Investigation on the interlinkage between gas and electricity scenarios and infrastructure projects assessment

Task 1 – Generic mapping - Sub-report

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1 Introduction and objectives of the focus study

Context

As the electricity and gas systems interact continuously through a wide range of technologies, ranging from gas-to-power technologies (e.g. CCGTs) to power-to-gas technologies (e.g. electrolysis and methanation), via hybrid technologies (e.g. hybrid heat-pumps), a closer cooperation between electricity and gas systems can help achieving climate goals in a more cost-efficient way by exploiting the synergies between the two systems.

Even if substantial uncertainties remain regarding the evolution of the interlinkages between the electricity and gas sectors (level of electrification of end-uses, uptake of biomethane, role of power-to-gas, deployment of electric and gas mobility, etc.), the planning of electricity and gas infrastructure developments should involve a certain degree of coordination to allocate financial resources in an efficient way.

Regulation (EU) No 347/2013

Regulation (EU) No 347/2013 states that the "basis for the discussion on the appropriate allocation of costs should be the analysis of the costs and benefits of an infrastructure project on the basis of a harmonised methodology for energy-system-wide analysis, in the framework of the 10-year network development plans prepared by the European Networks of Transmission System Operators".

To achieve this goal, Regulation (EU) No 347/2013 has tasked the ENTSOs with the development of a "consistent and interlinked electricity and gas market and network model including both electricity and gas transmission infrastructure".

Overview of the interlinked model submitted by the ENTSOs

On 21 December 2016, the ENTSOG and ENTSO-E (hereafter the ENTSOs) have submitted the required interlinked model to the European Commission and the Agency for the Cooperation of Energy Regulators (ACER) for approval [1].

The key element of the model submitted by the ENTSOs is the joint development of scenarios that constitute the basis for the cost-benefit analysis of gas and electricity infrastructure projects.

Once the scenarios have been commonly established, the submitted model proposes that each of the ENTSOs performs the cost-benefit analysis of infrastructure projects based on their specific tools and methodologies, as is illustrated by Figure 1.

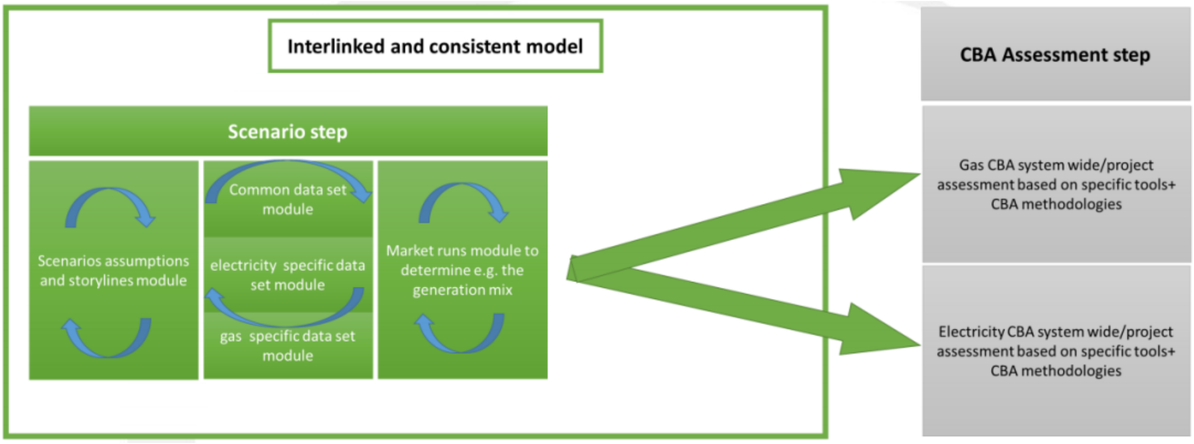


Figure 1 - Interlinked model and CBA steps. Source: [1]

The common development of the TYNDP scenarios by the ENTSOs ensure that the storylines are consistent and that a common database of input and assumptions is used by both associations (e.g. commodity and CO_2 prices).

The submitted model does not foresee any structural changes to the tools that are used in the sector-specific assessments, although it is the aim of the ENTSOs to continuously improve these tools for each new edition of their respective TYNDPs.

Overview of ACER's Opinion No 07/2017

In March 2017, ACER has published its opinion on the ENTSOs' draft consistent and interlinked electricity and gas market and network model [2]. ACER is of the view that the level of interlinkage between the modelling of the gas and electricity sectors is insufficient, and that the following phenomena should be investigated in further details:

- Interaction of the price formation process for the gas and electricity sectors;
- Interaction (potential competition and synergies) of electricity and gas infrastructure developments;
- Cross-sectoral influence of gas and electricity projects.

Objective of this focus study

The main objective of this focus study is to provide the ENTSOs with the elements allowing them to determine for which kind of projects a more thorough investigation of the impacts of interlinkages should be performed. In other terms, we aim at adding an intermediate layer between the green and grey areas shown on Figure 1. The intermediate layer is a screening process where:

- Projects that are assessed in a satisfactory manner with the current CBA methodologies are treated as usual
- Projects for which further interlinkages than those captured in the scenario building phase (green area) are of importance are detected and flagged for further investigation.

The objective of this study is to propose recommendations for the ENTSOs to develop the screening methodology described above. To achieve this objective, the focus study proceeds by first identifying all relevant interlinkages between the gas and electricity sectors, then qualitatively assess them via the definition and analysis of use-cases. The third step consists in a quantitative analysis of the use-cases to detect the cases where a more thorough investigation of gas and electricity interlinkages during the cost-benefit analysis would be valuable. Finally, the final task will be to propose recommendations for a screening process based on the quantitative results obtained in the third step.

Based on this work, the ENTSOs will develop a methodology to further analyse the impacts of interlinkages on the assessment of the projects that have been flagged by our proposed screening process.

Structure of this document

This document is structured as follows:

- Section 2 provides a short literature review of the interactions between the gas and electricity sectors and of their potential evolutions, along to the way these interactions are modelled,
- Section 3 presents the overall methodology for this focus study,
- Section 4 presents the results of *Task 1 – Generic mapping of all potential interactions between gas and electricity,*
- Section 5 is a glossary, and
- Section 7 presents references used during Task 1.

2 Gas and electricity interactions – A literature review

This section is devoted to the presentation of the European gas and electricity systems, of the different potential pathways towards the decarbonisation of the energy sectors and the corresponding roles gas and electricity may play in these scenarios, and of the way the interactions between gas and electricity are modelled in different contexts.

European gas and electricity systems – Key figures

As this focus study aims at assessing the potential impacts of interlinkages between the gas and electricity sectors on the assessment of projects, it can be useful to remind readers of key figures characterising the European gas and electricity systems. These order of magnitude will prove useful when analysing the potential impacts of interlinkages on project assessment in the subsequent tasks.

European gas system

In 2017, the European gas demand reached around 491 bcm, which corresponds to around 4800 TWh. The EU gas demand displays a strong seasonal behaviour as both production and consumption are around 1.5 times higher during wintertime (Q1 and Q4) than during warmer periods of the year (Q2 and Q3). On the other hand, gas imports do not exhibit such a strong seasonality. The EU gas system is characterised by a storage capacity of roughly 100 bcm. The storage units typically reach their maximum levels in October-November and minimum between February and April [3].

In Europe, gas is mainly used by industrial processes (around 1000 TWh in 2016), by the residential and commercial sectors for heating purposes (around 1800 TWh in 2016), and for power generation (around 1300 TWh of gas was used in power generation in 2016) [4].

Eurostat has Sankey diagram presenting the energy balance flows at the European level [4]. An example is provided below. We strongly encourage the reader to use this tool to obtain further insights on the structure of the European energy system and the role of the different energy vectors.

The following Sankey diagram shows the role of natural gas in the EU28 system in 2016, from import and production on the left, to final use on the right, via transformation steps in the middle (e.g. gas to electricity processes).

