets, it will be imperative to: a) integrate more renewable energy, including distributed energy resources (DER), into the electricity supply, and b) phase out fossil fuels through the electrification of end-use sectors. These changes, however, present considerable challenges linked to the increased level of electricity consumption and more variable generation, which put significant pressure on electricity grids. In response, the European Commission has released a Grid Action Plan[9] emphasizing the need for efforts at all grid levels but certainly at the distribution grid level, where most decentralized energy resources will connect and where changes in end-use behavior (coming from energy assets such as heat pumps and electric vehicles) are expected. Grid investments alone will be insufficient due to the time and financial resources required. Therefore, efficient grid usage and increased flexibility are necessary to manage fluctuations in renewable energy generation and increased consumption and to reduce investment costs.

While the electricity system is already more accustomed to flexibility at the transmission level, to deal with challenges in the distribution grid, there is a higher need for distribution-grid connected flexibility. The rise in DER and electrification at the same time introduces more flexible loads at the distribution level. To enable these sources to provide flexibility, a supporting regulatory framework is needed, and several initiatives have been taken at EU-level. The European Commission recognized the importance of demand-side flexibility already in

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[8] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202302413
[9] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A757%3AFIN&qid=1701167355682

2009 with the adoption of the third energy package[10] through the usage of the term demand-side management (Directive 2009/72/EC). With the Clean Energy package[11], the pivotal role of end-use sectors was highlighted even further, and consumer empowerment became a core pillar of the energy union strategy[12]. Particularly the Electricity Market Regulation (2019/943)[13] and Electricity Market Directive (2019/944)[14] (EMD) place consumers at the forefront of the energy transition. These regulations include provisions to facilitate the implementation of Demand Response (DR) mechanisms and ensure their participation in electricity markets. For example, Article 17 of the EMD ensures non-discriminatory access to all electricity markets for everyone. In addition, the Electricity Market Regulation and Directive put forward market-based procurement for the procurement of SO services (Articles 31, 32 and 40 of the EMD) as the default option. Furthermore, these regulations stress the importance of cost-reflective transmission and distribution tariff designs and support the introduction of time-differentiated network tariffs where appropriate.

The Third Energy Package foresees the development of EU-level Network Codes and Guidelines. These Codes and Guidelines are a set of European regulations in order to harmonize procedures across Europe and contribute to the integration and efficiency of the European electricity market. They have been mostly devoted to pan-European grids and markets, and the existing network codes and guidelines have mostly focused on the transmission networks and the flexibility needs of transmission system operator (TSOs). In particular the Electricity Balancing Guideline[15] has paved the way for the definitions of balancing products and services (frequency containment reserves, frequency restoration reserves and replacement reserves) and the creation of EU-level market platforms to procure these services.

In addition, Article 59(1), point (e) of the Electricity Market Regulation, authorizes the Commission to establish a new Network Code on Demand Response, covering rules on aggregation, energy storage, and demand curtailment (Network Code Demand Response - NCDR). The NCDR is applicable to all wholesale electricity market segments (including those for procuring services by TSOs and distribution system operators (DSOs)), but in addition also establishes European rules for the assessment of the need for, the procurement of and the use of local SO services, such as congestion management and voltage control, which were not covered yet by the guideline on energy balancing. The development of this network code is currently underway and a draft version[16] has been provided by ENTSO-E and EU DSO entity to ACER. When the NCDR is finalized, it will have to be implemented within the individual Member States.

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[10] https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/third-energy-package_en
[11] https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en
[12] https://energy.ec.europa.eu/topics/energy-strategy/energy-union_en
[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32019R0943
[14] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=uriserv:OJ.L_.2019.158.01.0125.01.ENG
[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2017.312.01.0006.01.ENG&toc=OJ:L:2017:312:TOC#d1e259-6-1
[16] https://www.acer.europa.eu/sites/default/files/documents/Official_documents/Public_consultations/PC_2024_E_07/1_NCDR_DSO_ENTITY_ENTSO-E.pdf

Finally, the European Commission has implemented various supporting measures to facilitate the large-scale deployment of demand-side flexibility, including the EU digital strategy[17] to support the energy transition through digitalization. Additionally, the Electricity Market Design reform[18] mandates Member States to evaluate their flexibility needs, set targets for increasing non-fossil flexibility, and implement support mechanisms focused on demand response and storage.

3.1.2 Belgian level context

The EU-regulation needs to be transposed for the different Member States. In Belgium, the federal and regional governments share responsibility for energy policy[19]. For Belgium, this means that, depending on the topic, there will be certain regulations at the federal or regional levels (Flanders, Brussels and Wallonia). The federal level is responsible for matters whose technical and economic indivisibility requires equal treatment at a national level, such as security of supply, while the regions are responsible for substantial policy elements on their territories such as the distribution of electricity, the transport of electricity through networks with a nominal voltage lower than or equal to 70,000 volts.

At federal level, the main regulation is the Electricity law[20] and the federal grid code[21] governing the operation of and access to the electricity transmission system. In line with EU regulation, Article 19 of the Electricity law defines that each end-consumer has the right to valorise its flexibility.

Furthermore, the regions have their own regional energy regulation. For Flanders, this is the Energy Decree[22], for the Walloon region the Walloon Energy Decree[23], and for Brussels the Ordinance[24]. All these regions foresee the non-discriminatory access of all types of flexibility to the electricity markets and the establishment of market-based procedures for the procurement of DSO services. Following the regional regulations, the regional regulators (VREG for Flanders, CWaPE for the Walloon Region, and BRUGEL for the Brussels Capital Region) set up technical regulations which need to be followed by the system operators and other market actors:

- For Flanders, with the addition of Article 4.1.17/6 to the Energy Decree, a framework was created in 2021 for the purchase of non-frequency related ancillary services by the distribution system operator. In accordance with Article 2.3.23 of the Technical Regulation for Electricity Distribution (Technisch

[17] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/shaping-europes-digital-future_en
[18] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2023%3A148%3AFIN
[19] https://economie.fgov.be/nl/themas/energie/energiebeleid/het-energiebeleid-van-belgie
[20] https://www.ejustice.just.fgov.be/cgi_loi/change_lg.pl?language=nl&la=N&table_name=wet&cn=1999042942
[21] https://www.ejustice.just.fgov.be/eli/besluit/2019/04/22/2019012009/justel
[22] https://codex.vlaanderen.be/portals/codex/documenten/1018092.html.%20%5bAccessed%2024%2006%202024
[23] https://www.ejustice.just.fgov.be/cgi/article_body.pl?language=fr&caller=summary&pub_date=2022-10-05&numac=2022033591
[24] https://www.ejustice.just.fgov.be/eli/ordonnance/2001/07/19/2001031386/justel

Reglement voor Distributie van Elektriciteit, TRDE[25]), the distribution system operators must draw up rules for the purchase of these services.

- For Brussels region, the Brussels Ordonnance[26] of the 19th of July 2001 states in art. 7 9° , that the DSO needs to procure non-frequency related ancillary products and services that are necessary for the efficient, reliable and safe operation of the distribution network, following transparent and non-discriminatory conditions and through a market-based approach, unless Brugel has determined that the purchase of these services cannot be carried out in a cost-effective manner. These rules are translated into the technical regulation[27], specifically in section 3.3 (art. 2.28) .
- For Wallonia, art. 11 of the electricity market regulation[28, 29] states that the network operator needs to define (after stakeholder consultations and after CWaPE approval) specifications for the acquisition of flexibility services, guaranteeing non-discriminatory access to all market players. Exemptions are possible if proven that such market-based procurement is not cost-efficient.

Given the fact that Belgium has three different regions and regulations, the system operators of the three regions also collaborate through Synergrid to define common technical regulations[30]. It should be noted that even though there have been significant efforts to harmonize the procedures over the three regions, applicable rules regarding flexibility markets and tariff design differ considerably in the different regions. The tables below summarize the current status and give an overview of respectively flexibility markets and tariff design at the different regional levels.

[25] https://www.vreg.be/sites/default/files/document/bijlage_1_trde_2023.pdf
[26] https://www.ejustice.just.fgov.be/eli/ordonnance/2001/07/19/2001031386/justel
[27] https://brugel.brussels/publication/document/notype/2024/nl/Technische-reglementen-Elektriciteit.pdf
[28] https://www.ejustice.just.fgov.be/eli/decret/2001/04/12/2001027238/justel#t
[29] https://www.cwape.be/sites/default/files/cwape-documents/2021.05.27-AGW%20approuvant%20le%20RTDE-NL.pdf
[30] https://www.synergrid.be/nl/documentencentrum/technische-voorschriften/elektriciteit

Table 3.1: Overview and status of markets for SO services at the different regional levels

Flanders	Regulatory framework for the procurement of flexibility services by the DSOs created in 2021 (Article 4.1.17/6 Energy decree). There have been several iterations on the rules for the purchase of non-frequency related ancillary services and grid losses by Fluvius[31]. The first market tests for reactive power are currently ongoing. First market tests for active power will be starting soon since the product definitions and applicable rules are being updated.
Wallonia	Today, ORES is thinking about launching a procurement process for a market platform for a flexibility market at Medium Voltage. Concrete steps are still to be taken, and local flexibility markets are therefore still non-existent in the Walloon region.
Brussels	Sibelga raised in its Smart Grid Roadmap[32] concerns linked to local flexibility markets and is therefore in the short run not planning to opt for such markets.

Table 3.2: Overview of tariff design at the different regional levels

Flanders	Currently, Flanders applies a capacity tariff[33] (CAPTAR) which is partially based on the effectively used capacity and partially based on consumption. The capacity part is calculated based on the average monthly peak in kW. This average peak is determined based on the average of the 12 latest monthly peaks. For customers without digital meters, an average peak is assumed. In addition, Fluvius is looking into the possibilities of ToU distribution grid tariffs.
Wallonia	Even though it is currently still a draft guideline, the regulator's decision on a new grid methodology[34] indicates that from 2026 ToU tariffs will be applied with different colours to give incentives during peak moments (green, orange, red). For now, the tariff is still voluntary, allowing consumers to opt for the regular tariff.
Brussels	Distribution grid tariffs are partially based on technical capacity (kVA) and energy volumes. The capacity part is currently taking up about 20-30% of the tariff. The volumetric part of the tariff consists of a peak and off-peak (day-night) tariff. Specifically for energy communities, reductions in grid tariffs are temporarily provided to incentivize them[35, 36, 37].

[31] https://partner.fluvius.be/sites/fluvius/files/2023-07/regels-voor-ondersteunende-diensten-en-netverliezen-2023.pdf
[32] https://www.sibelga.be/asset/file/5bfeeae0-1781-11ef-9451-005056970ffd
[33] https://www.fluvius.be/nl/factuur-en-tarieven/netkosten-elektriciteit-en-aardgas/2024?app-refresh=1727336873055
[34] https://www.cwape.be/sites/default/files/cwape-documents/2023.05.31-0773-M%C3%A9thodologie%20tarifaire%20pour%20la%20p%C3%A9riode%20r%C3%A9gulatoire%202025-2029%20.pdf
[35] https://www.brugel.brussels/publication/document/beslissingen/2024/nl/BESLISSING-264-TARIEFMETHODOLOGIE-2025-2029-DEEL-2.pdf
[36] https://energysharing.brugel.brussels/nl_BE/energysharing/netwerktarieven-409
[37] https://www.sibelga.be/asset/file/5bfeeae0-1781-11ef-9451-005056970ffd

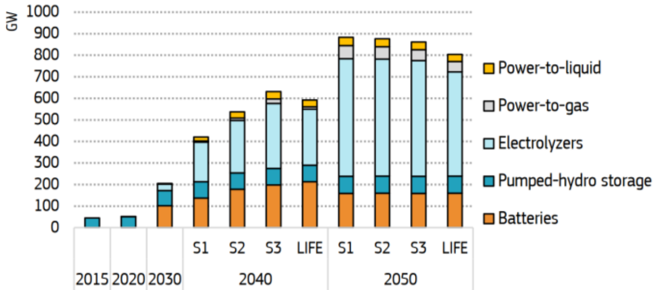
3.2 Power2X

3.2.1 EU-level context

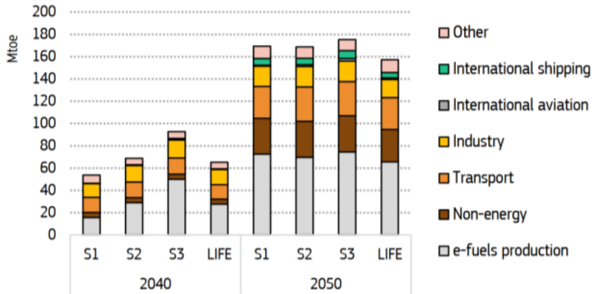
Power2X and the role of hydrogen receive much attention in the EU. Hydrogen is considered a key enabler of decarbonization, particularly for hard-to-abate sectors (energy-intensive industry, heavy transport) where direct electrification is not feasible. Hydrogen related ambitions and actions are put forward in a variety of policy documents, including the EU strategy on Energy System Integration (EC, 2020b), the EU hydrogen strategy (EC, 2020a), and REPowerEU (EC, 2022). A main 2030 target set out in REPowerEU is to reach renewable hydrogen consumption up to 20 million tons (Mt), aiming to produce 10 Mt within Europe and import the additional 10 Mt. This would imply a significant uptake of Power2X, with an estimated 125GW of EU electrolyzer capacity needed to produce 10Mt hydrogen (Marcu et al., 2024).

