Artelys | OPTIMIZATION SOLUTIONS

entsog european network of transmission system operators for gas

entsoe Reliable Sustainable Connected

Focus study – Interlinkages between gas & electricity

Workshop

Brussels, 15 May 2019

Artelys

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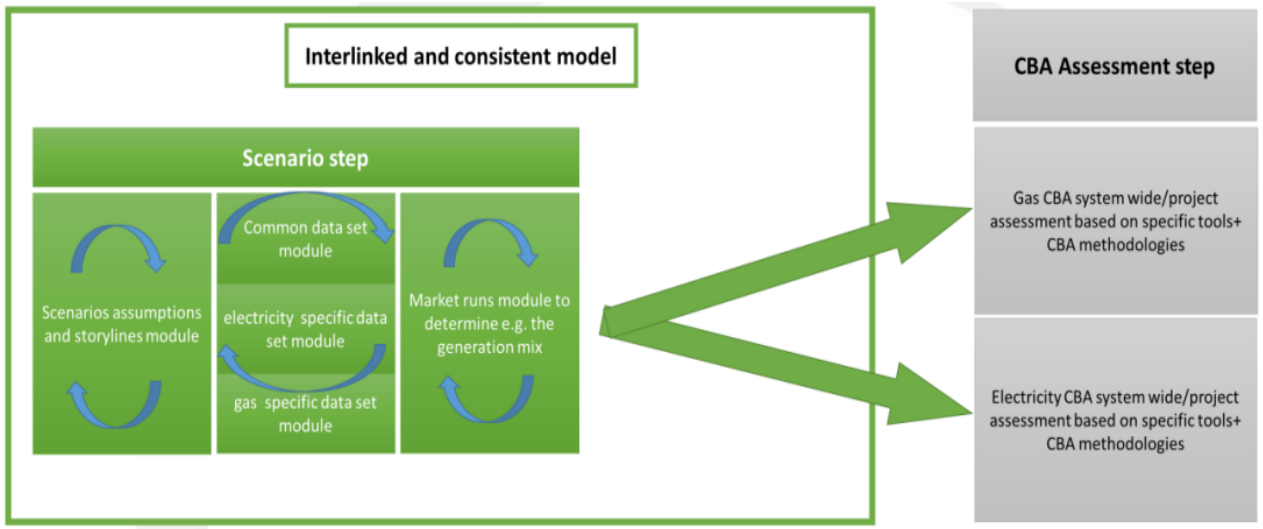
Objective of the focus study

What is this focus study about?

The overall objective of the study is to provide the ENTSOs with recommendations on the key ingredients to build a screening methodology to assess which projects should be subjected to a more thorough investigation of the gas-electricity interlinkages (dual system assessment).