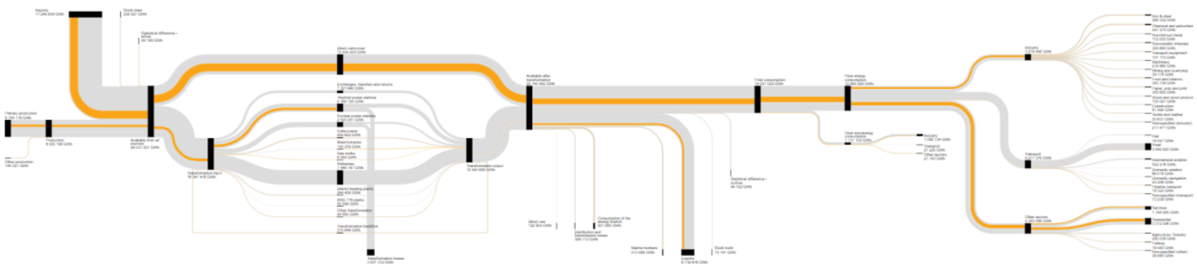


Figure 2 - Sankey diagram of the 2016 European energy flows (gas highlighted). Source: [4]

European electricity system

In 2017, the European electricity demand reached around 3700 TWh, of which around 770 TWh were produced by gas-fired power plants (CCGTs, OCGTs, CHPs) [5]. The European electricity system is undergoing a transition towards including more variable electricity generation technologies, such as wind turbines and solar panels.

The high level of interconnection between countries allows to dynamically adapt the output of the European generation portfolio according to external factors such as demand and weather patterns, and economic conditions. The total cross-border flows at the ENTSO-E level in 2017 reached around 450 TWh of imports and exports, the net position being very close from being balanced.

The following Sankey diagram shows the role of electricity in the EU28 system in 2016, from import on the left, to final use on the right, via transformation steps in the middle (e.g. RES, nuclear or fossil-based electricity generation).

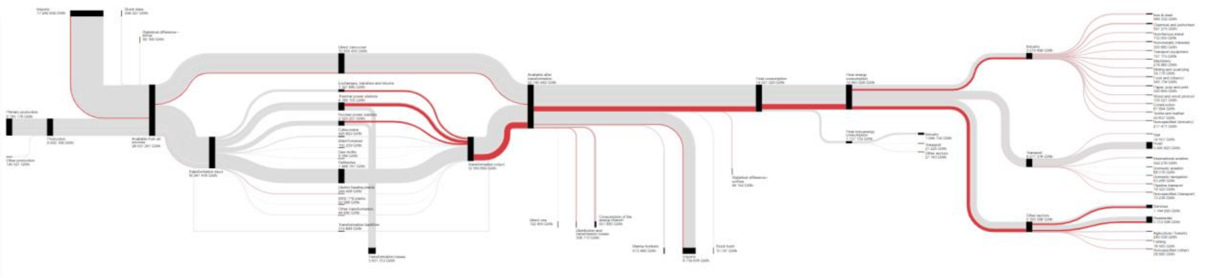


Figure 3 - Sankey diagram of the 2016 European energy flows (electricity highlighted). Source: [4]

The figures presented above represent the current situation of the gas and electricity systems. However, in order to meet the EU climate goals, and for the European energy system to transition towards a carbon-free energy system, the respective roles of the gas and electricity systems will change. The structure and importance of these changes are discussed below.

Potential impacts of decarbonisation on the gas and electricity sectors

The energy sector has a crucial role to play in order for the European Union to meet its ambitious decarbonisation objectives. The European Commission has recently been invited by the European Council to update its strategy for long-term EU greenhouse gas emissions reduction in accordance with the Paris Agreement by Q1 2019 [6]. This strategy is likely to rely on a total or close total decarbonisation of the electricity sector before 2050.

A successful decarbonisation strategy for the energy sector has to strongly involve energy efficiency measures and the use of renewable sources of energy in the electricity, heat, transport, and industrial sectors. Other carbon-neutral technologies such as nuclear power and CCS may also contribute to reaching the climate objectives, although the deployment of these solutions may subject to considerable political and/or technological uncertainties. In order to support the decarbonisation efforts, the role of infrastructure, and in particular of the gas infrastructure, may have to substantially change over the coming decades, depending on the pathway that will be selected to decarbonise the energy sector. We discuss a number of possible pathways (electrification of end-uses, green gas scenarios) and trends in the following paragraphs and shortly present their impacts in terms of infrastructure needs. Recent references include but are not restricted to [7], [8], [9], [10], [11].

Strong electrification of end-uses

One of the possible pathways towards decarbonisation of the energy sector is to electrify most of the end-uses. The set of end-uses that can electrified is substantial as it includes: heating and cooling in buildings (via district heating or heat pumps), mobility (passenger cars, delivery vans, trucks and vessels) and industry (hydrogen and synthetic methane production, heat production, etc.). A recent modelling work carried out by Eurelectric foresees that, at the EU level, direct electrification rates of more than 60% can be achieved in the transport and building sectors (compared to 1% and 34% in 2015 respectively), and a direct electrification rate of 50% can be reached in the industry [7].

Predicting the way the electricity and gas infrastructure would have to change in order to accompany a transition towards electrification is a challenging task. Relying solely on electricity for end-uses such as heating would result in a considerable pressure on the development of electricity transmission and distribution grids, and of electricity storage capacities. The gas infrastructure would have to develop in order to accommodate the power-to-gas and gas-to-power production, which will switch from using natural gas to using renewable gases. Estimating the importance of gas-to-power and power-to-gas generation has to take into account a number of factors such as the amount of deployed RES technologies, availability of electricity and gas storage, demand-response capacities, electricity and gas interconnection capacities, etc. and would require a specific modelling exercise. Finally, it is likely that not all end-uses would be electrified even in the most ambitious electrification scenarios. Gas could therefore have a role to play in mobility (e.g. heavy goods road transport) and industry (e.g. for the production of high-temperature heat, which is more difficult to generate with electricity).

Electricity and gas end-uses

Relying on a strong electrification of end-uses comes with its challenges, in particular in terms of electricity transmission and distribution infrastructure dimensioning. The pressure on these networks can be particularly acute during episodes with very cold temperatures as the demand for heat would have to be supplied by electricity only.

Maintaining gas end-uses would allow to reduce the strain on the electricity infrastructure, and, depending on the costs of equipment such as heat-pumps, might be a more cost-effective way of meeting the decarbonisation targets (see e.g. [8] in the gas of Germany). Analysing the costs of both strategies (relying on a strong electrification of end-uses or maintaining gas end-uses) is a complex exercise that has to take into account the latest projections of equipment costs (e.g. batteries, heat-pumps, etc.), the existing gas and electricity network and their respective expansion needs, etc.

End-uses that are eligible to directly consume gas (or other carriers but electricity) include mobility (where synthetic fuels are also an option), heating (either via direct gas heating or hybrid heat pumps) and industry.

A number of different scenarios can be elaborated, some involving a more important reliance on hydrogen, others favouring biomethane. The production of hydrogen and biomethane can either rely on power-to-gas installations or on the upgrading of biogas (as discussed above in the case of electrification). However, since the volumes of gas to be produced would be more important than in a scenario relying on strong electrification, the role of gas infrastructure would significantly differ from an electrification scenario, in particular at the distribution level since gas would have to be delivered to end-users.