The recent Impact Assessment (EC, 2024a) for the proposed 90% emissions reduction target for 2040 (EC, 2024b) further reflects the EU vision on the long-term energy system development, including the role of hydrogen and Power2X. Power2X is foreseen to play an increasingly important role both in final energy and non-energy consumption, as well as in providing flexibility. Following the S3 scenario reflecting a 90-94% emissions reduction target (i.e., in line with the commission's proposal), some key developments foreseen for 2040 and beyond are:

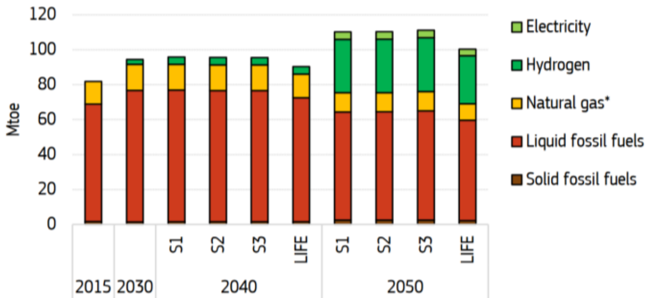
- A significant growth of electrolyzer and additional power-to-gas and -liquid capacity (Figure 3.1a)
- Hydrogen production amounting to 30-35 Mton in 2040, of which approximately half is used for producing synthetic fuels (Figure 3.1b).
- A significant uptake of hydrogen in Industry, mainly as a feedstock (non-energy consumption) and to a lesser extent as a fuel (Figure 3.1c)
- A significant uptake of hydrogen and other synthetic fuels and gasses in transport, mainly for Heavy Goods Vehicles (HGVs) (Figure 3.1d)



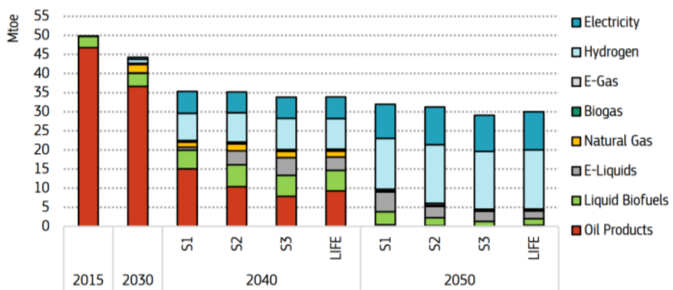
a) Net installed storage and new fuels production capacity



b) Consumption of hydrogen by sector



c) Final non-energy consumption in industry by fuel



d) EU energy consumption by Heavy Goods Vehicles

Figure 3.1 - Some key figures for power2X development from the recent Impact Assessment accompanying the EU 2040 emissions target. Scenario S3 aligns with the proposed 90% emissions reduction target. Note that 1Mt of hydrogen corresponds to roughly 3 Mtoe. Source: (EC, 2024a)

To accomplish these ambitious targets, the EU has put forward an extensive regulatory framework and investment support schemes. An overview of EU Policies Concerning Hydrogen & Financing can be found in (Marcu et al., 2024). The various policies in place affect different components of the hydrogen market (supply, demand, infrastructure) as shown in Table 3.1.

On the *supply side*, key elements are the 2030 total hydrogen production objectives formulated in the EU hydrogen strategy (EC, 2020a) and REPowerEU (EC, 2022). Other relevant aspects are the definitions of what classifies as sustainable hydrogen production (as defined in the EU taxonomy[38]) or renewable hydrogen (as defined in the first[39] and second[40] REDII Delegated Acts'). The first delegated act defines under which conditions hydrogen or other synthetic fuels and gases can be considered as Renewable Fuels of Non-Biological Origin (RFNBOs). This depends on the extent to which they are sourced from 'excess' renewable electricity and comply with temporal and geographical correlation criteria. The second act sets criteria for calculating the lifecycle Greenhouse Gas (GHG) emissions of RNFBOs. This is particularly relevant for recycled-carbon fuels that should lead to a minimum of 70% emissions reduction to be considered as a RFNBO. Being classified as RFNBO is crucial to be exempted from providing emissions allowances.

On the *demand side*, sector level targets apply in the recast Renewable Energy Directive[8] (REDIII). For industry, RED III sets a 2030 target of 1.6 percentage points annual increase in the use of renewable energy, and additionally a minimum of 42% of hydrogen consumption to come from RFNBOs, increasing to 60% by 2035. For transport, hydrogen and e-fuels need to account for at least 1 % of all fuels by 2030. RFNBOs thereby receive an additional 'weight', i.e., with volumes counted up to double their actual volume in the assessment of the target. Moreover, the Cross-border Adjustment Mechanism (CBAM) is a relevant policy as it may affect the pricing of imported hydrogen (depending on its life cycle carbon emissions), consequently impacting EU supply and demand.

For *infrastructure*, Alternative fuels infrastructure regulation (AFIR) sets mandatory deployment targets for hydrogen refueling infrastructure along main highway corridors[41]. The regulation on Trans-European Networks for Energy[42] (TEN-E) facilitates investment in cross-border energy infrastructure, for example, by providing regulatory and permitting provisions to accelerate the implementation of Projects of Common and Mutual Interest[43] (PCI and PMI).

[38] https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[39] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1184&qid=1704969010792
[40] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2023.157.01.0020.01.ENG
[41] https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en
[42] https://energy.ec.europa.eu/topics/infrastructure/trans-european-networks-energy_en
[43] https://energy.ec.europa.eu/topics/infrastructure/projects-common-interest-and-projects-mutual-interest_en

Finally, there are a variety of EU funds supporting hydrogen, with the EU hydrogen bank[44] as a primary instrument. Moreover, hydrogen can be eligible for State aid when classified as an Important Project of Common European Interest[45] (IPCEI).

Table 3.3 – Overview of EU policies affecting different components of the hydrogen market. Source: (Marcu et al., 2024)

Components of H_2 Market	**Policies (communications, directives, regulations, delegated acts)**
Supply	EU Hydrogen Strategy, RED II Delegated Acts, Hydrogen and Decarbonised Gas Market package, EU Taxonomy, Net Zero Industry Act, REPowerEU Plan, RefuelEU Aviation, Critical Raw Materials Act
Industrial and Transport Demand	EU Hydrogen Strategy, recast Renewable Energy Directive (RED III), REPowerEU Plan, Carbon Border Adjustment Mechanism (CBAM), FuelEU Maritime, RefuelEU Aviation, EU ETS
Infrastructure	EU Hydrogen Strategy, Hydrogen and Decarbonised Gas Market package, Net-Zero Industry Act, Alternative Fuels Infrastructure Regulation (AFIR), Trans-European Transport Network (TEN-T), Trans-European Networks for Energy (TEN-E), Critical Raw Materials Act

3.2.2 Belgian level context

In the federal Hydrogen Vision (Belgian Government, 2022), renewable hydrogen is positioned as an important enabler for reaching the EU climate and energy targets. Hydrogen and derivatives like ammonia, methanol and synthetic fuels are foreseen to be used in difficult-to-electrify sectors, mainly in industry, heavy-duty transport, shipping and aviation. Moreover, hydrogen can be used as a storage option to provide grid flexibility. Long-term hydrogen demand (inc. derivatives) is foreseen to rise to 125-200 TWh / year (~3.8-6 Mt hydrogen) in 2050, including bunker fuels for international aviation and shipping.

A main ambition is to position Belgium as 'import hub' for clean molecules for Europe. Domestic demands are for the largest part to be covered via imports[46]. To this end, an open access hydrogen backbone will be implemented connecting ports, industrial zones and neighboring countries. As laid out in the National Plan for Recovery and Resilience, Belgium supports the implementation of 100 – 160 km of open access hydrogen transport pipelines by 2026 (Belgian Government, 2021) and efforts are ongoing to build the hydrogen network in line with market needs (Fluxys, 2022). With the Federal Hydrogen Law[47] of 2023 and the provisional Flemish

[44] https://energy.ec.europa.eu/topics/energy-systems-integration/hydrogen/european-hydrogen-bank_en
[45] https://competition-policy.ec.europa.eu/state-aid/ipcei_en
[46] In the Hydrogen Vision, Belgium estimates its demand for hydrogen imports by 2030 to be 20 TWh and by 2050 to be 200-350 TWh to meet domestic demand and for transfer to other EU countries.
[47] https://economie.fgov.be/nl/themas/energie/bronnen-en-dragers-van-energie/waterstof/regulering-van-het-vervoer-van

Decree on hydrogen networks[48], main regulation for the transport and distribution of hydrogen is being defined (WaterstofNet, 2023).

Compared to imports, the potential for domestic production is seen as relatively limited. Yet, Belgium aims to reach at least 150 MW electrolysis capacity in operation by 2026, aimed at gaining expertise and supporting technological innovation (Belgian Government, 2022). Moreover, a coordinated planning between hydrogen and electricity networks is called for to take benefit of potential sector-coupling synergies. Considering the reliance on import, developing adequate RFNBO certification for clean molecules import is considered essential to protect the domestic hydrogen market (see also Hinicio, 2024). Further reforms to support the development of a hydrogen market are to develop a regulatory framework for H2 and CO2 markets and fiscal reforms for fossil fuels (Belgian Government, 2021).

The recent update of the NECP (Belgian Government, 2023) broadly confirms the targets and measures set out in previous policy documents, also on the regional policy level. Moreover, it points to ongoing efforts of international cooperation in the Pentalateral Energy Forum and North Seas Energy Cooperation to harmonize market designs, certification and cross-border infrastructure investment. Various investment support mechanisms are currently in place, including an additional 250MEuro reserved in 2023 for further hydrogen infrastructure development and innovation support under the Clean Hydrogen for Clean Industry & Import call and Energy Transition Fund (WaterstofNet, 2023). Finally, the industry ecosystem around hydrogen has strongly developed with main networks like Waterstofnet[49], Tweed[50], and the Belgian Hydrogen Council[51].

3.3 Multisector energy communities

3.3.1 EU-level context

Renewable Energy Communities and Citizen Energy Communities are initiatives designed at EU-level to empower citizens and local communities to participate actively in the energy transition, enhance energy efficiency, and promote the use of renewable energy sources. The main difference between RECs and CECs lies in their scope and the legal entities they involve (REScoop.eu, 2022). RECs focus specifically on renewable energy, involving local actors in the production, consumption, and sharing of renewable energy. At the same time, CECs have a broader scope, encompassing all forms of energy and allowing a wider range of participants, including non-local actors[52]. This distinction between RECs and CECS is outlined in the RED Directive 2018/2001 and the Internal Electricity Market Directive 2019/944 (Lennon & Dunphy, 2024). The implementation of RECs

[48] https://www.minaraad.be/themas/klimaat/waterstofnettendecreet-adviesvraag
[49] https://www.waterstofnet.eu/nl
[50] https://clusters.wallonie.be/tweed/en/ecosystems-0
[51] https://belgianhydrogencouncil.be/
[52] https://www.rescoop.eu/toolbox/second-generation-eu-legislation-for-energy-communities

and CECs varies significantly across EU member states, driven by differences in national legislation, local initiatives, and market conditions[53]. Monitoring the status of implementation involves looking at the regulatory frameworks, the number of active communities, and the success stories from different countries (REScoop.eu, 2022). In Belgium, the implementation of RECs and CECs is influenced by the country's unique federal structure, where energy policy responsibilities are divided between the federal government and the three regional governments: Flanders, Wallonia, and the Brussels-Capital Region, as explained above. This division leads to varying approaches and progress in different parts of the country, as each region has its own regulatory framework and policy initiatives.

The EU has established a legislative framework[54] that mandates member states to support the creation and development of RECs and CECs. The RED II and the Electricity Market Directive are the key legislative documents (Krug et al., 2023). Furthermore, each MS is responsible for transposing EU directives into national law, leading to varying levels of progress. Countries like Denmark, Germany, and the Netherlands have advanced frameworks, while others are still developing their legal structures[55].

3.3.2 Monitoring Implementation at Belgian level

Monitoring the implementation of RECs and CECs regulation at national levels[53] involves a comprehensive assessment of several key indicators. This includes tracking regulatory progress, which involves observing changes and updates in national legislation that directly affect the formation and operation of these energy communities (REScoop.eu, 2022). Community growth is another critical aspect, where the focus is on the number of new RECs and CECs, their size, and the energy capacities they manage. Financial mechanisms play a significant role as well, requiring an evaluation of the availability and effectiveness of financial incentives and support, such as grants, subsidies, and feed-in tariffs.

Monitoring the status of implementation in Belgium (Blixt et al., 2020) involves examining these regional regulatory frameworks, which differ in terms of support for energy communities and the ease of establishing RECs and CECs. For example, Flanders has been particularly proactive, with robust policies and incentives aimed at fostering community energy projects, whereas Wallonia and Brussels-Capital have their own distinct strategies and levels of progress[56]. Additionally, tracking the number of active energy communities across these regions and analyzing their growth provides insight into how well these frameworks are functioning.

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[53] https://www.rescoop.eu/policy/transposition-tracker

[54] https://sustainable-energy-week.ec.europa.eu/news/eu-energy-communities-legislation-20-upwards-trend-2024-03-14_en

[55] https://energy-communities-repository.ec.europa.eu/energy-communities-repository-legal-frameworks/energy-communities-repository-policy-database_en

[56] https://www.rescoop.eu/policy/transposition-tracker/rec-cec-definitions

4 Energy system modelling perspective

The perspective of energy system planning modelling examines how sector coupling is addressed in techno-economic energy system optimization models (ESOMs) (DeCarolis et al., 2017). By definition, these models are sector-coupled as they perform an integrated system optimization from the supply side to the demand side. This allows the user to incorporate various types of commodity flows, whether energy or material, into the model, which flow through several sector-coupled processes, from the supply (e.g., power-to-hydrogen conversion technologies) to the demand side (e.g., flexible electric vehicle charging, energy-intensive industrial heating processes). The optimization problem is then solved by minimizing the system cost under certain constraints such as resource availability, behaviour change (e.g., max. levels of flexible EV charging) or environmental policy (e.g., CO_2 emission targets).

4.1 Modelling sector coupling in Belgium

Some of the techno-economic system-level analyses conducted on sector-coupled models for Belgium in recent years have been carried out within the framework of projects such as EPOC[57], BREGILAB[58], or scenario analyses like PATHS2050[59] and SHIFT[60]. These analyses differ significantly in terms of focus and assumptions used; however, they share a common factor: they were conducted using the TIMES modelling framework (Loulou, 2016) to develop energy system models for Belgium, specifically the so-called TIMES-BE (a single-region model) and TIB3R (a tri-regional model).

All the aforementioned studies conducted scenario analyses within the context of decarbonizing the Belgian energy system by 2050. The scenarios developed for the BREGILAB project focused on the impact of deep electrification of the energy system in the residential and transport sectors, while EPOC centred on the effects of renewable energy scarcity ('Dunkelflaute') in an electricity system highly dependent on renewables. PATHS2050 defines three scenarios – Central, Electrification and Clean Molecules - based on a stronger emphasis on one or the other of the primary decarbonization solutions, whereas SHIFT explored the impact of reduced energy demand on decarbonization targets.

Next to these studies also stands the INTEGRATION[61] model, based on an open-source language developed by ULiège (GBOML[62]).