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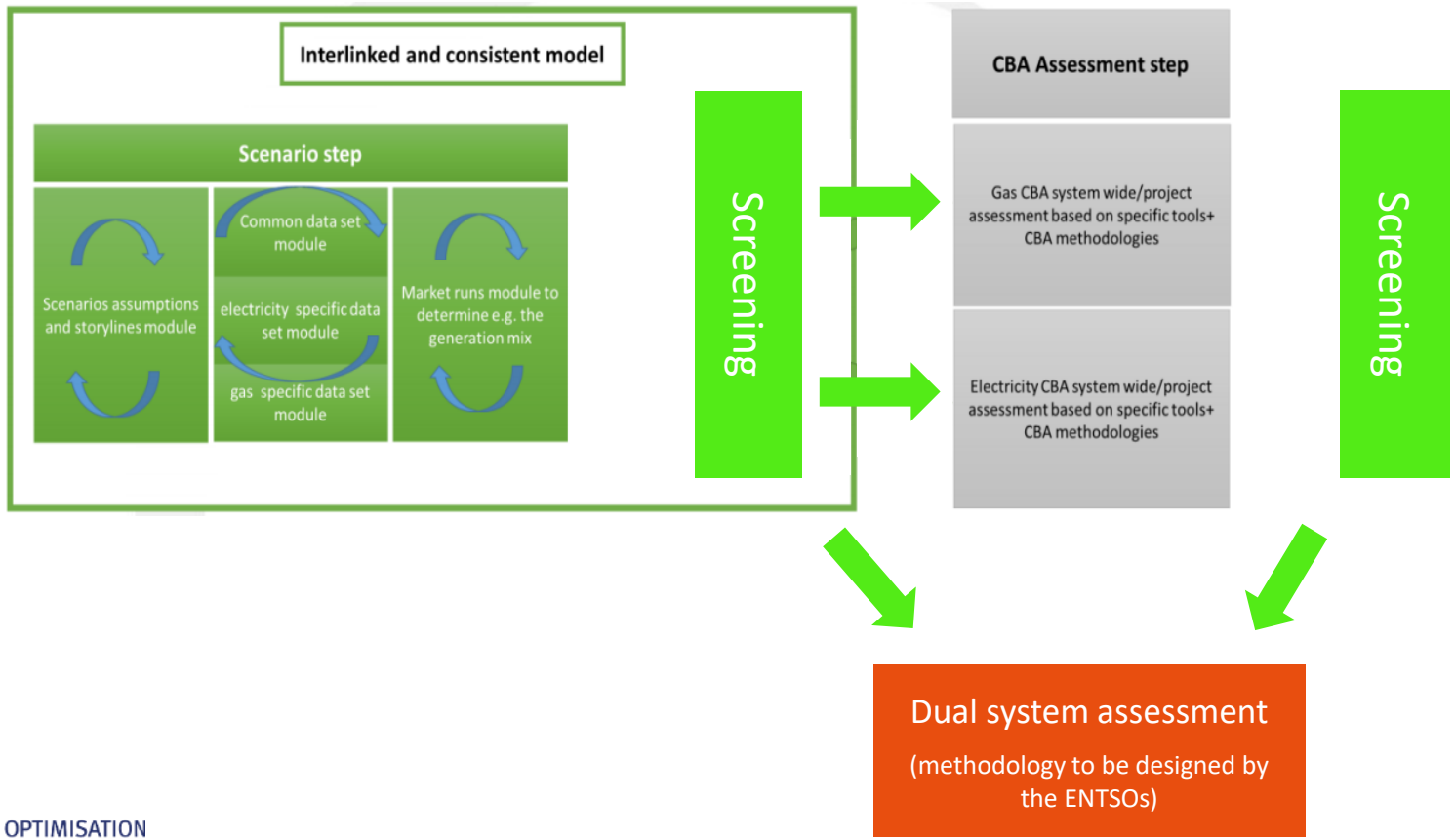
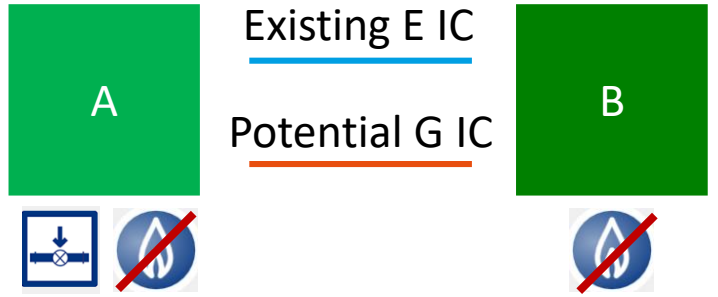


Example 1 – Situation where a SSA is sufficient

- Context
  - Two regions (A and B), both consuming gas
  - Region A has access to a source of gas, Region B has a growing gas demand for **heating**
  - The gas interconnector between A and B is congested
  - Both regions have a very low share of electricity being generated with gas-fired power plants (e.g. less than 1%)
  - No P2G or hybrid gas/electricity heating present in any of the regions

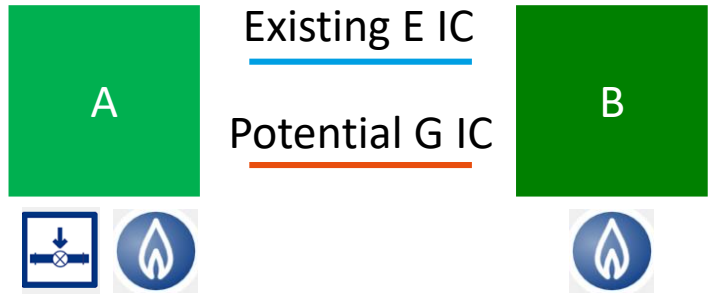
- Project
  - Gas interconnector to meet B's growing gas demand for heating

- Decision
  - The interlinkage between gas and electricity is low → a single system assessment is well adapted to this situation