An evolving technological landscape

Tackling the challenge of limiting the magnitude of climate change requires replacing carbon-emitting processes by carbon-neutral technologies by around 2050. As emphasised above, using energy more efficiently will be a key element of a successful decarbonisation pathway. The second key pillar will be the reliance of renewable energy, which will likely involve a number of technologies that are not yet mature and whose developments should be closely monitored. Besides energy efficiency, the following technologies are emerging as potential solutions to decarbonise the energy system:

- **Hydro, solar and wind** power generation will most probably remain the most important technologies in terms of overall generation volume of renewable electricity in Europe. The following figure presents the trend observed in Europe in terms of renewable electricity generation:

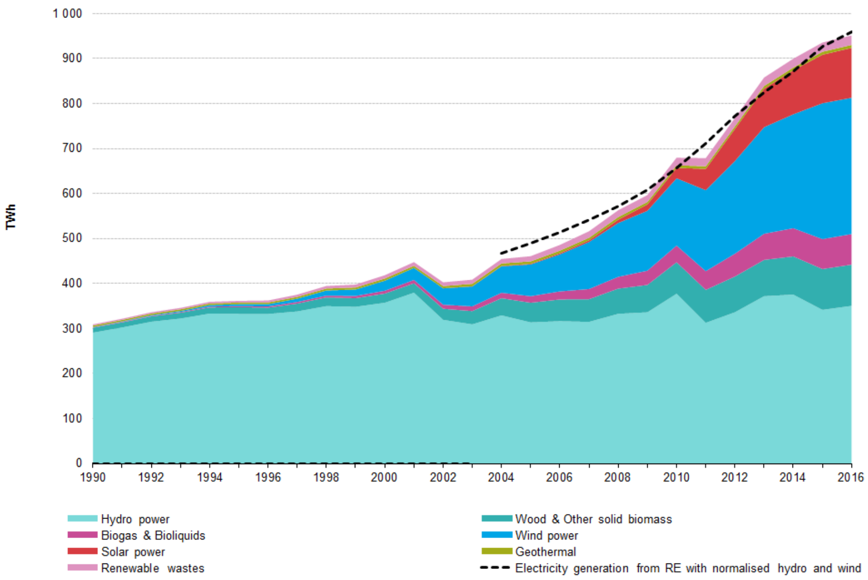


Figure 4 - Gross electricity generation from renewable sources at the EU28 level (Eurostat, nrg_105a)

- **Power-to-hydrogen** is likely to be the first power-to-X technology to emerge, as when coupled to cheap sources of electricity generation, the production of hydrogen by P2H2 facilities via electrolysis can become competitive with other sources of hydrogen (e.g. SMR, by-product of other industrial processes). Countries like Japan consider domestic power-to-hydrogen technologies to play a key role in their sourcing of hydrogen, together with the establishment of an international supply chains (Japan expects to scale up its hydrogen consumption from around 200 tonnes today to 300 000 tonnes in 2030 [12])
- **Power-to-methane** consists in combining hydrogen with carbon dioxide to produce methane. The required CO_2 can either be sourced by capturing emissions from other processes (e.g. power generation technologies such as biomass- or gas-fired plants combined with CCS) or via direct air capture technologies (see e.g. demonstrators such as H2020 project STORE&GO[1]). Without subsidies, the economic viability of P2CH4 technologies are expected to heavily depend on the price of CO_2 since the higher the CO2 price is, the more important the incentive to capture it becomes.

Other sources of renewable energy are available, either to produce renewable electricity (e.g. geothermal power, CSP, biomass), renewable gas (e.g. biomass) or even liquids (e.g. bioethanol), see e.g. [13] for a recent review of the prospects of such sources.

The sources of decarbonised gas and electricity are subsequently used in domestic, industrial and commercial applications by a portfolio of technologies that depend on the overall organisation of the energy sector (see above for a discussion of possible pathways towards a decarbonised energy system).

Interplay between gas and electricity infrastructure

In all pathways, ranging from scenarios assuming a strong electrification to scenarios relying on gas in a large number of end-uses, via scenarios where gas end-uses are only used as backups (e.g. hybrid heat-pumps), the impacts on the gas and electricity infrastructure will likely be important. Furthermore, the increasing level of interactions between the gas and electricity sectors that can be foreseen in all scenarios (e.g. gas-to-power, power-to-hydrogen, gas as seasonal storage, etc.) advocates for a coordinated planning of all system elements, including gas and electricity infrastructure [12].

Modelling interlinkages

Modelling techniques are one of the tools on which decision-makers rely to assess what is the most cost-efficient way to plan the development of infrastructure projects in order to meet pre-defined

[1] https://www.storeandgo.info/

policy objectives. The following paragraphs present recent references adopting an approach to gas and electricity planning that aims at capturing the synergies and interdependencies between these sectors.

Many multi-energy models have been used for policy development, including the MARKAL/TIMES family of models, top-down econometric models, general equilibrium models and more recently multi-energy market models.

At the European level, the Commission relies on several models to develop and assess the impacts of policy proposals: PRIMES, POTEnCIA, and METIS. While PRIMES and POTEnCIA focus on the generation of multi-energy scenarios, METIS is used to analyse the operations of the European energy system using an hourly time resolution.

In the US, the Illinois Institute of Technology has published a white paper on behalf of the Eastern Interconnection States' Planning Council (EISPC) and the National Association of Regulatory Utility Commissioners (NARUC) entitled "Long-term Electric and Natural Gas Infrastructure Requirements" [13]. In this paper, the authors recognise the importance of a joint approach to the operations and planning of gas and electricity sectors in the United States and mention that "An integrated gas-electric model is needed to allow detailed modelling of the physical delivery of gas from fields, through pipelines and storage to gas and electric demands. In the integrated model, gas and electric models are solved simultaneously allowing decision makers to trade-off gas investments, constraints and costs against other alternatives", and identify data exchange and consideration of sector-specific contracts/policies as the main difficulties to overcome.

A number of academic articles have been published on the topic of optimal expansion of electricity and gas transmission infrastructure, some of which being based on a detailed simulation of market operations, e.g. [14], others considering simulation techniques that are close to the ones to be used in this focus study, e.g. [15].

Recently, the European Climate Foundation has published a study using a joint model of gas and electricity to assess the potential role of infrastructure in the transition and to analyse security of supply [16], demonstrating that a joint approach can lead to substantial savings (avoided investments). Deane et al. implemented a similar type of model to assess security of supply in the EU [17].

At a more local level, a number of public authorities in France rely on a multi-energy modelling of gas electricity and heat to support their decisions to extend their gas, electricity and district heating infrastructure.

3 Overview of the methodology

This section is devoted to the presentation of the methodology we have designed for this focus study. Each sub-report also contains a section presenting the methodology of the task under consideration in a more detailed way. The goal of this section is to provide the reader with an overview of the methodology, without entering in all the details.

The focus study is structured as follows:

- **Task 1** – Generic mapping of all potential interactions between gas and electricity
- **Task 2** – Qualitative analysis of potential interactions between gas and electricity infrastructures
- **Task 3** – Quantification of interaction parameters
- **Task 4** – Recommendations on screening approach to identify projects to be retained for gas/electricity interaction assessment

3.1 Task 1

The objective of Task 1 is to provide a systematic and exhaustive list of all potential interactions between the gas and electricity sectors. We adopt a bottom-up perspective where we aim at exhaustively listing and characterising all the interactions that directly involve both energy vectors. An interaction is defined as being direct if both vectors are inputs or outputs of the interaction (e.g. CCGT, hybrid heat-pump, power-to-gas), while an interaction is defined as being indirect if gas and electricity interact through a third sector of the energy system (e.g. mobility). In relevant cases, we also discuss indirect interactions that we have identified as being important for the assessment of infrastructure projects.

The list of direct and indirect interactions that we identify in Task 1 can be seen as building blocks which when combined can allow for more complex interactions such as between infrastructure projects, interaction of price formation mechanisms, etc.

The following methods have been used to deliver the Task 1 sub-report:

- **Desk-based research**: literature review, based on the references cited in the terms of reference and additional references (see Section 7)
- **Stakeholder engagement**: a joint ENTSOG/ENTSO-E workshop has been organised by the ENTSOs on 17 May 2018. The purpose of this event was to present the objectives of the study to stakeholders. The methodology proposed for this assignment has been presented by

Artelys[2]. Following this workshop the ENTSOs have requested stakeholders' feedback by email on 25 May 2018. The objectives of this focus study have been presented by the ENTSOS during the 2018 Copenhagen Infrastructure Forum on 25 May 2018. Finally, the results of Task 1 have been presented by Artelys during a webinar organised by the ENTSOs on 10 October 2018.

A more precise description of the methodology and the results of Task 1 can be found in Section 4.

3.2 Task 2

The objective of Task 2 is to select and specify use-cases that will be analysed qualitatively in Task 2 and quantitatively in Task 3, leading to the design of the screening process in Task 4.