[57] https://energyville.be/en/project/epoc-2030-2050-belgian-research-institutes-join-forces-develop-models-sustainable-and-cost/
[58] https://vito.be/en/bregilab-0
[59] https://perspective2050.energyville.be/
[60] https://perspective2050.energyville.be/system-shift-materials-efficiency
[61] https://integrationdemonstrator.github.io/
[62] https://orbi.uliege.be/handle/2268/296930

In the following we describe how sector coupling is implemented in techno-economic energy system optimization models, focusing on the TIMES models for Belgium described above. We address the three main sector coupling topics identified in Chapter 2: electrification and demand-side flexibility, power2X and community energy.

4.2 Electrification and demand-side flexibility

For modelling sector coupling, the representation of the electricity system and its development over time is particularly important. Given the structure of the TIMES model, this must be addressed not only for electricity-generating technologies (on the supply side) but also on the demand side. For this reason, energy system models are in general, very well suited for representing flexibility options, having he possibility to also represent storage technologies, as well as sector-coupled solutions (Heider et al., 2021). For instance, in the transport sector, modelling applications show how enabling flexible EV charging may imply a reduction of peak power capacity requirements, lower battery storage needs, better integration of variable Renewable Energy Sources (RES), and lower energy system costs and electricity price fluctuations (Valkering et al., 2023).

Moreover, the TIMES models for Belgium considered here have a high level of detail in characterizing electrification options across different end-use sectors (Correa Laguna et al., 2023; Moglianesi et al., 2023). In **transport**, for example, the EV modelling approach aims to replicate the charging and discharging behaviour of the vehicle's battery in relation to the sector it is connected to (residential or commercial sector) (Figure 4.1). To this end, the car fleet is segmented into commuting cars and non-commuting cars and average driving profiles by segment are adopted. Charging is allowed only when (according to the driving profiles) the vehicles are parked near residential buildings (typically during nighttime hours, especially for commuting vehicles) or commercial buildings (during working hours for commuting vehicles). Battery discharge for powering the vehicle is modelled based on the average driving profiles, again in relation to their type of use (commuting or non-commuting). Battery charging profiles, besides being constrained by charger availability (which depends on the vehicle's sector location), can be restricted to typical profiles (non-flexible charging) or allowed to be partially or completely flexible (flexible charging). Additionally, in the latest version of the TIMES-BE model, the option to invest in Vehicle-to-Grid (V2G) technologies has been made available. All the aforementioned technologies, from EVs to various types of chargers (flexible or otherwise, with or without V2G capabilities), are characterized by the average techno-economic values of the technologies, which are detailed in Table 4.1.

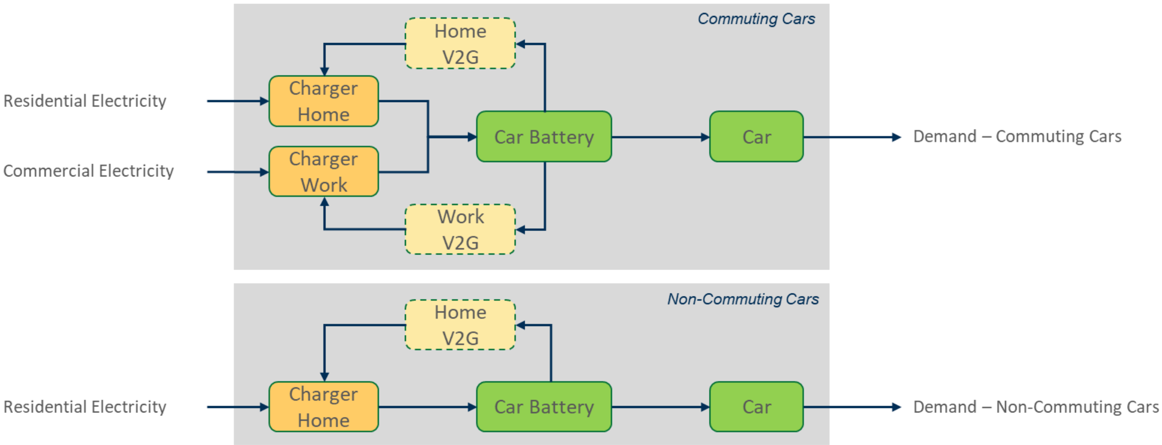

Figure 4.1: Schematic visualization of the modelling approach for Electric Vehicles in the considered TIMES models

Table 4.1 - Techno-economic parameters for EV and EV chargers (costs refer to 2024)

	Size [kW]	Battery size [kWh]	Efficiency [-]	Investment cost [€]
EV Charger (Uncontrolled)	9.6 (charging)	-	0.95	2000
EV Charger (Smart)	9.6 (charging)	-	0.95	2267
EV Charger (Smart and V2G)	9.6 (charging)	-	0.95	3621
EV	10.3 (discharging)	40.7	0.92	34249

Flexible EV charging, together with residential solar power generation, can contribute largely to the flexibility of the power system in 2050, as shown in the BREGILAB study (Correa-Laguna & Moglianesi, 2023). In the BREGILAB Central Scenario, in particular, solar capacity plays a crucial role with capacities nearing the maximum rooftop potential of approximately 100 GW for Belgium. Flexible EV charging is used extensively to match solar generation (Figure 4.2), while local battery storage options are only implemented when all other flexibility options are exhausted.

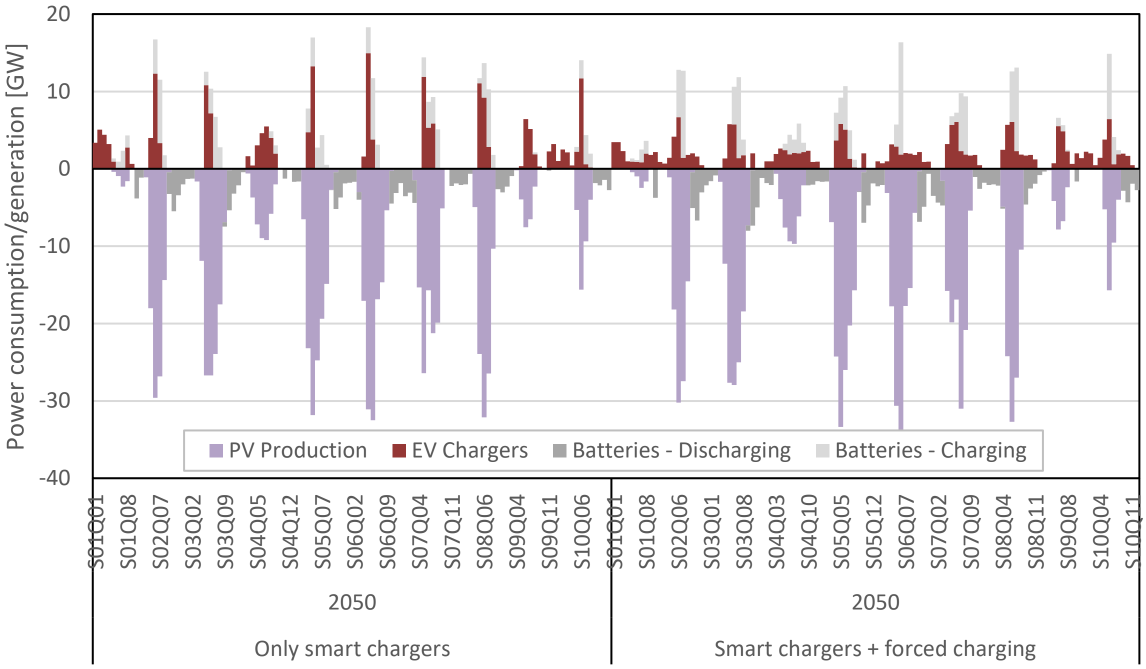

Figure 4.2 - Hourly profiles of PV production and EV charging (as well as battery charging/discharging), in a fully flexible charging scenario, and in a less flexible one (from the BREGILAB study)

Another sector where electrification plays a key role is the **building sector**, where heat pumps are expected to assume an increasingly significant role in the coming years and decades. For this reason, these are also modelled with particular attention in the TIMES models of reference. Heat pumps are available with varying levels of efficiency and are modelled to explicitly account for both electricity consumption and the use of ambient heat (Table 4.2). The assumption in the reference models is that these systems have limited flexibility; as for space heating, they must provide a thermal output profile that depends on external temperature, season, and building type. Currently, only for domestic hot water demand a heat buffer providing flexibility is considered. Other potential heat flexibility sources like the thermal heat inertia of buildings or underground heat storage are not yet considered.

Table 4.2 - Techno-economic parameters for heat pump technologies (costs refer to 2024)

	Size [kW]	COP [-]	Investment Cost [k€]
Air-air heat pump	8	2.9	6.235
Air-water heat pump	8	2.8	11.243
Air-water, high efficiency HP	8	3.0	20.402
Ground-source HP	8	3.7	16.865
Ground-source, high efficiency HP	8	4.0	28.784

Industrial flexibility is another crucial enabler for full decarbonization and the deep electrification of the energy system (Heider et al., 2021). In the PATHS2050 study, a sensitivity case was conducted with the option for production facilities to overinvest in capacity to allow for higher peak production during low energy price hours and reduced production during high price hours. This enabled a first exploration of industrial flexibility, especially focusing on some flexibility-enabling technologies such as the electric arc furnace for iron and steel production and electrical cracking furnaces in the chemical sector. The results show an important impact of such measures on the power generation mix, favoring a higher penetration of renewables and penalizing capital-intensive, fixed output sources such as nuclear (Figure 4.3) (Correa Laguna et al., 2023). Further work on industrial flexibility representing additional flexibility in other sectors (e.g., Elia, 2022) will be carried out under the ETF Galileo project.

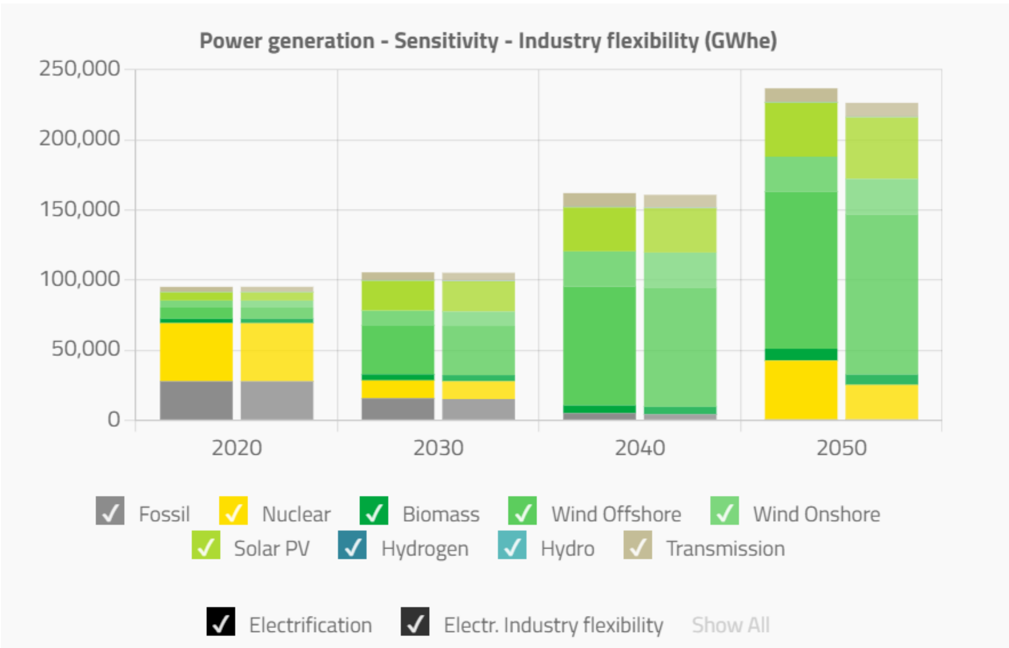

Figure 4.3 - Impact of industrial flexibility measures on the power generation mix

4.3 Power2X

4.3.1 Power2X in energy system modelling

Power2X (P2X) technologies are integrated into energy system models as key enablers of flexibility, sector coupling, and decarbonization. Increasing the flexibility within an energy system can bring down the total system cost, which - from an energy modelling perspective - can make P2X technologies strategically attractive investment options in long-term decarbonization scenarios. P2X is, therefore, a relevant part of these modelling exercises. Many energy system models exist which include these types of P2X technologies as a technology alternative (Heider et al., 2021). These models differ in spatial and temporal resolution as well as technological representation, balancing modelling detail with computational cost. Consequently, different models provide different representations and levels of details of P2X technologies. The following sections provide an overview of P2X modelling in different energy system models.

An example of a sector coupled European energy system model with Power2X is the Euro-Calliope model (Pickering et al., 2022; Tröndle & Pickering, 2021). This model includes P2X via hydrogen from electrolysis and CO2 from direct air capture, which are consequently combined in various processes to produce the hydrocarbons. The PyPSA-Eur-Sec model[63] (Brown et al., 2018; Hörsch et al., 2018) is a European energy system model developed using PyPSA. The model includes a variety of P2X technologies that facilitate the conversion of renewable electricity into other energy carriers via electrolysis, methanation, syn-fuel production and ammonia production. The PRIMES[64] model – used in the EU Impact Assessment (EC, 2024a) for the 2040 emissions target (Section 3.2.1) - includes the possibility of using hydrogen and synthetic fuels, and the possible emergence of non-fossil hydrocarbon feedstock in the chemicals. Thellufsen et al. (2023) find that to a large extent these models can evaluate power-to-heat options and P2X options such as hydrogen and synthetic fuel production, but the synergies from waste heat from industry and power to X to supply heating is lacking.

The JRC-EU-TIMES model[65] (Blanco et al., 2018a, 2018b) presents a detailed P2X representation, modelling a range of power-2-molecules and power-2-liquids technologies. Blanco et al. (2018a) assessed the potential for hydrogen and power-to-liquids (P2L) in several European decarbonization pathways towards 2050. The study finds that hydrogen and P2L contribute to energy security and independence. Further research by Beres et al. (2024) addressed the role of synthetic fuels in Europe's climate-neutral future energy system. This study linked the JRC-EU-TIMES model to an hourly resolution power system model, thereby offering a detailed analysis of the interaction between electricity, hydrogen, and synthetic fuel demand. The results show that synthetic fuel production and hydrogen are essential for decarbonization, making up 15-32% of the total energy consumption

[63] https://pypsa-eur-sec.readthedocs.io/en/latest/
[64] https://e3modelling.com/modelling-tools/primes/
[65] https://data.jrc.ec.europa.eu/dataset/8141a398-41a8-42fa-81a4-5b825a51761b

in 2050 (including feedstock). The study also indicates that higher levels of indirect electrification – referring to electrolytic hydrogen and synthetic fuels - increase electrolyzer capacity factors by 8%, which, on the one hand, leads to reduced renewable energy curtailment, while, on the other hand, improves the system reliability.