Example 2 – Situation in which a DSA may be necessary

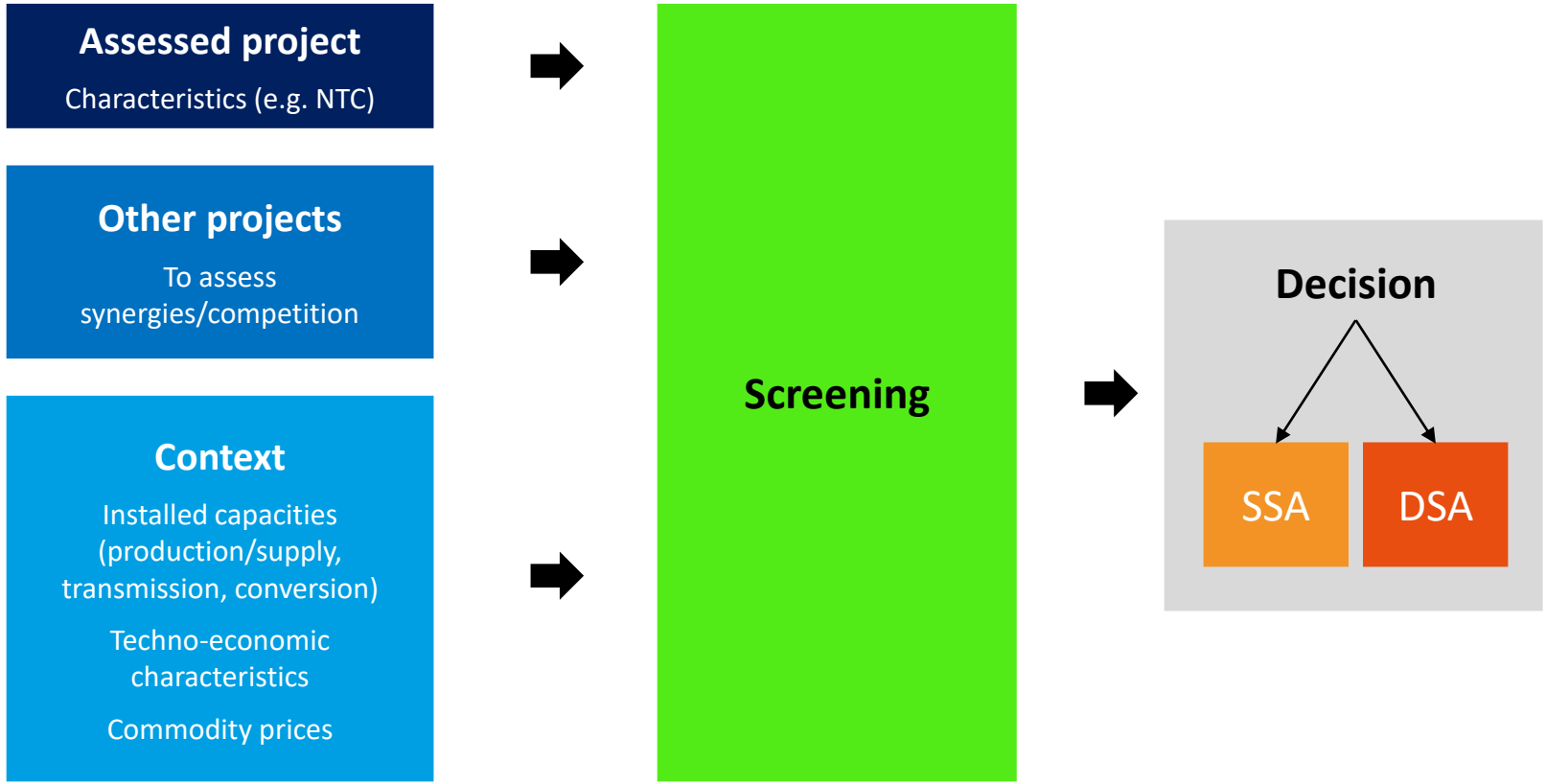
- Context
  - Two regions (A and B), both consuming gas
  - Region A has access to a source of gas, Region B has a growing gas demand for **gas-to-power units**
  - The gas interconnector between A and B is congested
  - There are very significant capacities of CCGTs/OCGTs in both regions (25%+ of gas-based generation in electricity)
  - No P2G or hybrid heating present in any of the regions
  - An electricity interconnection links A and B
- Project
  - Gas interconnector to meet B's growing gas demand for gas-to-power units
- Decision
  - Here, the interlinkage between gas and electricity is important → a dual system assessment may be necessary



Considering the electricity system may highlight that the increase in consumption can be managed using the flexibility of the electricity system.