The methodology of Task 2 relies on the selection and specification of a limited number of use-cases:

- **Selection of use-cases**
  The first step consists in building use-cases that involve direct interactions between the gas and electricity sectors by combining the building blocks identified in Task 1. Use-cases are abstract and generic representations of situations where interlinkages could impact the assessment of gas and/or electricity projects. They typically involve two zones (A and B) which differ in terms of gas and electricity demands, installed capacities (electricity generation, gas production/gasification), infrastructure (interconnectors, pipelines), etc.

  In the subsequent tasks, the use-cases will be quantitatively analysed in order to detect situations where the assessment of infrastructure projects requires a more thorough investigation of the gas-electricity interlinkages compared to the current project assessment process.
  The use-case selection criteria are the following:
    - "Direct" – Use-cases have to involve direct interactions since the way these interactions are taken into account could influence the assessment of infrastructure projects

[2] The slides are available on ENTSOG's website - https://www.entsog.eu/public/uploads/files/publications/Events/2018/20180517%20Focus%20Study%20Interlinked%20Model%20-%20Workshop%20-%20Joint%20Presentation%20final%20-%20updated%20by%20Artelys.pdf

   - “Relevant” – Use-cases have to represent realistic situations involving interactions identified in task 1, i.e. configurations which could materialise in the European energy system.

- **Specification of the use-cases’ parameters**
  Use cases are characterised by the value of parameters that define them and of ranges to be considered in the sensitivity analyses.

3.3 Task 3

The objective of Task 3 is to use quantitative methods to detect situations where a project would require an in-depth investigation of the impacts of the gas-electricity interlinkages. We will compare two approaches for each of the use-cases. The potential discrepancy between the results obtained in these two approaches will be an indicator that further investigation is required.

The two approaches that will be compared can be summarised as follows:

PA – Partial approach	CA – Coupled approach
In the first approach (PA), the assessment of an infrastructure project will be based on the use of simulations focusing only on gas or only on electricity, depending on the infrastructure project to be assessed. Some of the assumptions of the simulations to be used for the assessment (e.g. the gas-only simulations in the case of a gas interconnector assessment) might be generated via another simulation (e.g. the electricity-only model).	In the second approach (CA), the assessment of the infrastructure project will be carried out using a joint gas-electricity simulation, which reflects the mutual assistance between the two energy carriers. As a consequence, the value of some of the infrastructure projects that will be evaluated in the use-cases might differ from the one obtained with the partial approach.

Both approaches will be assessed using a common modelling platform, Artelys Crystal Super Grid, ensuring that the two approaches use consistent datasets. Should the proposed electricity and gas simulation methodologies differ from those developed by the ENTSOs for the assessment of infrastructure projects, we will identify the main differences and discuss their potential impacts.

3.4 Task 4

Finally, the goal of Task 4 will be to define simple and effective screening rules to detect the projects that require an in-depth investigation of the impacts of the gas-electricity interlinkages. The parameters entering the screening rules will be fixed by exploiting the quantitative analysis carried out in Task 3, which in particular involve a number of different sensitivity analyses.

4 Task 1 - Generic mapping of all potential interactions between gas and electricity

This Section is devoted to presenting the objective (Section 4.1), methodology (Section 4.2) and results (Section 4.3) of the generic mapping of all potential interactions between gas and electricity.

4.1 Objective of this task

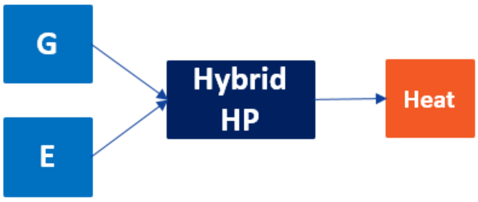
The objective of Task 1 is to present a generic and as exhaustive as possible mapping of all the potential interactions between the gas and electricity sectors. A characterisation of the interactions is introduced (direct and indirect interactions). Finally, the impacts of the interactions on the ENTSOs' Scenario Building exercise, gas and electricity prices, and gas and/or electricity infrastructure projects are qualitatively assessed.

4.2 Overview of the methodology

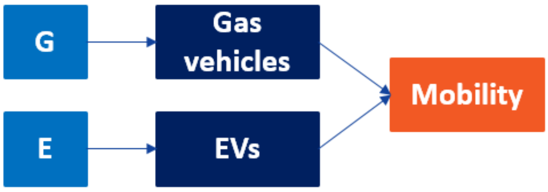
We adopt a bottom-up perspective where we aim at exhaustively listing and characterising all the interactions that directly involve both energy carriers. By interaction, we understand technologies that link both energy carriers.

We define direct and indirect interactions as follows:

- **Direct interaction** – An interaction is said to be direct if both electricity and gas are inputs or outputs of the interaction. For example, a CCGT is a direct interaction between the gas and electricity sectors as it consumes gas to generate electricity. A hybrid heat-pump (HP) is also a direct interaction as both energy carriers can be consumed to deliver heat. Direct interactions can be seen as the building blocks that dynamically link both energy sectors.



- **Indirect interaction** – An interaction is said to be indirect if gas and electricity are linked *via* a third sector. For example, the link between electric vehicles and gas vehicles is an indirect interaction since the electricity and gas are linked via mobility:



The distinction between direct and indirect interactions is particularly useful when considering the overall objective of this focus study, which is related to infrastructure project assessment. When assessing an infrastructure project, the results of simulating two situations are compared:

- **Original scenario** – The original scenario is one of the scenarios built by the ENTSOs during the Scenario Building exercise. It is defined by a set of installed capacities, demands and techno-economic characteristics. A reference grid is defined.
- **With/without the project** – The second situation is identical to the original scenario but for the presence of the project under scrutiny. If the project to be assessed is not part of the reference grid, then it is added to the scenario, while if it is part of the reference grid, it is removed from the scenario.

The value of the gas or electricity infrastructure project to be assessed can be measured through a number of different indicators that capture the influence of the infrastructure project on the operational management of the energy system.

In this context, the operational management of direct interactions are likely to be influenced by the presence of the assessed infrastructure project. For example, adding a gas or electricity interconnector would likely result in a different management of gas-fired power plants, power-to-gas units, hybrid heat-pumps, etc. due to the economic opportunities resulting from potential modifications of the gas and electricity flows.

On the other hand, indirect interactions are usually defined at scenario level, in adequacy with infrastructures. For instance, the consumption of mobility and the shares of electric vehicles and gas vehicles have to be consistent with power supply infrastructures, gas infrastructures, etc. Once defined, the annual consumption is not impacted by the addition or removal of a specific infrastructure project. Indeed, the indirect interactions cannot dynamically switch from one energy carrier to the other: for instance, the scenario-defined transport mix is not modified by the addition of one power or gas interconnection. The presence of a new project can however affect the dynamics of the consumption pattern if adequate price signals exist (e.g. the charging strategy of electric vehicles or the use of gas in district heating applications can change if a new interconnection is built).

The list of direct and indirect interactions that we identify in this sub-report can be seen as building blocks which when combined can allow for more complex interactions such as between infrastructure projects, interaction of price formation mechanisms, etc. The bottom-up methodology introduced above, primarily based on an effort to identify all potential direct interactions, is therefore very well suited to study the phenomena listed by ACER in Opinion No 07/2017.

The results presented in this sub-report have been obtained by the following means:

- **Desk-based research**: own research and literature review, based on the references cited in the terms of reference and additional references (see Section 7)
- **Stakeholder engagement**: a joint ENTSOG/ENTSO-E workshop has been organised by the ENTSOs on 17 May 2018. The purpose of this event was to present the objectives of the study

to stakeholders. The methodology proposed for this assignment has been presented by Artelys[3]. Following this workshop the ENTSOs have requested stakeholders' feedback by email on 25 May 2018. The objectives of this focus study have been presented by the ENTSOS during the 2018 Copenhagen Infrastructure Forum on 25 May 2018. Finally, the results of Task 1 have been presented by Artelys during a webinar organised by the ENTSOs on 10 October 2018.

4.3 Results of the mapping

This section lists all the direct and indirect interactions that have been identified and provides a short description of each of them together with an assessment of their impacts on the ENTSO's scenario building exercises, gas and electricity prices and infrastructure projects.