Hydrogen plays a significant role in sector coupling by serving as a versatile energy carrier that links various sectors—such as power, industry, transportation, and heating—into an integrated energy system. It enables the conversion, storage, and transport of energy across these sectors, potentially allowing for greater flexibility and efficiency in energy use. Neumann et al. (Neumann et al., 2023) investigate the potential role of a hydrogen network in Europe. The paper highlights hydrogen's potential to decarbonize sectors that are difficult to electrify, such as heavy industry, long-haul transport, and parts of the heating sector. A hydrogen network with power2H_2 could facilitate the integration of renewable energy by absorbing excess renewable electricity to produce hydrogen, which can be stored and used when needed, reducing overall system costs. Kountouris et al. (2024) assess the emergence of hydrogen infrastructure connecting hydrogen import and domestic production centers with Western and Central European demands via four distinct hydrogen corridors from 1) Spain and France, 2) Ireland and the United Kingdom, 3) Italy, and 4) Southeastern Europe. The study states that a deep decarbonization of not only the power sector but also an advanced sector coupling through least-cost-optimal and no-regrets decisions is shown to result in the most significant emission reduction, as supported by He et al. (2021) which describes using hydrogen to lower the cost of energy system decarbonization through increased sector coupling. Namazifard et al. (Namazifard et al., 2024) assess the need for hydrogen infrastructure for industrial decarbonization in Belgium using Mixed Integer Linear Programming for hydrogen infrastructure design combined with the TIMES-BE investment model scenario results. Further research is foreseen to examine the development of a hydrogen network in the North-West European trilateral region (Belgium, the Netherlands, and North Rhine Westphalia, Germany).

4.3.2 Power2X in TIMES Belgium

The following paragraphs will provide a more detailed overview of P2X technologies that are included in the TIMES-BE model. Mostly, this reflects recent work as part of the ongoing ETF Procura project. The TIMES-BE model provides the option to synthesize a variety of synthetic gasses and fuels to be primarily used in the chemical and transport sectors. Figure 4.4 gives an overview of the molecules production routes that are available in the model. An overview of the different P2X options in the TIMES-BE model is provided in Table 4.3.

TIMES-BE includes a variety of processes describing electrolysis to produce hydrogen. It includes three types of electrolyzers, all available in a centralized large or medium capacity, and on-site (for the steel sector and ammonia production). In addition, an offshore electrolyzer technology is available, which is assumed to be of the Proton Exchange Membrane (PEM) type due to its relatively high flexibility. The offshore electrolyzer is assumed to have a 60% higher investment compared to the onshore alternative technology. Furthermore, the model includes the option to synthesize carbon-based molecules, such as e-methane, e-methanol and e-fuels. E-fuels production typically takes syngas as an input, which is represented in a single co-electrolysis process or as a synthesis from hydrogen and CO_2.

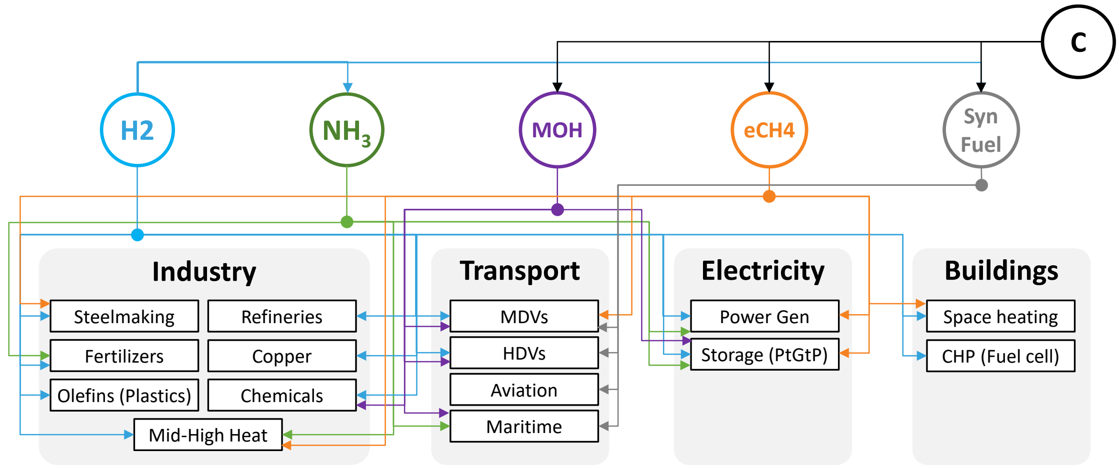

Figure 4.4 - TIMES-BE molecules production and end-use sectors

Table 4.3 – Main Power2X processes in TIMES-BE

Molecule	Process description
Hydrogen	Alkaline electrolyzer → medium size / large size / on-site
	PEM electrolyzer → medium size / large size / on-site
	Solid oxide electrolyzer → medium size / large size / on-site
	Offshore electrolyzer (PEM)
e-Ammonia	Ammonia synthesis → from H_2
e-Methanol	Methanol synthesis → from H_2 with ambient, biogenic or captured CO_2
e-Methane	Sabatier methanation → from H_2 and captured CO_2
e-Syngas	Co-electrolysis → from ambient or biogenic CO_2
	Hydrogen and CO_2 synthesis → from H_2 and ambient or biogenic CO_2
e-Fuels: kerosine, naptha, diesel, gasoline	Fischer-Tropsch process and conversions: → from e-Syngas → from e-Methanol (for gasoline only)

Power to Gas to Power (PtGtP) plays a significant role in the recent PATHS2050 scenarios. Hydrogen can be produced through electrolysis during periods of low electricity demand and converted back to electricity in a hydrogen turbine during periods of high demand. This coupling between the power and supply sectors, where hydrogen is produced, allows the hydrogen to act as a buffer in the energy system. This is illustrated in Figure 4.5 which shows the installed capacity and generation mix of the three PATHS scenarios. In the Central and Clean Molecules scenarios (but not in the Electrification scenario), hydrogen-based power plays a major role from 2040 onwards. The Clean Molecules Scenario thereby has the largest installed capacity of hydrogen turbines (5 GW in 2040 and 12 GW in 2050) due to the lower molecule import prices and more limited Carbon Capture and Storage potential. Consequently, the 2050 hydrogen demand in the Clean Molecules Scenario is covered by approximately 90% of imported hydrogen (91 TWh imported hydrogen and 14 TWh electrolytic hydrogen). Approximately 70% of this hydrogen demand goes to the power sector and the remaining part to the industry sector. The Central Scenario covers its 2050 hydrogen demand with 23 TWh of electrolytic hydrogen and 36 TWh of imported hydrogen. Approximately two-thirds of this hydrogen demand is consumed in the power sector, while one-third is used in the industry sector.

Figure 4.5 - Hydrogen power generation and installed capacity PATHS2050.

Viable electrolyzer operation requires a high number of operating hours at low electricity prices. The IEA (IEA, 2019) estimates that an electrolyzer should operate more than 4000 hours a year, equivalent to a utilization factor of 0.46, to reduce the impact of investment cost on the H2 production cost. The BREGILAB study (Correa-Laguna & Moglianesi, 2023) analyses the operating conditions of the electrolyzers in TIMES-BE. The study finds that in TIMES-BE, local centralized production with electrolyzers is already viable at an annual utilization factor of 0.20 in 2040 and 0.22 in 2050. These lower utilization factors impact the marginal system cost of hydrogen, which equals the import price during most hours of the year, with only limited hours of cheaper electricity-based hydrogen, as illustrated in Figure 4.6. The corresponding hydrogen production profile for 2050 (Figure 4.7) shows a strong correlation to solar production. This indicates P2H$_2$ competes with other flexibility sources like flexible EV charging (compare Figure 4.2). Analyzing how different demand-side flexibility options affect the business case of domestic hydrogen production is an interesting venue for further research.

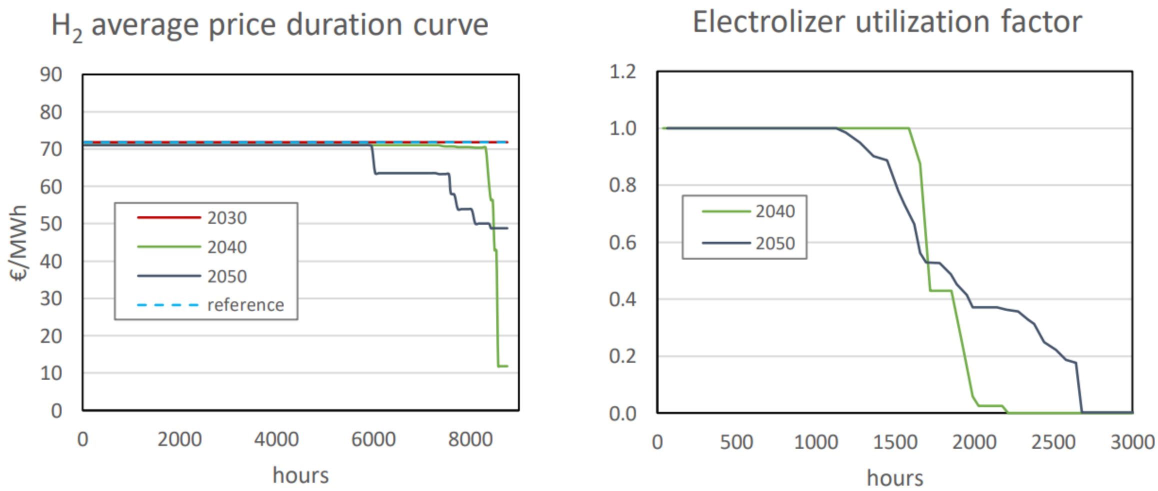

Figure 4.6 - H2 price (left) and electrolyzer utilization factor (right) for the TIMES-BE energy system from the BREGILAB study.

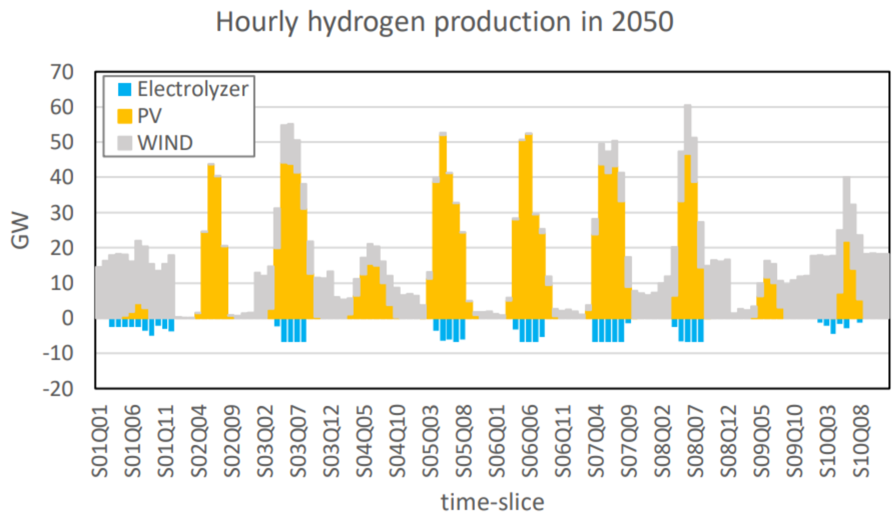

Figure 4.7 - Hourly solar and wind generation, and hydrogen production in 2050 in the TIMES-BE energy system from the BREGILAB study.

4.4 Community energy

Energy Communities are often recognized as a form of organization that could play a key role in the decarbonization of the energy system by enhancing decentralized RES investment and collective demand-side flexibility. Yet, they are frequently neglected in national level energy system modeling exercises or not represented with sufficient detail. This is primarily due to the challenges associated with accurately representing them in an energy system model (Barabino et al., 2023). In TIMES-BE, for example, rooftop solar PV generation can be consumed 'behind the meter' (i.e., within the sector the PV electricity was produced) or in any other sector. The latter requires transportation over low, medium and/or high voltage grids, which, however, are represented without spatial detail, i.e., as single processes operating at national level) characterized by a capacity cost, lifetime and efficiency. The model is thus incentivized to favor 'local' consumption (i.e., within the same sector of rooftop PV production) to minimize grid investment costs. However, this modelling approach does not represent potential grid benefits actual energy communities may generate. To analyze the role of local consumption and flexibility, Valkering et al. (2023) performed sensitivity analyses of an energy system model representing the residential and commercial sectors with EV charging. The sensitivity was analyzed of model results to variations of the share of the (residential or commercial sector) load that can be met 'behind the meter' (in the study expressed in terms of the 'Prosumer Potential'). Results indicate that this Prosumer Potential significantly affects cost-optimal investment levels of rooftop PV, also in relation to decentralized flexibility in the form of EV charging and battery storage. An interesting venue could be to expand sector coverage further, adding additional flexibility sources, and soft-linking with distribution grid models to better represent spatial heterogeneity of electricity grids.

5 Business Model Perspective

Various business models exist for the residential, community, and industry sectors. These focus on energy management and sustainability at large and may equally help to facilitate sector coupling specifically. In industry, business models emphasize on-site solutions such as electrification of processes to replace fossil fuels, use of electrolyzers and hydrogen services, energy storage, and P2X, all supporting efficiency, flexibility, and decarbonization efforts. In the residential sector, models like Energy as a Service (EaaS), peer-to-peer energy trading, virtual power plants, shared energy systems, vehicle-to-grid technologies, and Heat as a Service enable consumers to access energy services and contribute to decentralized energy networks. In communities, these models expand to collective approaches, including self-consumption, virtual power plants (VPPs), and larger-scale P2P trading, with the added use of Power-to-X technologies to convert and store energy. These models offer adaptable solutions to meet the unique needs of each sector.

Business models are made of key components, i.e., revenue streams, channels, value propositions, customer segments, etc. Therefore, when analyzing these business models, it is essential to define specific key components, drivers, and barriers that influence their success or failures. Drivers are the factors that enable the adoption of new business models, including political, regulatory, economic, and technological influences. On the other hand, barriers represent the challenges or obstacles—like regulatory uncertainty or high upfront costs—that may hinder the effective implementation of these models. Understanding and addressing these aspects is key to fostering successful business models that align with the overarching goals of sector coupling.