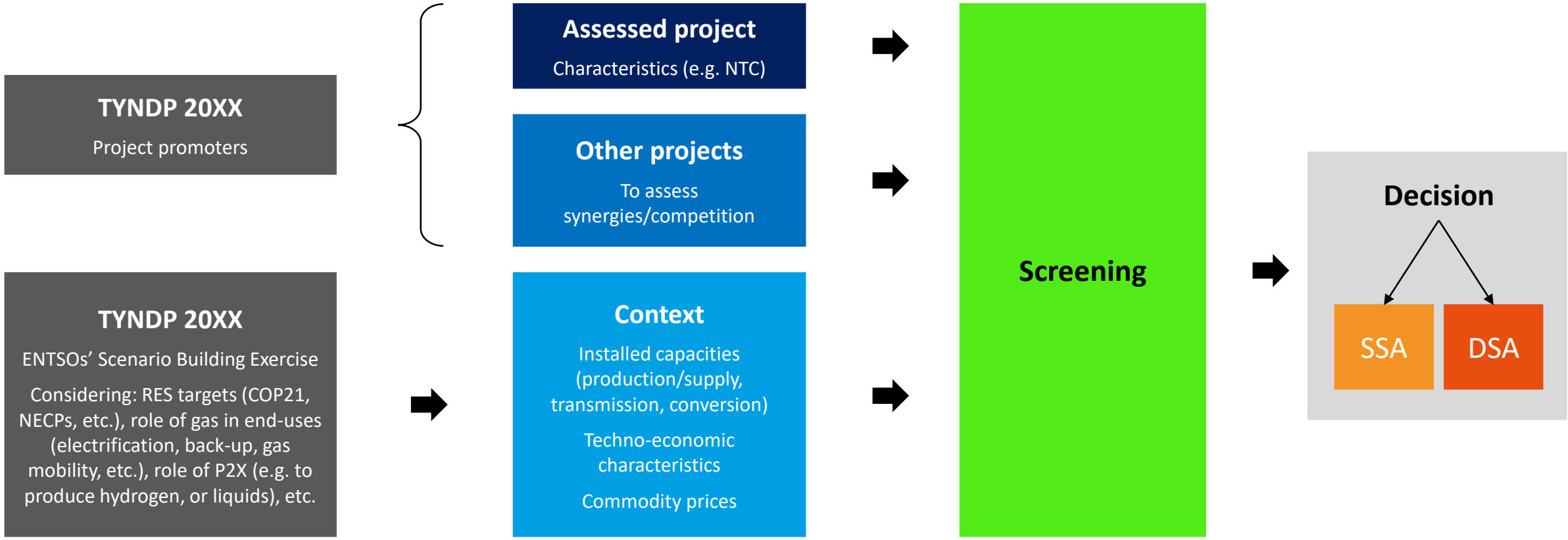
For instance, depending on the available flexibilities, it may be possible to import electricity in B with the existing infrastructure instead of increasing the gas interconnection capacity.

A closer look at the inputs of the screening methodology



SSA: Single system assessment DSA: Dual system assessment

A closer look at the inputs of the screening methodology



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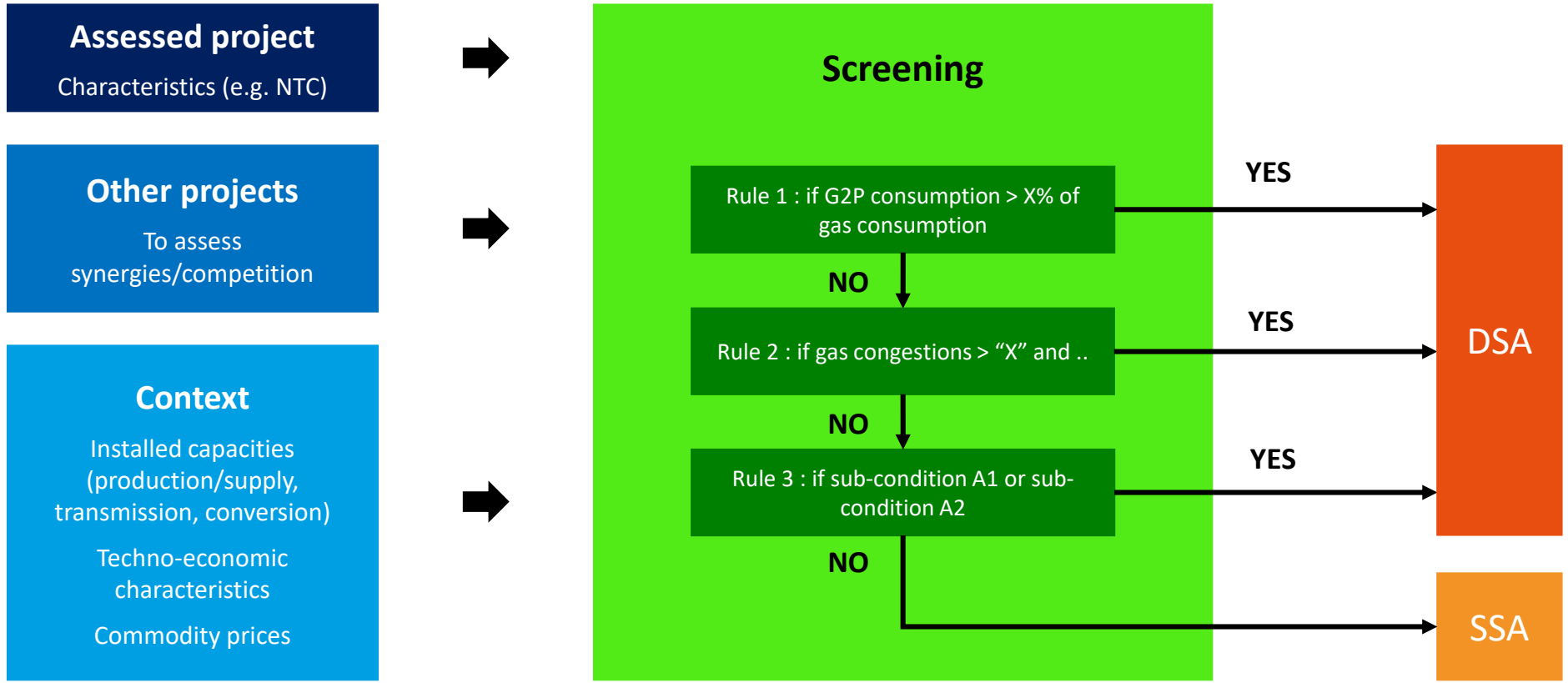
SSA: Single system assessment