We first list all direct interactions which involve the conversion of one of the energy carriers into the other, then direct interactions where one of the energy carriers assists the other, and finally we list a number of cases where there is a competition between end-uses (indirect interactions).

Direct interactions

1. **Conversion**
   a. Gas-to-power
      i. OCGTs and CCGTs
      ii. Gas CHPs
   b. Power-to-gas
      i. Power-to-hydrogen
      ii. Power-to-gas (hydrogen or methane injection into gas network)
2. **Assistance**
   a. Electricity-driven gas compressors
   b. Hybrid heating technologies
      i. Industrial gas furnaces with electric boilers
      ii. Hybrid heating (residential & tertiary sector, district heating)
   c. Hybrid transport technologies (if any)

Indirect interactions

3. **Competition**
   a. Mobility
   b. Heating

[3] The slides are available on ENTSOG's website - https://www.entsog.eu/public/uploads/files/publications/Events/2018/20180517%20Focus%20Study%20Interlinked%20Model%20-%20Workshop%20-%20Joint%20Presentation%20final%20-%20updated%20by%20Artelys.pdf

c. Biogas

The identified interactions are presented below on the Sankey diagram used in the scenario building phase, which represents the interactions between the gas and electric systems. This diagram focuses on the perimeter covered by the gas and electricity joint scenario building, and as such it does not necessarily represent the interactions between all energies (e.g. waste heat, bio fuels, solar heat, etc.).

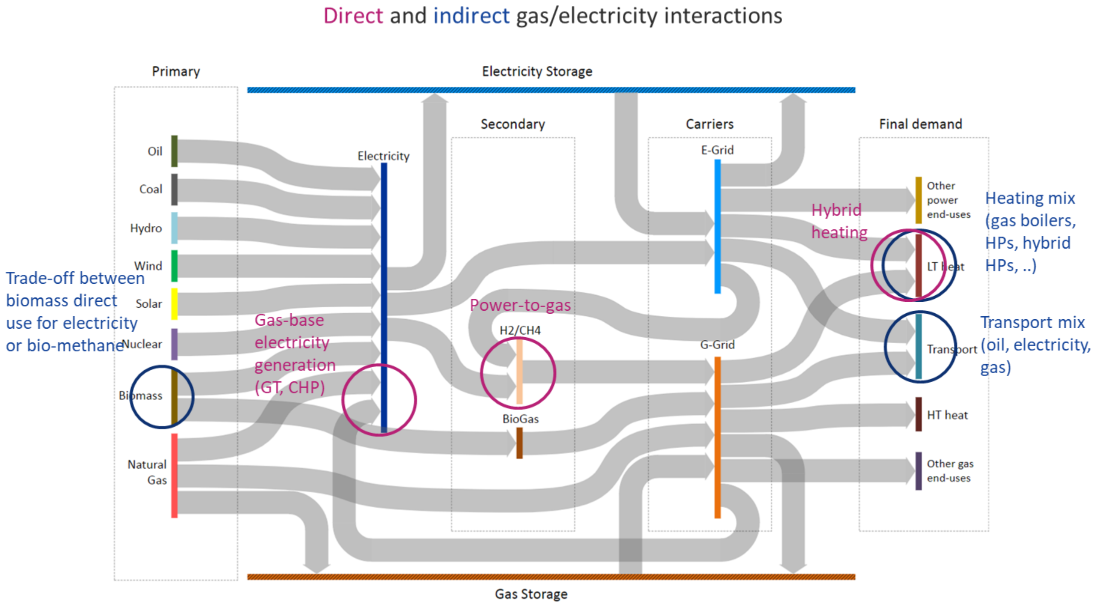


Figure 5. Direct and indirect interactions identified in task 1 on the Sankey diagram used for scenarios building phase.

Fiches describing the interactions can be found in the following sections, and are structured as follows:

- **Overview** – Short description of the considered interaction
- **Direct/indirect interaction** – Qualitative discussion of the direct or indirect nature of the considered interaction
- **Typical size/number of instances** – When available, typical size of the interlinkages (e.g. in MW) and estimation of the importance of the interlinkage at the European level in 2018
- **Relation with ENTSOs' Scenario Building Exercise** – Qualitative assessment of the characteristics (if any) of the interlinkage that are currently captured by the ENTSOs' Scenario Building Exercise.
  One should note that it is not part of the objectives of this focus study to undertake an analysis of the methodology developed by the ENTSOs to build common scenarios and to generate parameters to be used in their respective CBA analyses. However, in order to discuss the relation with the ENTSOs' Scenario Building Exercise, assumptions regarding the elaboration of the scenarios may have to be made, especially for the quantitative analyses to be carried out during Task 3. Based on [1], the ENTSOs use an iterative process where the results of simulations with sector-specific models are compared. Assumptions related to prices and

generation volumes may then be updated to ensure an overall consistency between gas-to-power consumption (gas-specific model) and gas-fired electricity generation (electricity-specific model) at the annual level.

- **Impact on gas and electricity prices** – Qualitative assessment of the potential structural impacts on prices[4] of the considered interaction. For both direct and indirect interactions, we aim at qualitatively assessing whether the considered interlinkage can impact the gas and electricity prices in two ways:
  - First, via the deployment of the considered technology (ceteris paribus). What would happen should we change the assumptions made at the scenario-level?
  - Second, we aim at providing an analysis of the way the operational management of the technologies involved in the interaction can change when an infrastructure project is added to the system.
- **Impact on infrastructure projects** – Qualitative assessment of the potential impacts of the considered interaction on the valuation of infrastructure projects.

4.4 Direct interlinkages

4.4.1 OCGTs and CCGTs

Interaction #1 – *Gas-to-power – OCGTs and CCGTs*	
Overview	**OCGTs** are mature gas-to-power technologies. Due to their efficiency (around 40%, see e.g. [18]), producing electricity with OCGTs is costlier than with most of the other currently available technologies. OCGTs are therefore primarily used to cover peak periods, thanks to its short start-up time. **CCGTs** are mature gas-to-power technologies that combine a gas turbine with a steam turbine, allowing for efficiencies of the order of 60% (see e.g. [18]). OCGTs and CCGTs can indifferently run on methane or bio-methane (upgraded biogas).
Direct/Indirect nature of the interlinkage	OCGTs and CCGTs are direct interactions since these technologies take gas as input and generate electricity.

[4] The qualitative assessment of the interaction sources focuses on gas and electricity commodity prices. The effect on these prices can translate into evolution of other prices, e.g. capacity prices. Gas price refers to the price of gas in the gas network, which can come from different sources: natural gas, SNG, H2, bio-methane, etc.

Typical size and number of instances in 2018	Typically, OCGT capacities ranges from 30 to 600 MW_e and while CCGT capacities range from 100 to 1500 MW_e. The overall gas-fired installed capacity over ENTSO-E's area is around 240 GW [5].
Relation with ENTSOs' Scenario Building Exercise	The installed capacity of OCGTs and CCGTs (together with their techno-economic characteristics) are part of the assumptions that are made during the Scenario Building Exercise.
Impact on gas and electricity prices	The installed capacity of OCGTs and CCGTs has a high impact on electricity and gas prices. Indeed, if the installed capacities were to be less important (ceteris paribus), more expensive electricity generation technologies would have to be used, leading to higher electricity prices. On the other hand, the demand for gas from gas-fired power plants would decrease, which can lead to lower gas prices in scenarios with a significant penetration of electricity for heating (in which gas demand for electricity is an important part of the total consumption). In case one were to increase the OCGT and CCGT installed capacities, the electricity price may decrease if these additional capacities can displace more expensive ones. If this is the case, gas prices would increase as a result of the higher demand for gas. The operational management of gas-fired generation capacities is primarily driven by fuel and CO_2 prices and by the installed capacities of other technologies, including infrastructure elements. Indeed, adding an interconnector or a storage unit can modify the arbitrage opportunities and impact the management of OCGTs and CCGTs, and thereby the gas and electricity prices. The precise impact on gas and electricity prices is however strongly dependent on the commodity prices and other installed technologies. For example, adding an electricity storage element will lead to lower average electricity prices, but the impact on gas prices depends on the merit order between gas-fired generation and the other technologies. If coal is cheaper than gas, the introduction of an electricity storage element would result in a higher exploitation of coal technologies, leading to a lower demand for gas from the power sector, which could lead to lower gas prices (in scenarios where gas consumption for power is a high part of the consumption).
Impact on infrastructure projects	The presence of OCGTs and CCGTs can have a significant impact on the assessment of infrastructure projects: on one hand, gas needs to be routed to the power generation units which can affect the imports of gas in the country (in volume and capacity), while on the other electricity has to flow from OCGTs and CCGTs to load centres (which can affect the exports of electricity, in volume and capacity.