In industry, key factors such as resource pooling or technological innovation focus on the collaborative and technical capabilities (i.e. ability of different entities—such as companies, industries, or stakeholders—to work together in a coordinated way to achieve large-scale energy management and decarbonization) crucial for large-scale energy management and decarbonization. By contrast, in the residential sector, business model elements, such as revenue streams or customer segments focus on how individuals or smaller groups interact with business models, emphasizing the financial and customer-related dimensions of energy management solutions.

5.1 Industry

5.1.1 Key Business Model components

The industrial sector currently operates with several business models aimed at decarbonization, efficiency, and flexibility. These include Energy as a Service, which allows industries to outsource their energy needs, on-site electrolyzers for hydrogen production; hydrogen as a service to enable industries to adopt hydrogen without upfront investment; and energy storage as a service for flexible energy management.

In addition to these models, electrification of industrial processes is increasingly recognized as a core strategy for decarbonization. Wherever feasible, industries are replacing fossil-fuel-based processes with electric alternatives to enhance energy efficiency and utilize renewable electricity sources. Electrification, especially in energy-intensive sectors like steel and chemicals, offers significant emissions reductions. For example, in steel production, hydrogen can replace traditional carbon-based processes, enabling the transition to green steel (Material Economics, 2019).

For processes that are harder to electrify due to technical limitations—such as high-temperature processes—industries are adopting alternative solutions like green hydrogen and Power-to-X technologies. Hydrogen, produced via electrolysis using renewable energy, can substitute fossil fuels in sectors with high energy demands. On-site electrolyzers integrated into business models enable efficient, low-carbon hydrogen production tailored to facility-specific needs (IEA, 2023). For example, chemical plants can leverage this approach for cleaner energy use.

The business models outlined for the industry sector, such as energy as a service (EaaS), on-site electrolyzers, hydrogen as a service, and energy storage, apply differently depending on the energy intensity of the industry. For energy-intensive industries like steel and chemicals, these business models are important for large-scale decarbonization efforts, as they rely heavily on energy and can significantly benefit from innovations like P2X and hydrogen technologies to reduce carbon emissions and enhance energy efficiency. For example, in steel production, hydrogen can replace traditional carbon-based processes, enabling the transition to green steel. At the same time, chemical plants might use on-site electrolyzers to generate hydrogen for cleaner energy use. In contrast, less energy-intensive industries (i.e., SMEs) may not require large-scale energy solutions like electrolyzers or extensive hydrogen infrastructure. Instead, they are more likely to adopt models like electricity as a service, or energy storage as a service, which offer more flexible and scalable energy management options tailored to their lower energy consumption. The principles of these business models remain the same, but their implementation will vary according to the energy demands and financial capacity of each industry type.

In this context, process flexibility becomes a key component of successful industrial business models. Flexibility enables industries to dynamically adjust to fluctuations in energy availability, particularly with renewable energy integration. Flexible processes allow industries to shift energy consumption patterns or switch between energy sources depending on availability and pricing (Silvestre Bengoa, 2018). This flexibility is essential for optimizing energy use, enhancing operational resilience, and supporting decarbonization goals (Hamwi et al., 2021).

Several key components shape successful business models in the industrial sector. One critical component is resource pooling, where industry stakeholders collaborate by sharing financial capital, technology, and human resources. This collective approach fosters cost savings, shared expertise, and enhanced innovation capacity, which are essential for maintaining competitiveness in a rapidly evolving market (Urban et al., 2024; Wiegner et al., 2024).

Technological innovation is another important key component. Industries must continually adopt and integrate new technologies to remain competitive. This involves the development and implementation of cutting-edge solutions that can improve operational efficiency, reduce costs, and support broader sustainability goals. The importance of technological innovation is evident in the ongoing advancements that allow industries to adapt to changing market conditions and regulatory demands (Michaelis et al., 2024; Prina et al., 2023). Moreover, *profit and risk sharing* among stakeholders is crucial for the long-term success of industrial ventures. Effective business models align incentives across the supply chain, ensuring that all parties involved benefit from cooperation. This alignment is particularly important in complex industries where risks and rewards need to be distributed fairly to encourage collaboration and sustained investment (Giehl et al., 2023). Finally, customer awareness and demand play a critical role in driving industrial business models. For industrial businesses, understanding and influencing customer demand requires robust awareness campaigns and strategies to promote sustainable and innovative solutions. The alignment of business models with sustainability targets is becoming increasingly critical, helping industries meet regulatory requirements while enhancing reputation and long-term viability (Bogdanov et al., 2021; Victoria et al., 2021)

5.1.2 Key Business Model Drivers

Several key drivers influence the development and implementation of business models in the industry sector. *Political and regulatory drivers* are particularly influential, as government policies and regulations shape the environment in which industries operate. Supportive legislation, subsidies, and incentives can significantly drive innovation and sustainability efforts, helping industries transition towards more sustainable practices (Aalto et al., 2021; Vanhanen et al., 2023). *Economic and market conditions* also play a fundamental role as drivers of business models. Factors such as market demand, competition, and the availability of resources influence business strategies and decisions related to investment in new technologies. Economic conditions often dictate the pace at which industries can innovate and adopt new business models (Araújo et al., 2024).

Technological innovations provide ongoing opportunities for industries to innovate and optimize their business models. The adoption of digital tools, automation, and sustainable technologies is crucial for maintaining competitiveness and meeting the demands of an increasingly digital and environmentally conscious market (Osorio-Aravena et al., 2023; Song et al., 2023).

Furthermore, collaborative networks are essential for enhancing resource pooling, innovation, and market reach. Partnerships between industry players, academic institutions, government bodies, and other stakeholders can drive significant advancements in business models. These collaborations enable industries to leverage collective expertise and resources, leading to more robust and innovative solutions (Trencher et al., 2021).

5.1.3 Key Barriers to Business Model Implementation

Despite the drivers, several barriers can impede the successful implementation of business models in the industry sector. One significant barrier is the silo mentality that can prevail within organizations. This mindset hinders resource sharing and collaboration, making it difficult to implement integrated business models that require cross-functional cooperation (Wiegner et al., 2024). Another challenge is the *misalignment of value propositions* among different stakeholders, which is similar to silo mentality and lack of collaboration. When the goals and incentives of stakeholders do not align, it becomes challenging to foster effective collaboration and risk-sharing, which are essential for the success of complex industrial projects (Giehl et al., 2023). High initial costs associated with adopting new technologies and business models present another formidable barrier. Many industries struggle to secure the necessary capital for these investments, which can slow down the pace of innovation and adoption of new, more sustainable practices (Prina et al., 2023). Finally, regulatory and market uncertainty can create significant risks, deterring investment and making long-term planning difficult (Aalto et al., 2021)

5.2 Residential sector

5.2.1 Key Business model components

The residential sector currently employs a variety of business models, with a strong focus on consumer-centric and decentralized energy solutions. These models include Energy as a Service (EaaS), which provides households with flexible, outsourced energy solutions, peer-to-peer energy trading where residents can buy and sell energy with each other, virtual power plants that aggregate distributed energy resources, and vehicle-to-grid systems that allow electric vehicles to supply energy back to the grid.

In the residential context, business models increasingly focus on consumer-centric approaches and the integration of sustainable energy solutions. One significant component is the development of consumer-centric electricity markets, which are designed to meet the specific needs and preferences of residential consumers. These markets emphasize flexibility, affordability, and accessibility, giving consumers greater control over their energy usage and costs while fostering engagement in sustainable energy practices (Michaelis et al., 2024).

Additionally, the deployment of solar photovoltaics has become a key component within residential settings. The advancements in PV technology, coupled with its decreasing costs, make it a viable option for residential energy supply, contributing to the energy independence of households and supporting the broader goals of energy sustainability (Vanhanen et al., 2023; Victoria et al., 2021)

In addition to the aforementioned business models, the electrification of heating is becoming a critical component in residential energy solutions, particularly in Belgium, where there is a strong focus on replacing natural gas-based heating systems with electric alternatives. This shift is driven by the need to reduce carbon emissions and align with the country's long-term sustainability goals, as outlined in Belgium's National Energy and Climate Plan (European Commission, 2023)

The transition to electric heating systems, such as heat pumps, is a significant step towards decarbonizing the residential sector. Heat pumps are being promoted for their high efficiency and ability to integrate with renewable energy sources like solar PV. This transition is aligned with Belgium's broader strategy to reduce reliance on natural gas and contribute to achieving its climate targets (Bellahcene & Dan Stefanica, 2022). The move towards electrification also opens opportunities for demand response programs, where households with electric heating systems can help balance the grid during peak periods, enhancing both flexibility and sustainability in the residential energy market (IEA, 2022).

5.2.2 Key Business Model Drivers

The main drivers in residential business models are technological advancements and economic factors. Solar photovoltaics, for example, have become a game-changer in residential energy systems due to their cost-effectiveness and scalability (Victoria et al., 2021). Economic drivers, such as the rise of local energy markets and energy communities, enable consumers to manage their energy resources collectively (Kubli & Puranik, 2023; Maldet et al., 2023).

In regions where energy demand and supply fluctuate significantly, large-scale electricity storage can stabilize the energy grid and provide backup power during peak periods. This technology is particularly relevant in the context of transitioning residential areas to carbon-neutral energy systems, as seen in the insights gained from Germany's energy transition efforts (Xie et al., 2023).

Another important driver in residential business models is the policy shift towards electrifying heating **systems** in Belgium. The country's NECP outlines the goal to phase out gas-based heating in favor of electric alternatives, with heat pumps being a cornerstone of this transition. Economic incentives, such as subsidies for the installation of heat pumps and energy efficiency measures, are encouraging consumers to move away from gas-based heating, particularly in new builds and deep retrofits (Bellahcene & Dan Stefanica, 2022). This shift is supported by the integration of renewable energy sources, such as solar power, which can supply electricity for heating, reducing overall household energy consumption and carbon emissions (European Commission, 2023).

5.2.3 Key Barriers to Business Model Implementation

While the replacement of gas with electric heating systems is a viable pathway for reducing emissions, several barriers must be addressed. The upfront cost of installing electric heating systems, such as heat pumps, can be prohibitive for many households, even with subsidies and incentives (IEA, 2022). Additionally, the challenge of retrofitting existing buildings, especially older homes that may not be well-suited for electric heating systems, could slow down the transition. Moreover, grid infrastructure will need upgrades to handle the increased demand for electricity during winter months when heating demand is high, adding complexity to this transition. Finally, public awareness and acceptance of electric heating alternatives are critical to ensuring a smooth transition from gas to electricity.

Despite these drivers, several barriers can hinder the successful implementation of business models in the residential sector. One major barrier is the complexity of integrating multiple energy systems, which can lead to significant operational challenges. Ensuring the reliability and stability of energy supply during peak demand periods is a critical concern that needs to be addressed in the residential sector, especially with the increasing integration of decentralized energy systems like solar PV and electric heating solutions. (Monsberger et al., 2023). Another significant barrier is the high initial investment required for implementing advanced energy systems, particularly those involving sector coupling and the integration of renewable energy. Securing sufficient funding can be a challenge for residential communities, slowing the adoption of these innovative models (Javanshir et al., 2023). Regulatory uncertainty remains a significant obstacle. While there is growing support for sustainable energy initiatives, inconsistent regulations can create uncertainty for both investors and consumers. This uncertainty can deter the implementation of ambitious projects aimed at transforming residential energy systems, potentially slowing progress toward sustainability goals (Bogdanov et al., 2021).

5.3 Energy communities and districts

5.3.1 Key Business model components

The business models emerging for energy communities and districts focus on collective energy management and self-sufficiency. Models like community energy projects, which involve local energy generation and sharing, virtual power plants, which connect decentralized energy resources, and positive energy districts that aim to produce more energy than they consume, are leading examples of how communities can manage energy collectively.

Several key components are essential for the success of energy communities. One critical factor is the development of consumer-centric electricity markets tailored to community needs (Michaelis et al., 2024). Another component is the integration of sector coupling, allowing for optimized energy distribution across electricity, heating, and transportation sectors (Prina et al., 2023)

In addition to these key components, the integration of innovative energy sources and technologies specific to energy communities plays an important role. For instance, the use of photovoltaic systems, , electric vehicles, and thermal systems, combined with smart grid technologies, can significantly improve energy management within these communities: in other words, enhance the ability of energy communities to efficiently manage their energy generation, distribution, and consumption by integrating advanced technologies like photovoltaic systems, electric vehicles, thermal systems, and smart grids These energy sources are not only environmentally sustainable but also contribute to the economic viability of energy communities by reducing dependency on external energy supplies (Maruf et al., 2023).

5.3.2 Key Business Model Drivers

The development and success of business models in energy communities and districts are driven by several factors. Technological advancements are a primary driver, particularly in integrating renewable energy sources and sector coupling technologies. These advancements allow communities to harness local energy resources efficiently, reducing reliance on external energy supplies and enhancing sustainability (Maldet et al., 2023).

Economic incentives also play a crucial role as a driver. The economic benefits of local energy markets and energy communities are significant, particularly when communities can collectively manage and optimize their energy resources. This collective approach often leads to cost savings and greater energy security, which are compelling reasons for communities to adopt new business models. Government policies and financial incentives further support the development of these models by encouraging the adoption of renewable energy technologies and fostering the growth of energy communities (Kubli & Puranik, 2023).

Furthermore, the concept of positive energy districts is increasingly recognized as a key component. These districts are designed to produce more energy than they consume, leveraging advanced technologies like renewable energy sources, smart grids, and energy storage systems. The creation of positive energy districts requires strong collaboration between local authorities, energy operators, and community members, emphasizing the importance of integrated planning and community engagement (Vanhanen et al., 2023)).

Additionally, the role of participation and sensemaking within communities is a critical driver. Ensuring that community members are engaged in the decision-making process and understand the benefits of energy transition technologies is essential for the successful implementation of business models. Participation not only boosts the acceptance of new technologies but also empowers community members to take an active role in managing their energy consumption (Lucas-Healey et al., 2024).

5.3.3 Key Barriers to Business Model Implementation

Despite the numerous drivers, several barriers can impede the successful implementation of business models in energy communities and districts. One significant barrier is the complexity of integrating multiple energy systems within a community. This complexity can lead to operational challenges, particularly in maintaining the reliability and stability of energy supply across different sectors (Wiegner et al., 2024).