DSA: Dual system assessment

Structure of the screening methodology

Our recommendation is that the screening methodology could take the following form : a checklist of conditions taking as inputs the datasets generated during the scenario building exercise.



Structure of the project

The project has been organised in four tasks:

1. **Identify the interlinkages between gas and electricity**
   - Systematic mapping of all interlinkages between the gas and electricity systems
   - Establishing what is already captured the scenario building step

2. **Understand what phenomenon can create interactions and what are the key parameters impacting their intensity**
   - A qualitative analysis of the interactions created by the interlinkages
   - Highlighting the key parameters affecting the interactions

3. **Determine thresholds/conditions under which a project should be subject to a dual assessment**
   - Large quantity of **simulations** with different type of projects and different structure of energy (gas/electricity) mix to capture the sensitivity of the assessment of a project to key parameters
   - Identification of thresholds/conditions via analysis of the results (e.g. statistical analysis, clustering)

4. **Design of a workflow combining the thresholds/conditions identified in Task 3**

What this study is *not* about

- **Scenario Building**

Whilst the screening methodology will take as input elements of the scenarios (which already capture some of the interlinkages: level of electrification, role of P2G, deployment of hybrid heat pumps), the objective of the study is not to analyse the scenario building methodology.

- **CBA methodologies**

The study is not providing recommendations on single-system CBA methodologies.

- **Dual system assessment methodology**

The study is not providing recommendations on the design of the dual system assessment methodology. This methodology will be designed by the ENTSOs. The study however provides recommendations on what aspects to look at when assessing the dynamic interactions between gas and electricity

- **Assessing specific projects**

The study does not consider specific infrastructure projects. The simulations performed during the course of this project are not representative of specific projects.

Structure of the presentation

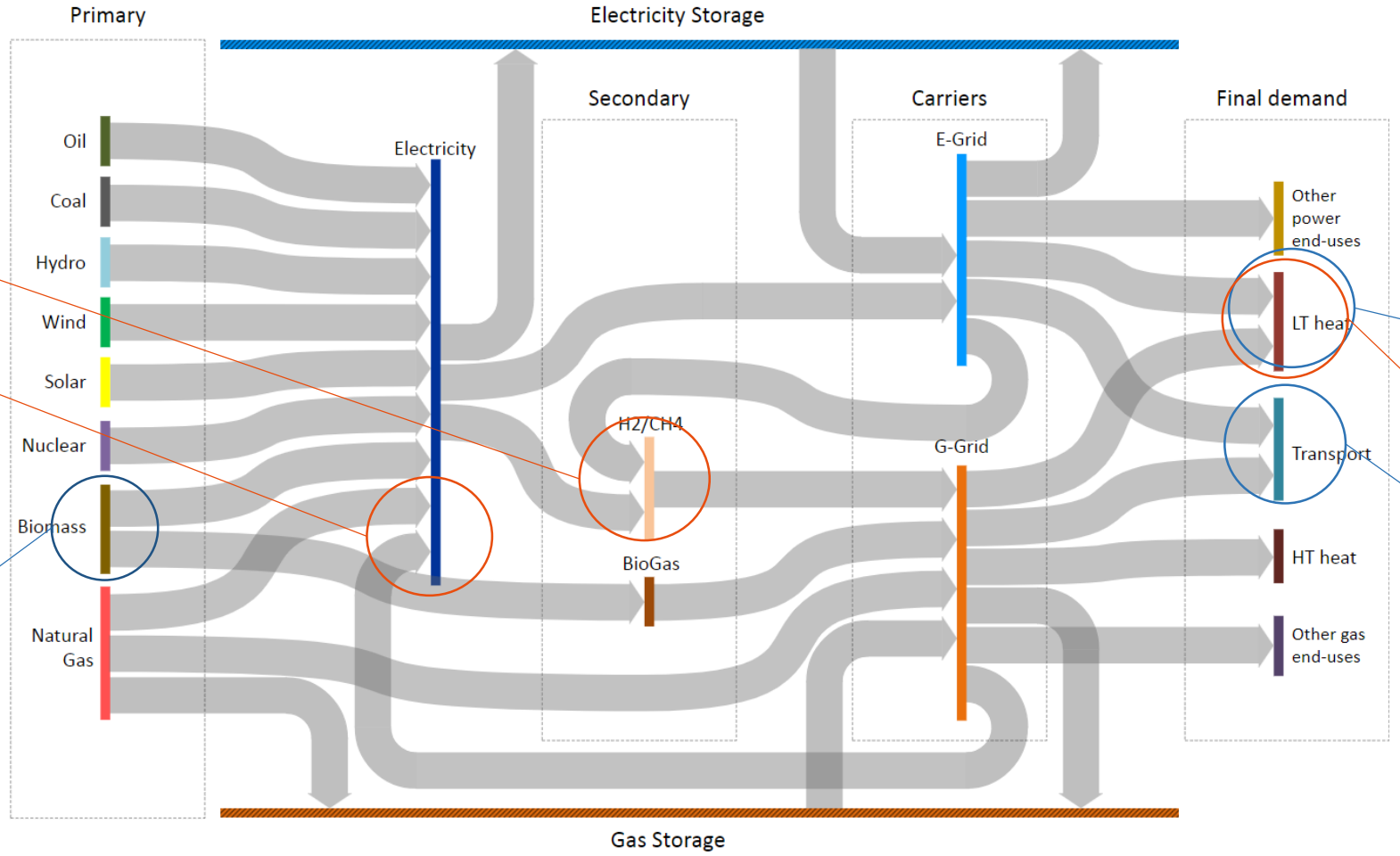
The presentation of the main findings of the project is organised as follows:

1. Mapping of gas/electricity interlinkages

2. Effect of gas/electricity interactions on project assessment
   - This section is divided by interlinkages, considering the most relevant interlinkages identified during the mapping, i.e. gas-to-power, power-to-gas and hybrid consumption technologies. For each interlinkage we look at:
   - the gas/electricity interactions it creates,
   - The potential effect on infrastructure assessment
   - Main parameters that affect the interactions and effects on infrastructure assessment

3. Overview and example of application of the proposed screening methodology

Mapping of the interlinkages between gas and electricity



Power-to-gas

Gas-base electricity generation (GT, CHP)

Trade-off between biomass direct use for electricity or bio-methane

Heating mix (gas boilers, HPs, hybrid HPs, ..)

Hybrid heating

Transport mix (oil, electricity, gas)

Indirect interactions

Direct interactions

Mapping of the interlinkages between gas and electricity

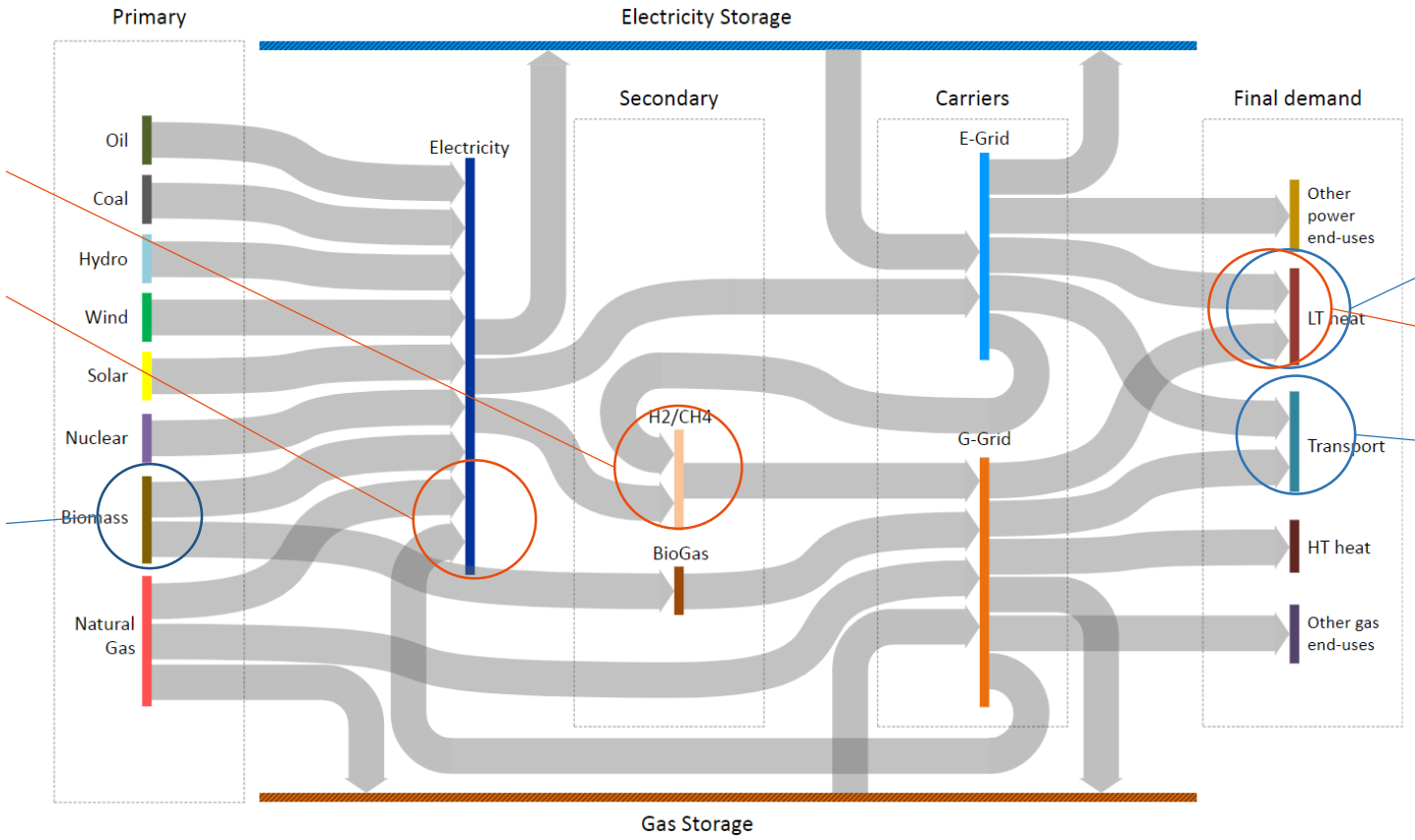
Interlinkages can be indirect (competition between technologies, usually taken into account during the scenario building step) or direct (technologies that dynamically link the operation of gas and electricity systems).