4.4.2 Gas CHPs

Interaction #2 – *Gas-to-power – Gas CHPs*	
Overview	Gas-fired CHPs use gas to generate electricity and useful heat. Most small-scale CHPs are based on reciprocating engines. CHPs can be used in a number of different settings: - District heating - Industrial applications - Micro-cogeneration (domestic or tertiary) The operational management of CHPs might be subject to constraints from one or both of its outputs: for example, the heat demand profile might induce constraints on the management of the CHP. Such constraints have to be properly accounted for when assessing the flexibility that can be brought by CHPs to the electricity sector.
Direct/Indirect nature of the interlinkage	CHPs are direct interactions since these technologies take gas as input, and generate electricity and heat.
Typical size and number of instances in 2018	Typical size: 50 kW_e to several MW_e Approximate installed capacity in Europe: 120 GW_e/300GW_{th} [19]
Relation with ENTSOs' Scenario Building Exercise	The installed capacity of gas-fired CHPs (together with their techno-economic characteristics and constraints) are part of the assumptions that are made during the Scenario Building Exercise.
Impact on gas and electricity prices	The presence of gas CHPs in an energy system can have a structural impact on gas and electricity prices similar to that of OCGTs and CCGTs (see Section 4.4.1). However, because of the constraints imposed by the supply of heat, CHPs operational planning is more regular than OCGTs' and CCGTs'. The deployment of CHPs can thus affect electricity prices mostly during the winter, and can also affect gas prices, gas needs increasing with the CHP capacity.
Impact on infrastructure projects	The constraints on the operational management of CHPs imposed by the supply of heat reduced the flexibility of CHPs, and hence their impact on the assessment of infrastructure projects.

4.4.3 Hydrogen production

Interaction #3 – *Power-to-gas – Power-to-H2 for direct use*	
Overview	The first power-to-gas technology to be investigated is the production of hydrogen for industrial or mobility use. The injection into the gas network will be discussed in the next fiche. Different electrolysis technologies are available, among which the most commonly used being alkaline and proton exchange membrane (PEM). Solid oxide electrolyte cells have not yet fully reached market maturity (see e.g. [20]). The hydrogen produced by such technologies when coupled to a steady source of electricity (e.g. nuclear or RES with batteries) can be a competitor to typical hydrogen production technologies such as steam methane reforming (SMR), potentially coupled to carbon capture and storage (CCS).
Direct/Indirect nature of the interlinkage	Power-to-gas technologies are direct interactions since these technologies take electricity as input, and generate gas.
Typical size and number of instances in 2018	Electrolysis is a mature technology, used in various industrial environments. Recent projects that exploit cheap RES generation include HyBalance in Denmark (hydrogen to be used in the industry and for mobility) and H2Future in Austria where the electrolyser will also provide ancillary services.
Relation with ENTSOs' Scenario Building Exercise	Assumptions related to power-to-hydrogen, where hydrogen is used in the industrial or mobility sector, should be part of the assumptions that are made during the Scenario Building Exercise. Indeed, the scenarios have to reflect assumptions on the amount of hydrogen being produced by taking it into account when setting the assumptions related to electricity generation technologies' installed capacities (to ensure enough electricity is available to produce hydrogen) and to gas supply mix (since power-to-hydrogen is competing with alternative sources of hydrogen production that use methane).
Impact on gas and electricity prices	The impact on prices of different assumptions of installed capacities of power-to-hydrogen depend on the role of hydrogen in the scenario. Indeed, the deployment of this technology is capped to the capacity allowing it to cover the demand for hydrogen from different end-uses (e.g. mobility, industry).

	In a scenario strongly relying on hydrogen, the deployment of power-to-hydrogen solutions can have a high impact on gas and electricity prices, while for other scenarios the impact can be lower. Structurally, the presence of power-to-hydrogen technologies can trigger an increase of electricity prices, especially during low and negative price episodes in poorly connected areas. Indeed, the electricity consumption of power-to-hydrogen technologies increases the demand for electricity and thereby power prices. Finally, when adding an infrastructure project, the power-to-hydrogen technologies will adapt their operational management according to the new conditions. As for other technologies, the precise impact depends on the location of the power-to-hydrogen technology relative to the infrastructure project. For example, a new electricity interconnector could result in fewer episodes of low electricity prices in poorly connected areas and hence limit the hydrogen production by electrolysis. On the contrary, if an area has high variable e-RES surpluses, and there is high power-to-hydrogen capacities in a neighbour area, a new electric interconnector can increase the use of power-to-hydrogen.
Impact on infrastructure projects	The development of power-to-hydrogen can have an important impact on the assessment of infrastructure projects, especially if decarbonisation strongly relies on hydrogen. Indeed, local hydrogen production could decrease the need for gas imports (for SMR) and reduce electricity exports.

4.4.4 Hydrogen or methane injection in the gas network

Interaction #4 – *Power-to-gas – Injection in the gas network*	
Overview	This interaction between the gas and electricity systems takes place when injecting hydrogen generated via electrolysis or methane produced by combining hydrogen with CO_2 into the gas network for storage and subsequent use (e.g. power generation, heating, mobility). The overall power-to-CH4 is CO_2-neutral, since the CO_2 emissions released by the gas use (e.g. in a gas turbine, gas mobility, etc.) had previously been captured (e.g. from industrial CO_2 intensive processes or direct air capture) and used in the methanation process. Power-to-gas is a natural candidate to provide flexibility to the energy system, in particular for seasonal storage in gas storage facilities.
Direct/Indirect nature of the interlinkage	Power-to-gas technologies are direct interactions since these technologies take electricity as input, and generate gas.
Typical size and number of instances in 2018	At the moment, hydrogen injection lighthouse projects and large-scale demonstration projects have been launched (e.g. HyDeploy in the UK, GRHYD and JUPITER1000 in France, Eoly in Belgium). While electrolysis and catalytic reactors are well-established technologies, their combination to produce and inject methane into the gas network is still at an early stage of its development. A number of demonstration projects are ongoing (see e.g. JUPITER1000, CO2-SNG, STORE&GO, Méthycentre, HELMETH, etc.). As for hydrogen blending, the deployment of power-to-C H4 depends both on regulatory and techno-economic factors.
Relation with ENTSOs' Scenario Building Exercise	Assumptions related to power-to-gas with injection in the gas network, are part of the assumptions that are made during the Scenario Building Exercise. Indeed, the scenarios ensure consistency between assumptions on the installed capacities of power-to-gas technologies that are consistent with the electricity demand, the power generation installed capacities, and the gas supply. A process similar to the one ensuring consistency checks between gas-to-power and gas-fired electricity generation could be applied to power-to-gas (i.e. a consistency check between the amount of electricity going into power-to-gas solutions in the electricity-specific tool and the amount of gas produced by these technologies in the gas-specific tool).

	Additionally, hydrogen injection can have a significant impact on infrastructure needs in the gas network
Impact on gas and electricity prices	As for hydrogen production, the presence of power-to-gas technologies can trigger an increase of electricity prices, especially during low and negative price episodes in poorly connected areas. Indeed, the electricity consumption of power-to-gas technologies increases the demand for electricity and thereby power prices. In turn, the gas prices may also be impacted since the supply from other sources would decrease since part of the supply is taken care of by power-to-gas solutions. Finally, when adding an infrastructure project, the power-to-gas technologies will adapt their operational behaviour according to the new conditions. As for other technologies, the precise impact depends on the location of the power-to-gas technology relative to the infrastructure project.
Impact on infrastructure projects	The development of power-to-gas can have an important impact on the assessment of infrastructure projects, especially if decarbonisation strongly relies on green gases. For example, a zone might end up exporting gas instead of electricity, which will considerably impact the assessment of interconnection projects. The development of power-to-gas is also related to variable e-RES development and more generally power supply which have to be consistent as defined by the scenario.