Another barrier is the high initial costs associated with establishing advanced energy systems. Implementing technologies like smart grids, renewable energy infrastructure, and energy storage solutions requires substantial investment, which can deter some communities. Securing the necessary funding and financial support is often a major challenge that can slow down the adoption of these innovative models (Araújo et al., 2024).

Regulatory uncertainty also remains a significant obstacle. Inconsistent regulations and policies can create confusion and risk for communities attempting to implement new business models. This uncertainty can deter investment and delay the adoption of advanced energy solutions, making it more difficult for communities to achieve their sustainability goals (Bogdanov et al., 2021).

6 Market design perspective

To achieve climate goals and secure energy supply, while keeping energy affordable for consumers, efficient markets that provide adequate investment signals and properly reflect the costs of the different energy vectors are needed. In this regard, energy markets are structured systems where energy vectors (such as electricity, gas, heat, and hydrogen) are sold and bought. There are several types of energy markets with different purposes and operating at various stages of the energy supply chain (e.g., wholesale, retail). Currently, each energy vector is traded under distinct market mechanisms, which are tailored to the specific characteristics of the vector. A detailed description of the current market organization of each energy vector, with a focus on wholesale markets, is provided in this section.

6.1 Electricity

In the pre-liberalization period, the electricity sector in Europe was vertically integrated, with state-owned companies performing most of the activities within the electricity supply chain (i.e., generation, transmission, and distribution). A set of liberalization reforms was adopted in Europe starting in 1996 to introduce competition into the electricity market (Ciucci, 2024). These reforms transformed the sector, for example, by creating a competitive wholesale electricity market, unbundling vertically integrated activities, and opening national markets to cross-border trading.

Electricity can be traded in the form of bilateral contracts or through trading in the wholesale market. The European wholesale electricity market comprises multiple temporal stages, including the forward, day-ahead, intraday, and balancing markets. Figure 6.1 illustrates the typical temporal organization of European electricity markets. Years to two days before delivery, the forward market allows market participants to hedge the risk against future short-term price fluctuations (ACER, 2023). In the short-term, electricity is traded one day before delivery in the day-ahead market (i.e., an hourly auction-based mechanism), where, in the simplest cases, market participants submit their price-quantity bids for each operating hour of the next day. In the intraday market, market participants are allowed to modify their day-ahead commitments either through continuous bilateral trades or auction-based mechanisms. The TSO procures balancing capacity and energy to correct any imbalances between supply and demand. Depending on market regulations, reserve capacity is procured from years or hours in advance (Papavasiliou et al., n.d.). In fact, European markets have largely moved towards day-ahead capacity procurement for balancing reserves with the establishment of European balancing market platforms (ACER, 2024b). Right before delivery time, the balancing energy market takes place, where the TSO activates energy reserves for different balancing products (e.g., frequency containment reserve (FCR), automatic frequency restoration reserve (aFRR), and manual frequency restoration reserve (mFRR) (*Electricity Balancing - Entsoe*, n.d.)). After electricity delivery, the imbalances caused by Balance Responsible Parties (BRPs), which are responsible for the balance at each access point to the grid, are remunerated or penalized depending on their individual imbalance and their imbalance position compared to the system imbalance.

The aforementioned electricity market aims to efficiently allocate electricity resources across member states. For this purpose, the Agency for the Cooperation of Energy Regulators[66] (ACER) and the national regulatory authorities (e.g., the CREG in Belgium) regulate the operation and support the integration of EU national markets. Moreover, the European Network of Transmission System Operators for Electricity (ENTSO-E) and the transmission system operators (e.g., Elia for Belgium) facilitate cross-border trading and ensure a secure and optimal functioning of the interconnected electricity markets (ENTSOE, 2024).

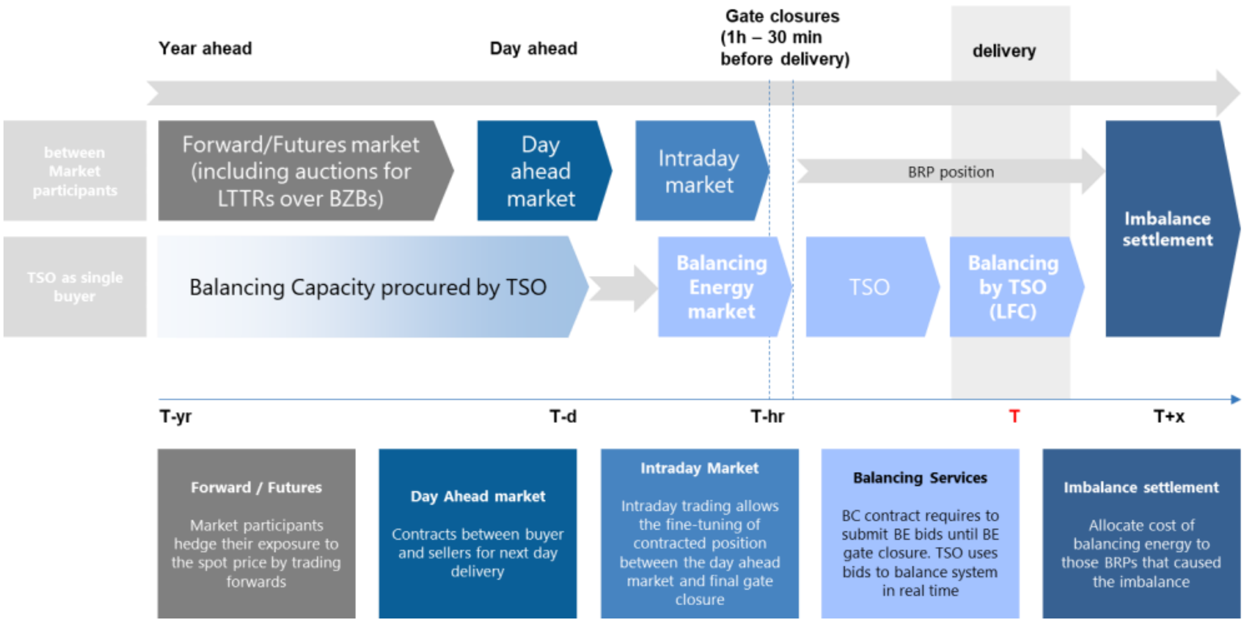

Figure 6.1 Temporal stages of European electricity markets (ACER, 2024c)

6.2 Gas

Similar to the electricity market, the gas market has gone through a liberalization process starting in the late 90s. With the goal of establishing a competitive single natural gas market in Europe, the first gas directive was adopted by the European Parliament in 1998 (Haase, 2008), in a market where prices were determined by long-term contracts indexed to oil prices (Zeniewski, 2021).

[66] https://www.acer.europa.eu/the-agency/our-mission

Gas trading includes physical transactions (i.e., buying and selling actual gas volumes) and financial transactions (i.e., trading of derivatives and futures), and it is performed over-the-counter and on market exchanges such as the European Energy Exchange (EEX) (EEX, 2024b). The European gas market is characterized by an interconnected network of trading hubs such as the Dutch Title Transfer Facility (TTF), the British National Balancing Point (NBP), and the Trading Hub Europe (THE). In Belgium, the Zeebrugge Trading Point (ZTP) is the virtual gas trading point which has been operated since 2012 by Fluxys.

Similar to the electricity market, gas can be traded for near-term delivery in the spot market. However, a significant proportion of trading takes place using derivatives, which includes a wide range of timeframes and contracts (e.g., futures, options). Gas futures are agreements to deliver/buy gas at a certain hub at a certain future time for an agreed price. On the other hand, options give the holder the right (not the obligation) to buy or sell the agreed volume at a certain future date at a pre-agreed price (ICE, 2022).

The European gas market operates under the guidance and regulation of ACER and the national regulatory authorities, which are responsible for gas market monitoring (ACER, 2024a). Moreover, the European Network of Transmission System Operators for Gas (ENTSOG) coordinates cross-border gas flows, develops network codes and defines network development plans (ENTSOG, 2024).

6.3 Heat

Contrary to the electricity and gas markets, the market for heat is less homogeneous and has not been liberalized (since there are too few producers to have an actual heating market with competition (Varmelast, 2024)). Heat trading, which takes place through district heating networks, is predominantly local, with considerable differences across European countries. In countries like Denmark and Sweden, district heating systems are well-developed and play a vital role in meeting heating demands (Directorate-General for Energy, 2022). However, in countries like Belgium, less than 1% of the residential demand is met through district heating networks (VEKA, 2021; VREG, 2023).

In countries with highly developed district heating networks, where predominant models of ownership are cooperative ownership in rural areas and municipal ownership in urban areas (Johansen & Werner, 2022), prices are highly regulated, and regional authorities choose suppliers based on socio-economic benefits (Vad Mathiesen & Petersen, 2018). In most cases, heat trading takes place through long-term contracts between heat producers and consumers where supply volumes, prices, and quality standards are defined. However, in cities like Copenhagen, the transmission companies optimize and operate the heat production plan from various providers (e.g., CHP plants, waste incinerators, peak boilers, etc.) to meet the heating demand with a day-ahead dispatch plan for the subsequent two days and an intraday plan (Vad Mathiesen & Petersen, 2018). The cost of heat depends on fuel prices, capacity and efficiency of the plants, OPEX, energy and CO2 taxes, income from the power market and production subsidies.

The regulation of heat markets is largely diverse across the continent, with limited overarching EU-level directives. National regulations defined by national and regional authorities (e.g., The Flemish Energy Agency in Belgium) regulate the operation of the district heating network by focusing, for example, on tariff setting, consumer protection, and promoting the use of renewable energy sources in heating (Directorate-General for Energy, 2022).

6.4 Hydrogen

The hydrogen market in Europe is still in its very initial stage, but it is rapidly evolving with significant policy support (EC, 2020a). Currently, hydrogen trading is limited and primarily occurs through bilateral agreements. However, as part of the transformation of the energy sector, the European Commission has established a common framework to support the creation of hydrogen markets in the EU. More specifically, Directive (2024/1788)[67] lays out a set of rules aimed at facilitating the emergence of markets for hydrogen, commodity-based hydrogen trading and liquid trading hubs. This directive is aligned with the EU Hydrogen Strategy (EC, 2020a), which advocates for a unified and competitive internal hydrogen market, where cross-border trade flows freely. This strategy is expected to enhance competition, lower costs, and bolster energy security across the EU. Additionally, the strategy highlights the importance of developing a liquid market characterized by commodity-based hydrogen trading, which would not only facilitate the entrance of new producers but also promote closer integration with other energy sectors. In this regard, as the market matures, it is expected that trading mechanisms will evolve to include exchanges and standardized contracts, with efforts already underway by, for example, the European Energy Exchange (EEX, 2024a).

[67] https://eur-lex.europa.eu/eli/dir/2024/1788/oj/eng

7 Sector-coupling implementation barriers

This chapter reviews sector coupling implementation barriers derived from literature reporting on common EU-level barriers, from practical experiences in the ReInvent test cases, and from further literature describing barriers specifically related to energy markets and business models.

7.1 Common barriers to the roll-out of sector-coupling

For implementing sector coupling, different types of barriers currently exist. Even though barriers often touch upon different domains, these are commonly categorized as technical, economic/financial, legislative/regulatory, and social (or ‘societal’) barriers. A recent study (Trinomics. et al., 2024) on the status of energy system integration at the EU-level provided an inventory of main barriers to sector coupling implementation, both for electrification and decentralized renewables, as well as hydrogen uptake[68] (see Table 7.1 for an overview). Main barriers to electrification and decentralized renewables, include (amongst others) inadequate grid connection capacity, high upfront and operational costs, delays in the national transpositions of the EU’s electricity market design, and still a lack of professionals (e.g., installers) for electricity-based appliances. These findings are in line with (Borragán et al., 2024) that show that for consumers, specific technology attributes and costs are common adoption barriers across electrification technologies such as electric vehicles, photovoltaics, heat pumps, home batteries, and smart appliances. For hydrogen-related projects, it remains challenging to reach bankability, while complex permitting, and lack of social acceptance related to toxicity and safety are among other barriers being faced. A main barrier to hydrogen investment is uncertainty across the value chain. For example, to make hydrogen supply projects viable requires binding off-take agreements, which, however, are still largely lacking (Marcu et al., 2024).

Specifically for the implementation of RECs and CECs, significant challenges remain. These include regulatory barriers, difficulties in accessing financing, issues with grid integration, and the inherent complexity of establishing energy communities. However, these challenges are counterbalanced by substantial opportunities. Increasing public awareness, improved regulatory support, technological advancements, and a growing interest in sustainable energy offer promising prospects for the expansion of RECs and CECs across Europe (Yiasoumas et al., 2023).

[68] The study additionally addresses waste heat utilization.

Table 7.1 – Main barriers for energy system integration at the EU-level for electrification and decentralized renewables and the uptake of hydrogen. Source: (Trinomics. et al., 2024)

	Electrification and decentralised renewables	**Uptake of hydrogen**
Technical	• Insufficient distribution network expansion and reinforcement • Delays in the rollout of smart metering equipment • Insufficient digitalisation at distribution level • Delays in grid connection and permitting	• Insufficient manufacturing capacities for electrolysers
Economic and financial	• Upfront costs for equipment and installation • Operational costs for electrical equipment	• Cost gap of renewable and low-carbon H2 towards costs of fossil-based hydrogen • Complex use of additional revenue streams, such as balancing market services • Reaching bankability for hydrogen related projects • Competition from non-EU sources of hydrogen • Lack of H2 transportation and storage infrastructure
Legislative and regulatory	• Adjusting regulation at national level	• Missing international regulation and import policy • Long, complex, unstandardized permitting processes for RES and H2 projects • Lack of a skilled workforce e.g. for H2 project management and H2 project permitting
Societal	• Lack of professional experience and skills • Lack of consumer awareness and/or knowledge	• Lacking acceptance of derivatives of hydrogen such as ammonia (high toxicity) or methanol and safety issues

7.2 Barriers for Test Cases

For the ReInvent Test Cases, which represent the main use cases of sector coupling and integration and will be analyzed as part of the project, specific barriers are at play. An inventory of barriers was made based on a survey collecting written input from the test case owners on the main perceived barriers within different categories. An overview is given in Figure 7.1[69]. Main technological barriers included technology development and, to a lesser extent, issues with data, monitoring and connectivity. Optimization – i.e., finding an optimal sizing of assets – is relevant to at least two test cases and could potentially be addressed with energy modelling. For economic and financial barriers, three topics stand-out equally: upfront investment costs, limited competitiveness, for example, due to novel technology, and financial risks due to uncertain revenues and investment costs. Market & regulatory barriers reveal commonly recognized barriers related to permitting and taxation, as well as inadequate subsidies that focus on hardware, whereas they should better focus on flexibility based on services. One test case specifically mentioned unclear market valuation of CO_2 reductions as a barrier. Social & organizational barriers are equally divided among perceptions (safety, fairness), time availability, complex collective decision-making, and lack of Willingness (or possibility) to Pay. The latter concerns, for example, infeasibility for low-income groups to pay for EV sharing community membership fees.