Three main categories of direct interlinkages were identified : P2G, G2P, and hybrid consumption technologies (e.g. HPs)

Power-to-gas

Gas-base electricity generation (GT, CHP)

Trade-off between biomass direct use for electricity or bio-methane



Heating mix (gas boilers, HPs, hybrid HPs, ..)

Hybrid heating

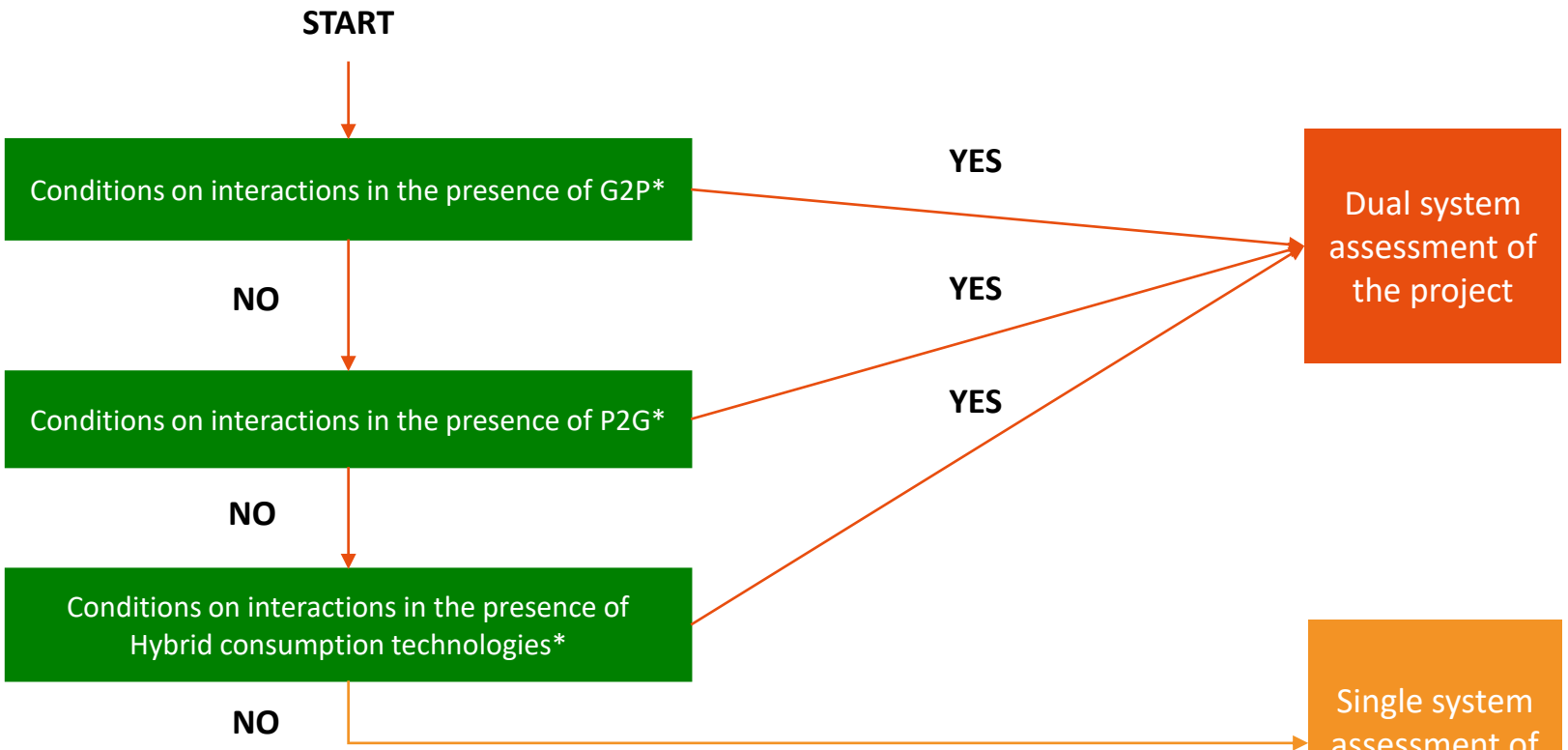
Transport mix (oil, electricity, gas)