4.4.5 Electricity-driven gas compressors

Interaction #5 – *Electricity-driven gas compressors*	
Overview	Gas compressors are mechanical devices allowing to increase the pressure of gas, and thereby trigger gas flows in pipelines for delivery to markets, and flows in and out of gas storage units. Gas compressors may be driven by gas-fired reciprocating engines, gas turbines, or electric motors. The presence of electricity-driven gas compressors can have a significant impact on security of supply in extreme events (e.g. in case of electricity black-out, gas could not be taken out of storage to supply OCGTs, CCGTs or gas-fired CHPs).
Direct/Indirect nature of the interlinkage	Electricity-driven gas compressors are direct interactions since these technologies can be seen as taking electricity and gas as inputs, and generate gas.
Typical size and number of instances in 2018	Typical size: 20 to 75 BHP, i.e. 15 to 55 MW
Relation with ENTSOs' Scenario Building Exercise	The deployment of gas compressors should be coherent with the evolution of the gas demand in the ENTSOs' assessment (gas compressors are a type of project collected as part of the TYNDP project collection process). The electricity consumption of electricity-driven gas compressors should be accounted for in the electricity demand but will remain limited.
Impact on gas and electricity prices	Electricity-driven gas compressors are likely to have a low structural impact on electricity prices, except in during peak electricity demand periods where a high demand for electricity triggers a demand for extracting gas from storage, which would then impact the electricity prices by increasing the

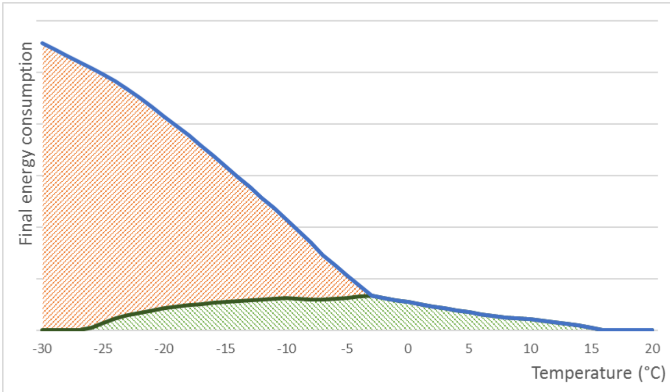
	electricity demand from electricity-driven gas compressors.
Impact on infrastructure projects	The presence of electricity-driven gas compressor in a system creates a security of supply interaction between gas and electricity. Indeed, a blackout can make inoperable gas facilities like gas storage that are relying on electric compressors, which could trigger gas and power curtailments..

4.4.6 Hybrid generation of industrial heat

Interaction #6 – *Hybrid heating technologies* – hybrid generation of industrial heat	
Overview	Industrial heat can be generated by a number of different technologies, among which gas furnaces (the gas combustion heats air that is distributed via a blower motor) and electric boilers (water is heated to generate steam, which is then distributed through a series of pipes). High-temperature heat is mainly supplied by gas solutions. Coupling both gas-based and electricity-based technologies allows for a greater flexibility and adaptability (e.g. to adapt the consumption to the gas and electricity prices). For example, one could imagine electric resistances immerged in fossil-fuelled boilers (see e.g. [21] and [22]). In [21], the authors estimate that electricity-driven equipment could replace up to several dozen Mtoe of natural gas in the industry if the cost of electricity and of the technologies themselves continue to decrease. However, the economic potential for hybrid equipment is not discussed.
Direct/Indirect nature of the interlinkage	Hybrid heating technologies are direct interlinkages since the can consume both gas and electricity to supply heat.
Typical size and number of instances in 2018	Currently the hybrid heating technologies are not very developed in Europe.
InRelation with ENTSOs' Scenario Building Exercise	In their scenarios, the ENTSOs publish the number of hybrid heat pumps. Further details related to the hybrid equipment in the industry could be a useful addition. The assumptions should be consistent with the amount of energy that is needed for low- to high- temperature applications, and with the electricity generation and transmission capacities. If relying on variable e-RES, gas generation capacities might also be considered to provide flexibility.
Impact on gas and electricity prices	The presence of hybrid equipment can significantly impact gas and electricity prices by dynamically adapting to electricity and gas prices, although the inertia of the various hybrid solutions may reduce the ability to react to price signals.
Impact on infrastructure projects	The deployment of hybrid industrial equipment may impact the need for network reinforcements, depending on what the alternative technologies are. Unless very large industrial complexes begin using hybrid technologies or high-temperature applications use electricity instead of gas, the

	deployment of hybrid technologies will not be one of the key drivers of the value of potential infrastructure projects. .

4.4.7 Hybrid heating equipment for domestic or district heating use

Interaction #7 – *Hybrid heating technologies – Hybrid equipment*	
Overview	Hybrid individual heat pumps can be deployed in residential and tertiary environments. These devices primarily use electricity to produce heat. However, as the temperature decreases, the efficiency of the heat pump drops. One of the solutions to avoid over-dimensioning heat pumps (and the accompanying infrastructure such as electricity generation and storage capacities) is to use a backup heater, which can be gas-fired.  **Figure 6 - Back-up (red) and heat-pump (green) consumption Source: Artelys** Hybrid heat-pumps can therefore provide flexibility to the electricity systems by progressively switching to a gas boiler mode as temperature decreases and/or when the electricity prices are high. In district heating applications, where centrally generated heat is distributed for domestic or tertiary use, hybrid heat-pumps can also participate in the provision of heat next to CHPs, geothermal/solar heat, waste heat, etc. As in a domestic application, heat pumps on district heating networks can be combined with gas boilers.
Direct/Indirect nature of the interlinkage	Hybrid heating technologies are direct interlinkages since they can consume both gas and electricity to supply heat.
Typical size and number of instances	The typical size of a residential/tertiary heat pump is around 2-20 kW_{th}, while those active on district heating applications can reach over 20 MW_{th}. Several commercially available heat-pumps for domestic applications have the ability to dynamically switch from one fuel to the other depending on the respective prices of gas and electricity.

Relation with ENTSOs' Scenario Building Exercise	In their scenarios, the ENTSOs publish the number of heat -pumps, including the number of hybrid heat-pumps. Adding details related to the capacity and efficiencies of these technologies could be a useful step forward. The assumptions should be consistent with the amount of energy that is needed to supply heat-pumps, with the electricity generation capacity, with gas supply and the electricity and gas transport infrastructure. If heat-pumps are primarily linked with a strong variable e-RES deployment, gas generation capacities might also be considered to provide flexibility.
Impact on gas and electricity prices	Hybrid heat pumps can significantly impact power prices during very low temperature episodes by shaving electricity consumption peaks, compared to a situation where heating is only relying on heat-pumps. If hybrid heat pumps are temperature driven, switching to a gas consumption when the temperature becomes lower than a threshold, additional infrastructure projects will not impact their operational management. However, if the hybrid heat pumps share in the heating mix becomes very important and their operation is price-driven, the switch in consumption from electricity to gas (or the opposite) could lead to change in gas and electricity prices.
Impact on infrastructure projects	The deployment of hybrid heat pumps may impact the need for network reinforcements, depending on what the alternative technologies are and may impact the assessment of infrastructure projects.