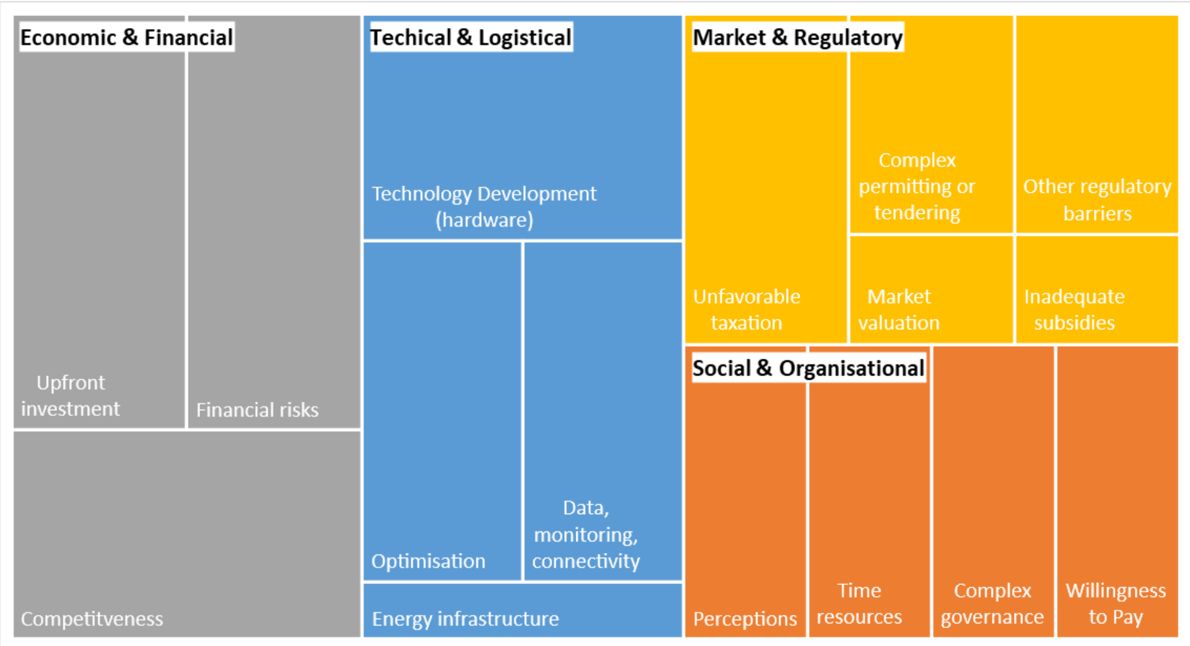

Figure 7.1 - Overview of barriers for Test Cases. A total of 40 barriers were collected, further sub-divided over the categories and sub-categories displayed in the figure.

7.3 Barriers to viable business models

From the perspective of business models, the literature described in Chapter 5 suggests that economic & financial barriers stand out. High initial costs, such as those associated with PV systems and energy storage,

[69] A spreadsheet with a full overview of collected barriers is available on demand.

often require substantial upfront investment, which is a particular challenge for residential and community projects. Regulatory and market uncertainty, including inconsistent regulations, lack of supportive policies, and market unpredictability, can lead to financial risks hindering long-term investments across all sectors. The complexity of integrating multiple energy systems—such as electricity, heating, cooling, and transportation—presents both technical and operational challenges, which are equally apparent in Figure 7.1. Additional barriers can be found as well. For example, silo mentality and lack of collaboration, particularly in industrial and community contexts where sectors or departments operate independently without coordination, further hinder the implementation of integrated business models. Misalignment of stakeholder incentives, where goals and incentives between energy producers, consumers, and regulators do not align, creates challenges for effective cooperation.

Consumer awareness and engagement also remain problematic, as many consumers are either unaware of sector coupling technologies or not fully engaged in decarbonization, leading to delayed adoption of energy-efficiency measures. The technological interoperability of sector coupling technologies, such as P2X, smart grids, and hydrogen infrastructure, is still evolving, with the lack of mature and standardized systems posing challenges to scalability and widespread adoption. Resistance to change and legacy systems also presents a barrier, as industries and communities using older technologies may resist adopting new systems due to disruption, retraining needs, and uncertainty. Finally, scaling and replicability of sector coupling models from small pilot projects to broader applications is often challenging due to varying local conditions and resource availability.

The test case barriers reflected in the diagram align with several themes found in the literature, though with some differences in emphasis. Similar to the literature, economic and financial barriers, such as upfront investment costs and financial risks, are consistent challenges across sectors. Likewise, technical and logistical issues, like technology development, optimization, and infrastructure, echo the literature's focus on integration and interoperability of energy systems. However, the test cases emphasize data, monitoring, and connectivity challenges more specifically, highlighting the practical difficulties of real-time energy management, which are less explicitly addressed in the literature. On the market and regulatory side, both the literature and test cases identify complex permitting, unfavorable taxation, and inadequate subsidies as significant obstacles, but the test cases also give more attention to market valuation and how it impacts sector coupling adoption. Lastly, the social and organizational barriers found in both the test cases and literature, such as perceptions, governance complexities, and willingness to pay, show that cultural and organizational challenges remain critical in energy transition efforts. However, the test cases place greater emphasis on the availability of time and resources, which is less frequently highlighted in theoretical models but emerges as a crucial factor in practice.

7.4 Barriers related to energy market design

In the EU Strategy for Energy System Integration (EC, 2020b), it is emphasized that, to grasp the full benefits of a more integrated energy system, efficient markets should be developed. These efficient markets should result in correct pricing that properly reflects the cost of different energy carriers, which would guide customers towards the economically most-viable investments. There are, however, still many barriers which hamper the establishment of efficient markets.

One of the barriers mentioned in the EU Strategy for Energy System integration and (Trinomics. et al., 2024) is that taxes and levies on electricity are generally higher in EU Member States compared to those on other energy carriers like gas, and these charges on electricity have been steadily increasing. This has led to an asymmetry in non-energy costs between electricity and gas. When taxes and levies are not applied uniformly across energy carriers and sectors, it can result in distortions that favor the use of specific energy carriers over others.

The Magnitude project (Belhomme et al., 2021) also found that, although non-discriminatory market access is one of the main EU principles, in practice, there are still unfavorable conditions in market and service procurement mechanism designs which limit or prevent energy trading and/or the provision of flexibility by conversion technologies in several energy and system service markets or mechanisms. This could be restrictions linked to aggregation, min bid sizes, exclusivity clauses, or the type of remuneration for service delivery, etc.

The EU Strategy for Energy System integration also touches upon the need to reassess the gas market, i.e., to integrate the adoption of renewable gases and enhance customer empowerment, while maintaining an integrated, liquid, and interoperable internal gas market across the EU. This development is still in its infancy. The OneNet project (Gandhi et al., 2023) also stresses the lack of alignment and coordination of markets of different carriers as an important barrier. Markets for different energy carriers are typically organized in isolation, with limited attention to potential synergies, such as aligning market timings. This creates challenges for conversion technologies, as their market revenues depend on the accuracy of price forecasts for both input and output carriers. Without proper coordination between these markets, such technologies face significant forecasting risks, which can lead to profit losses or even market outcomes that are technically unfeasible. This key market barrier is thoroughly addressed in the ReInvent project, where innovative multicarrier wholesale market models are investigated to explore solutions that improve coordination between different energy markets. These efforts contribute to creating a more integrated and efficient energy system, fostering synergies between various energy carriers, and ultimately supporting the transition to a decarbonized energy system in Belgium.

8 Conclusions and outlook

This final chapter provides an outlook for ReInvent research on sector coupling concepts, modeling and impact analysis, and concludes with a reflection on how the identified barriers are addressed.

8.1 Novel integrated market design for Belgium

Work package 1 will elaborate different innovative concepts that would lead to improved sector coupling. This work package will study how the market design of different energy carriers needs to be adapted, work out archetypes of innovative multi-sector business models, and assess different financial models considering improved risk management.

8.1.1 Towards new market designs for a sector-coupled energy system

The markets described in Chapter 6 —electricity, gas, heat, and hydrogen—currently operate independently, each with its own regulation and market mechanisms. However, interactions between these markets do occur and have significant implications. For instance, gas prices affect the bid price of gas-fired power plants participating in the electricity market, while electricity prices influence the supply costs of heat pumps in district heat networks. Sector coupling would significantly improve the overall efficiency of the energy system by supporting an efficient allocation of resources across these different energy vectors. Additionally, a more integrated setup diversifies energy sources, which enhances energy security and leads to significant economic benefits for society.

In this context, the ReInvent project will investigate several new market designs for a sector-coupled energy system. These novel designs will explore different levels of market integration:

- Isolated Markets: This baseline level represents the current setup, where each market operates independently and is cleared sequentially.
- Coordinated Markets: In this structure, markets are still cleared by independent operators in sequence but with shared information to optimize the interaction between different energy vectors.
- Fully Integrated Markets: At this level, markets for different energy vectors are cleared simultaneously by a central market operator. This approach involves a single optimization problem aimed at maximizing the socio-economic welfare of the integrated energy system.

Additionally, the project will consider multiple temporal stages of the electricity market to enhance the benefits of integrating the electricity market with other energy vectors. This integration is expected to provide flexibility to the electricity market, optimizing resource allocation and improving system efficiency compared to the current independent operation. Hence, it is expected to address implementation barriers related to investment and financial risk.

8.1.2 Towards new multi sector business models

New business models offer several ways to address the barriers to adopting sector coupling technologies (see Table 8.1). One key barrier, high initial costs, can be mitigated through models like Energy as a Service or shared ownership approaches, where financial burdens are either transferred to service providers or spread across multiple users. In the face of regulatory and market uncertainty, adaptable business models focused on flexibility, such as modular energy systems, can provide a hedge against unpredictable policy changes. Public-private partnerships could also be formed to push for consistent, long-term policy frameworks that support sector coupling.

To overcome the complex process of integrating multiple energy systems, integrated platforms or services could simplify energy management, where service providers manage the technical aspects, allowing users to benefit without needing in-depth technical knowledge. Cross-sectoral collaboration models can help break down the silo mentality often seen in industrial and community settings by fostering cooperation between different sectors, such as electricity, heating, and transportation. These partnerships can be further incentivized through shared innovation funds or joint carbon credits that align the goals of various stakeholders.

Business models that tie rewards to outcomes, such as performance-based financing, can realign misaligned stakeholder incentives. This can create mutual benefits, for example by rewarding industries for energy savings and offering consumers financial incentives for participating in energy flexibility programs. Meanwhile, consumer awareness and engagement can be enhanced through the use of personalized energy services and gamified platforms that encourage active participation in energy-saving efforts. Smart meters and data-driven recommendations could help consumers understand and manage their energy consumption, making sector coupling technologies more accessible.

To address the issue of technological interoperability, new models can push for open-source platforms and standardization consortia that foster compatibility across various technologies like Power-to-X (P2X) and smart grids. Encouraging open data-sharing standards can facilitate smoother integration of diverse systems into existing energy networks. Funding and investment challenges can be addressed through green financing mechanisms such as green bonds, sustainability-linked loans, and crowdfunding for community energy projects. Pooling funds across small projects could attract institutional investors, making funding more accessible.

Resistance to change, particularly within industries reliant on legacy systems, could be reduced by introducing transition services, including retraining programs and technical support. Hybrid models that integrate new sector coupling technologies alongside existing systems can ease the transition, minimizing disruptions. To tackle the scaling and replicability issues, business models could focus on scalability by design, utilizing modular or standardized technologies that can be adapted to different regions and sectors. Franchise-style models for community energy projects could accelerate the replication of successful pilot initiatives, offering a blueprint that can be adapted to local conditions.

Business models will be developed within the ReInvent project, tailored to the specific needs of target groups—residents, communities, and industry—by customizing key components like value propositions, customer segments, and revenue streams. The goal is to create models that address each group's unique preferences while considering legal, technical, and market-specific factors. For residents, the focus is on accessibility, affordability, and ease of use, with solutions like Energy as a Service or peer-to-peer energy trading that empower consumers to manage their energy. For communities, business models will emphasize collective energy management and collaboration, incorporating virtual power plants or shared energy systems. Customization will account for shared ownership, governance, and energy-sharing regulations. The objective is to create business models precisely tailored to each group's requirements, ensuring technical, legal, and social factors are integrated for optimal adoption and success.

The results of this tailored approach will be used to create optimized models through modelling techniques. Based on the key components identified for communities and other target groups, these models will be fine-tuned to ensure the best possible performance. The optimization process will consider not only the technical feasibility of the business models but also their economic viability and social acceptance, leading to models that are both efficient and scalable. This will ensure that the business models are not one-size-fits-all but instead are finely tuned to the unique characteristics and needs of the target groups, leading to more effective and sustainable solutions for sector coupling.

Table 8.1 – Linking business model barriers to potential business model solutions. Columns Ind, Res, and EC indicate whether the identified barrier is applicable to industry, the residential sector and Energy Communities

Main business model barrier	Relevant sector(s)			Potential business model solutions
	Ind	Res	EC	
High initial costs	x	x	x	Energy as a Service Shared ownership
Regulatory and Market Uncertainty	x	x	x	Modular energy systems Public-private partnerships
Complexity of Integrating Multiple Energy System	x	x	x	Integrated platforms or services
Silo Mentality and Lack of Collaboration	x	x	x	Cross-sectoral collaboration models
Misalignment of Stakeholder Incentives	x	x	x	Performance-based financing
Consumer Awareness and Engagement		x	x	Personalized energy services Gamified platforms
Technological Interoperability	x	x	x	Open-source platforms Standardization consortia
Funding and Investment	x	x	x	Green financing mechanisms Crowdfunding
Resistance to Change and Legacy Systems	x	x	x	Transition services
Scaling and Replicability		x	x	Scalability by design

8.1.3 Financing solutions and automated transactions

Financial models are needed to improve the bankability of sector coupling projects. Based on a review of the factors influencing bankability, ReInvent aims to develop a credit policy for investment decisions in the context of multi-energy projects. Moreover, the sector coupled energy system of the future will be more and more distributed. In this context, an exponentially growing number of transactions will need to be facilitated. To this end, an automatic solution will be designed for seamless electronic transactions and interactions without manual intervention with a focus on E-mobility applications.

8.2 Opportunities for improved modelling

Work Package 2 (WP2) aims at developing a simulation environment able to model cross-sector coupling opportunities to support the Business Use Cases (BUCs) of Work Package 3 (see ReInvent Deliverable 3.1) and the impact assessment and recommendations of Work Package 4. The simulation environment, depicted in Figure 8.1, considers:

- two different spatial levels: the local level (e.g., electricity/heat/cold/mobility at the community level) and the energy system level (e.g., at the wholesale level, for electricity and molecules)
- two different time scales: short-term (e.g., daily with a quarter-hourly resolution to model optimal dispatch) and long-term planning horizons for which investment decisions in energy assets must be taken.

As such, it addresses four main topics:

- Development and improvement of energy system planning models (see Chapter 4) accounting for different sources of flexibility (residential, conventional power plants, connections between different energy carriers, utility-scale batteries, etc.) arising from cross-sector coupling (system level, long term).
- Analysing new market designs for multi-carrier markets (see 8.1.1) and addressing the impact of cross-sectoral technologies on the operation of new markets (system level, short term)
- Cross-sector coupling opportunities for local end-users (individuals and communities) between electricity, heat/cold, and mobility (more particularly EVs), from the short-term (dispatch) and long-term (planning) perspectives. This work draws from the end-user-oriented business model designs (see 8.1.2).

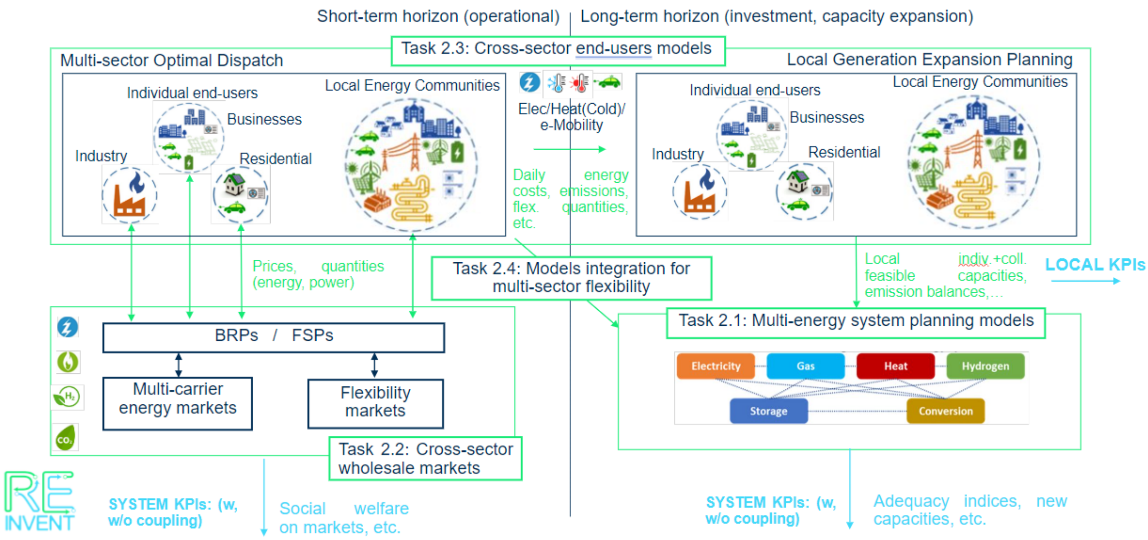

Figure 8.1 The ReInvent simulation environment for modelling cross-sectoral coupling opportunities in the Belgian energy system

8.2.1 Development of integrated multi-energy system models

From the perspective of integrated multi-energy energy system planning models (Task 2.1), we foresee the following main research opportunities:

<u>*Comprehensive coverage of demand-side flexibility, including heat flexibility*</u>

As described in Chapter 4, current TIMES models for Belgium already have a sound coverage of demand-side flexibility in transport. Improving flexibility options in the industry is relevant and will be addressed in the recently started ETF Galileo project. In ReInvent, the main research opportunity lies in a better representation of heat flexibility. We particularly intend to focus on how various flexible resources should optimally be leveraged in the future energy system. Indeed, flexible resources (e.g., residential batteries, P2X, links with the heating sector, etc.) are characterized by different techno-economic parameters and behavioral patterns. Therefore, various sources of flexibility should likely be leveraged for different purposes, i.e., day-ahead arbitrage or balancing provision. We aim to capture short-term uncertainty in long-term planning models (such as TIMES) to examine how these different sources of flexibility should ideally be valorized.

<u>*Analyzing domestic onshore and offshore hydrogen production with respect to different levels of demand side flexibility in the power system*</u>

Current TIMES models for Belgium have a broad coverage of Power2X options, as outlined in Chapter 4. Yet, various research challenges remain for understanding the possible role of Power2X and specifically Power2H2 in the Belgian energy system. For example, analyzing how different demand-side flexibility options affect the business case of domestic hydrogen production is an interesting venue for further research. To address this issue, methodological challenges apply, mostly due to limitations in spatial and temporal resolutions. Higher spatial resolutions are needed to better understand cost-optimal roll-out of hydrogen infrastructure, connecting demand and supply centers, from an integrated energy system perspective. Higher temporal resolutions may be necessary to better represent electrolyze operating hours and corresponding economic viabilities. Since spatial and temporal resolution are inherently limited in the TIMES models for Belgium[70], soft-linking with higher resolution models is an increasingly relevant venue of research. In the context of ReInvent, soft-linking with the Fluxys INTEGRATION[71] model and potentially the recent modelling work of (Namazifard et al., 2024) is foreseen.

8.2.2 Analyzing multi-carrier wholesale market designs

Analysis of multi-carrier wholesale market designs (Task 2.2) involves the following:

Analysis of integrated multi-energy market designs

As described in Section 8.1.1, investigating various integrated market designs, e.g., isolated, coordinated, and fully integrated, as well as the possible combinations of different energy vectors and temporal stages, is a crucial research avenue. In doing so, optimization-based models for the considered multi-carrier market designs will be developed, using the designs developed from WP1 as the basis. Special attention is foreseen to modelling existing electricity and gas markets, district heating networks, and future hydrogen markets.

Impact analysis of cross-sectoral technologies in wholesale electricity markets

Owning large-scale cross-sectoral technologies, such as large-scale electrolysis or energy storages, might benefit electricity suppliers, e.g., wind-based producers, participating in wholesale markets. At the same time, the use of such technologies can affect the electricity market clearing prices, and consequently market efficiencies. Therefore, ReInvent will analyze the optimal usage of cross-sector technologies (e.g., whether it has adequate participation factors) and evaluate its impact on market efficiency and the revenue of the producers. To this end, properly modelling the optimal bidding behavior of an energy producer equipped with cross-sectoral technologies is needed. Focus on modelling a hybrid plant with wind farm, electrolyzers, and batteries participating in an offshore bidding zone is foreseen.

8.2.3 Development of multi-sectoral end-users models

Development of multi-sectoral end-users models (Task 2.3 and 2.4) entails:

[70] Typically operating at the national or regional level, with bi-hourly time resolution based on 10 representative days.
[71] Compared to TIMES-BE, INTEGRATION requires exogenous energy demands, yet operates at higher temporal resolution and with a broader geographical scope.

Analysis of cross-sectoral technologies for individual consumers and communities

Developing a community model with shared cross-sectoral flexibility assets is foreseen. Particular assets that will be considered include solar panels, batteries, electric vehicles, and heat pumps, as well as the use of electric vehicles to provide flexibility. From the developed model, an analysis of how acting as a community, as opposed to acting individually, in using cross-sectoral assets can economically benefit the community members will be performed. Furthermore, an impact assessment on the grid, e.g., grid stress, from optimal community behaviors will also be conducted.

Development of local community-level market designs for multi-sector communities

Energy Communities consist in organized groups of end-users (consumer and prosumers) who may source (part of) their electricity from local renewable generation, in addition to standard retail contracts. This new local market mechanism has been attracting a lot of attention in the scientific community these past few years. Numerous local market designs have been proposed, but these tend to focus on the electricity market only. In that context, ReInvent will propose new local market frameworks for multi-sector communities and evaluate them using standard market KPIs (such as fairness of the allocation, efficiency, etc.), and will analyze their impact on the long-run business models from the end-user (and third-party investor, if any) perspectives.

Development of optimal dispatch models for coupled electricity and heat/cold distribution networks

Optimal dispatch models within communities aim at scheduling the use of energy assets (i.e., physical quantities, such as e.g., charge/discharge of storage assets, load shifting, etc.) and of the internal/external energy exchanges (i.e., economic variables, such as, depending on the local market design, the quarter hourly quantities purchased locally and on the retail market, etc.). The literature on communities usually formulates the problem as a centralized optimization problem, constrained possibly by the power flow equations of the electricity distribution system, with ad-hoc convexification techniques. Nevertheless, the explicit modelling of flow equations in heat/cold networks introduce a priori strong non convexities, so that optimality is not guaranteed any more. Ad-hoc linearization techniques, using e.g., Machine Learning, will be proposed in ReInvent.

Revenue stacking arising from the participation to local energy markets and system-level flexibility markets, at the end-user level

The electricity system may benefit from additional flexibility thanks to cross-sector coupling (e.g., heat stored in the district heating network itself, building thermal inertia, portfolios of EV, distributed batteries, etc.), so that revenues arising from local energy trading may be complemented by revenues from flexibility provision (balancing, ancillary services, etc.). This work stream will develop an end-user bidding model, which is aware of these extra cross-sectoral revenues opportunities and will refine the corresponding business models accordingly.

8.3 Impact assessment and KPIs

WP4 aims to analyze the role and impact of the various ReInvent sector coupling applications on the Belgian system. To this end, improved techno-economic energy system planning models (e.g., TIMES-BE, INTEGRATION) will be applied in an integrated scenario analysis, and further modelling insights will be integrated in the analysis. A scenario framework will be developed to highlight different levels and forms of sector coupling, all under the same objective of reaching net-zero emissions targets. Insights from an analysis of the scalability and replicability potential of sector-coupling applications (Task 4.1) will be used to set model boundary conditions on the uptake of different sector coupling options. The energy system planning models will consequently be applied under Task 4.2 to assess cost-optimal implementation of – and interaction between – different sector coupling options in the context of the broader energy system development.

Concretely, the impact of enhanced levels of sector coupling will be assessed based on a number of system-level KPIs. These are provisionally defined as follows:

- Total system costs, optionally split by sector
- GHG emission pathways
- Electricity mix: capacity and generation
- Electricity demand and electrification, including temporal variability and peak demand
- Electricity prices, including temporal variability and peak prices
- Grid investment needs
- Level of self-consumption
- Hydrogen production: onshore, offshore and imports
- Hydrogen usage, as feedstock, energy vector, and storage option

An innovative feature of the scenario analysis is the integration of knowledge on market designs and business models (WP1), and sector coupling test cases (WP3). This knowledge will enrich the optimization-based scenarios with qualitative (and where possible quantitative) insights. Based on these insights, consistent narratives will be developed that describe the main potential implementation barriers pertaining to each modelled scenario, as well as the possible solutions that need to be implemented to enable the sector coupling benefits (as calculated in the scenarios) to be realized. This will set the basis for developing policy recommendations and a roadmap for sector integration in Belgium.

8.4 Conclusion

This report provides the basis for analyzing the future of sector-coupling in Belgium, focusing on electrification and demand-side flexibility, Power2X (converting electricity to gas, liquids, and heat), and community energy. We described how the regulatory landscape has advanced at both EU and Belgian levels, with key EU frameworks and policies and their implementation at federal and regional levels. The report subsequently describes the state-of-the-art in three energy research domains. For the domain of energy system planning models, we find that Belgium's energy system models (TIMES-BE, TIB3R, INTEGRATION) are advanced but can benefit from further research on heating flexibility, leveraging flexibility for different purposes, and cross-model analysis. For energy markets, we describe how electricity, gas, heat, and hydrogen markets operate separately, while multi-energy markets are needed to harvest potential synergies. Looking into business models, we find that a suite of business models with associated drivers and barriers exist, but that an overarching structure for applying innovative business models to sector coupling is lacking.

Implementing sector coupling faces several barriers: economic (high costs, limited competitiveness), market-related barriers (restricted access, poor coordination), technical (interoperability, optimization), and social (lack of awareness, resistance to change). Addressing these issues is crucial for advancing sector coupling in Belgium. ReInvent research on sector coupling concepts, modelling and impact will address a number of sector coupling barriers as follows:

- A main focus is the investigation of new sector-coupled market designs, from isolated, coordinated, to fully integrated designs. Such sector-coupled designs are expected to provide flexibility to the electricity market, optimizing resource allocation and improving system efficiency, thereby addressing implementation barriers related to investment and financial risk.
- New local market frameworks for multi-sector communities will be developed to analyze their impact on the long-run business models from end-user perspectives, also addressing fairness of the distribution of the costs and benefits, which is perceived as a barrier.
- Innovative financing solutions will address main barriers related to bankability due to the lower maturity, high risk and the complexity of the solutions.
- Modelling applications at the local level will, to some extent, address technical barriers to sector-coupling. For example, modelling short-term dispatch and cross-sectoral technologies contributes to a more optimal sizing and operation of decentralized assets, and creates a better understanding of how optimal community behaviors may help to reduce grid stress.
- Research on tailored sector coupling business models typically covers a broad range of barriers going beyond purely economic indicators. New collaboration models, for example, may help to spread

investment risk. Also, evaluating different community-based business models in the end-user oriented modelling applications may show how to unlock sector coupling benefits in energy communities.

- Energy planning models are suited to analyze the long-term economic viability of sector coupling options under a range of possible future conditions. A main focus is to understand the trade-offs between demand-side flexibility and Power2X, and study how flexibility should be leveraged for different purposes of day-ahead arbitrage or balancing provision.
- The impact analysis based on the energy planning models aims to enrich modelled energy scenarios at different levels of sector coupling with insights on the main barriers and enablers of the sector coupled pathways. The work on business models, market designs and financing can provide tangible pathways for overcoming key barriers and realizing the potential of sector coupling. This will set the basis for the development of policy recommendations and a roadmap for sector integration in Belgium.

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