4.5 Indirect interlinkages

4.5.1 Mobility

Interaction #8 – *Mobility: electric mobility and gas mobility*	
Overview	In the mobility sector, electricity and gas-powered vehicles (hydrogen/liquefied or compressed methane) will likely see their share increase in the coming years and decades, and progressively replace conventional vehicles using high-carbon fuels. The role of electricity, gas and synthetic fuels in mobility depends on a number of factors: costs of producing the vehicle, cost of producing the fuel, constraints associated to each technology, sector (passenger cars, delivery vans, trucks, vessels, planes, etc.). Some sectors might not allow for a straightforward electrification (e.g. heavy duty, shipping, aviation). One should also note that there is a certain degree of inertia when it comes to choosing between various potential mobility technologies.
Direct/Indirect nature of the interlinkage	Mobility is an indirect interlinkage since electricity and gas interact via a third sector, and do not directly interact via electric or gas vehicles.
Typical size and number of instances	In 2016, there were around 200 000 electric vehicles (see e.g. [23]) and around 1 300 000 gas vehicles in Europe (see e.g. [24]).
Relation with ENTSOs' Scenario Building Exercise	The deployment of electric and gas vehicles is a choice that has to be made during the scenario development phase, in a coherent and consistent way with the installed capacity for power generation, gas supply, electricity and gas transport infrastructure, etc.
Impact on gas and electricity prices	Choosing a portfolio of vehicles rather than another one will have a very important impact on gas and electricity prices, especially as conventional high-carbon fuels are phased-out. The impact of electric mobility on prices is complex to apprehend since electric cars might also be a source of flexibility (power-to-grid mode) for the power system.
Impact on infrastructure projects	The assessment of a given infrastructure project is highly likely to be considerably impacted by the assumptions related to mobility. However, as noted above, the choice of mobility solutions made at the Scenario Building stage should be coherent with other assumptions, and in particular with the gas and electricity infrastructure (e.g. more power supply infrastructures are needed in a scenario with a high share of electric mobility). Therefore, one should be careful when performing sensitivity analyses of the assessment of

	an infrastructure project to the composition of the mobility fleet. Indeed, changing the composition of the mobility fleet ceteris paribus might lead to unrealistic valuations of the considered infrastructure project. For instance, considering a scenario with a higher electric mobility without adapting the electric supply infrastructures will increase the electricity prices and increase the potential benefits from interconnection with other countries.

4.5.2 Heating

Interaction #10 – *Heating – Gas heating and electric heating*	
Overview	A wide range of technologies can supply heat, some are using electricity, others are using gas, and then some can use either gas or electricity. Hybrid technologies have been addressed in previous sections, this fiche only concerns gas heating and electric heating.
Direct/Indirect nature of the interlinkage	Heat is an indirect interlinkage since electricity and gas interact via a third sector, and do not directly interact via electric or gas heating technologies (only caveat being hybrid technologies treated in previous sections).
Typical size and number of instances	The typical size of heating systems depends on their application (residential/commercial/industry/district heating/etc.)
Relation with ENTSOs' Scenario Building Exercise	The deployment of electric and gas heating technologies is a choice that has to be made during the scenario development phase, in a coherent and consistent way with the installed capacity for power generation, gas supply, electricity and gas transport infrastructure, etc.
Impact on gas and electricity prices	Choosing a portfolio of heating technologies rather than another one will have a very important impact on gas and electricity prices. Indeed, a high share of electric heating will increase the seasonality of electric prices.
Impact on infrastructure projects	The assessment of a given infrastructure project can be impacted by the assumptions related to heating. However, as noted above, the choice of heating solutions made at the Scenario Building stage should be coherent with other assumptions, and in particular with the gas and electricity infrastructure. Therefore, one should be careful when performing sensitivity analyses of the assessment of an infrastructure project to the heating technologies portfolio (changing the composition of the heating sector ceteris paribus might lead to unrealistic valuations of the considered infrastructure project). Indeed, increasing the share of electric heating without increasing peak generation will increase prices at peak hours.

4.5.3 Biogas

Interaction #10 – *Biogas*	
Overview	Biogas is produced by breaking down organic matter (animal by-products, vegetable by-products, waste, dedicated crops). Biogas is primarily composed of methane and carbon dioxide. Biogas can be used in a wide range of applications: it can serve as a fuel after having been compressed, can be used by CHPs to produce electricity and heat, etc. A number of additional applications require biogas to undergo a cleaning and upgrading process so as to be turned into biomethane (CH_4) by removing water, CO2, hydrogen sulphide, etc. Biomethane can be injected into the gas network and be employed for applications ranging from electricity production to domestic heating or mobility.
Direct/Indirect nature of the interlinkage	Biogas is an indirect interlinkage between the electricity and gas sectors as biogas can either be turned into electricity (e.g. in CHPs) or be injected into the gas grid (when installations can dynamically switch between a gas-injecting mode and CHP mode according to electricity and gas prices, this interaction could be considered as being a direct interaction)
Typical size and number of instances in 2018	Biogas can be produced in installations requiring from circa 10 000 tonnes of biomass per year (e.g. individual farms, small waste processing units) to up to 100 000 tonnes per year (e.g. animal by-products processing plants, large waste processing plants).
Relation with ENTSOs' Scenario Building Exercise	Assumptions related to the way biogas is being used (mainly share being injected into the gas network and share being dedicated to electricity production) should be part of the assumptions that are made during the Scenario Building Exercise. These assumptions have to be consistent with the electricity demand (since CHPs burning biogas can reduce the needs for electricity supply) and gas supply (since biomethane can be injected into the gas grid). Furthermore, the infrastructure should also be dimensioned so as to be able to cope with the way the scenarios assume biogas is being used.
Impact on gas and electricity prices	Choosing a portfolio of biogas applications rather than another one will have a very important impact on gas and electricity prices, especially in scenarios with important biogas deployment, as it will either reduce the needs for electricity supply (if biogas is directly burnt) or reduce the gas import needs (if biogas is mostly converted to biomethane)

Impact on infrastructure projects	The assessment of a given infrastructure project can be impacted by the assumptions related to biogas. However, as noted above, the assumptions related to the way biogas is used that are made at the Scenario Building stage should be coherent with other assumptions, and in particular with the gas and electricity infrastructure. Therefore, one should be careful when performing sensitivity analyses of the assessment of an infrastructure project to the biogas exploitation portfolio (changing the way biogas is being used ceteris paribus might lead to unrealistic valuations of the considered infrastructure project). Indeed, reducing the share of bio-gas direct use for electricity and increasing the bio-methane generation without adapting the electricity mix will increase electricity prices and increase the potential value of electric interconnectors.

5 Task 1 Webinar – Summary of the feedback

On 10 October 2018, during a webinar organised by the ENTSOs, Artelys has presented the results of Task 1. The attendees, representing gas and electricity TSOs, NGOs, European institutions, etc., have had the occasion to share suggestions and to ask questions.

We provide a summary of the main themes of interest below:

Exhaustivity of the Sankey diagram

Some comments have been made on the Sankey diagram use for the scenario building exercise. In particular, participants mentioned that some elements are missing:

- Alternative sources for heat
- The role of interconnectors and of energy efficiency
- The electricity consumption of some CO_2 capture processes

Answer: While they are not displayed for simplification of the diagram, these elements are captured by the Scenario Building exercise. Details have been added in Section 4.3.

Power-to-gas operation

One participant mentioned that the use of power-to-gas is not limited to RES-e surplus periods, but that in some scenarios power-to-gas installations will have to run even in periods of relatively high electricity prices.

Answer: The paragraph on power-to-gas has been updated and now accounts for situations in which the gas production via power-to-gas is not limited to periods of RES-e surplus.

Power-to-gas development

Participants asked if the injection of both hydrogen and SNG into the gas grid was taken into account. Another participant mentioned that power-to-hydrogen will likely be deployed before power-to-gas.

Answer: The report mentions both H2 and SNG injection and both are considered in the study. On the second point, studies show indeed that the economic viability threshold of P2H is likely to be reached before that of P2G.

Gas prices

Participant asked some precisions about the denomination 'prices' in the report.

Answer: In the report, prices refer to commodity prices for both gas and electricity, i.e. the prices of gas and electricity in the network or equivalently the marginal gas and electricity prices. It has been clarified in Section 4.3.

6 Glossary

ACER	Agency for the Cooperation of Energy Regulators
CBA	Cost benefit analysis
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CHP	Combined heat and power
ENTSO-E	European Network of Transmission system operators of electricity
ENTSOG	European Network of transmission system operators of gas
e-RES	Renewable energy sources of electricity
HP	Heat pumps
OCGT	Open cycle gas turbine
RES	Renewable energy sources
SMR	Steam methane reforming, for hydrogen production
SNG	Synthetic natural gas
TYNDP	Ten-year network development plan

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