Indirect interactions

Direct interactions

Overview of the proposed screening methodology

Given the interlinkages identified, the screening methodology for a given project in a given scenario could be structure as follows:



* To be checked for both connected areas, for an interconnection project

Interactions in the presence of gas-to-power

Interaction in the presence of G2P

G2P creates interlinkages on different time scales

At the daily level, gas consumption for G2P can be very 'peaky' due to constraints on the power system (e.g. very low during off-peak hours, at maximum capacity during peak hours). The variability of the gas consumption is not in itself a problematic constraint for the supply/demand equilibrium, as it can be absorbed to a large extent by linepack storage.

At a monthly or weekly scale, the variability of the gas consumption for G2P can be significant, in particular in an area where the electric system has a large share of wind power. Indeed, in the case of weeks with low wind, a significant gas storage capacity might be necessary. However, this need for storage is covered by seasonal storage assets.

The main concern for the G2P gas consumption is at an annual level, if the gas supply capacity is not sufficient to cover the additional gas demand for G2P (e.g. in the case of limited supplier or congested capacities), which can be non-negligible in areas with large share of G2P.

The G2P can also create a need for gas storage capacity to be able to cover the additional seasonal variability of the gas demand due to the G2P gas consumption.

Interaction in the presence of G2P

G2P creates interlinkages on different time scales

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The G2P can also create a need for gas storage capacity to be able to cover the additional seasonal variability of the gas demand due to the G2P gas consumption.

→ Focus on the annual time scale for G2P

Interaction in the presence of G2P (2)

Effects of G2P on project assessment in areas with a high share of G2P

Assessment of electricity projects	Assessment of gas projects
In areas with limited gas supply or expensive gas, electricity interconnections can reduce the use of G2P by importing electricity from non-constrained neighbours (provided the neighbouring area has available generation) This affects the value of electricity infrastructure, which gains an additional value while taking into account gas constraints. The value of the electricity interconnection related to the potential reduction of gas constraints would diminish if the gas constraints are less important, e.g. in the case of a higher gas interconnection with neighbouring areas	In areas with limited gas supply or expensive gas, gas interconnections can allow to avoid congestions or allow the import of gas from cheaper sources. This reduces the costs of electricity generation by G2P and the overall costs for the electricity system. The addition of flexibility on the electricity side can reduce the value of the gas infrastructure since the electricity network would be used to transfer G2P generation from one area to the other (instead of transferring gas)

Interaction in the presence of G2P (3)

The interactions between gas and electricity systems in the presence of G2P depends on the following key parameters:

- The share of G2P consumption compared to the overall gas demand
  - If G2P only plays a minor role in the gas system, the impact of the interaction on the assessment will be small
- The presence of constraints on the gas system
  - The import capacity : the higher the import capacity the lower the gas constraints, which makes SoS issues less frequent
  - The gas storage capacity
  - The difference of gas price with the neighbouring area
- The presence of flexibilities in the electricity system that can reduce the use of G2P
  - **Presence of flexibilities such as electricity storages (capacity and volume),**
  - **Electricity interconnections capacities**
  - Demand-side response
  - Presence of more expensive non-gas generation (e.g. oil, biomass, ..)

Interactions in the presence of power-to-gas

Interaction in the presence of power-to-gas

The interaction created by P2G differs depending on P2G operation

Power-to-gas can/could be operated with a dedicated electricity generation capacity (e.g. in North Sea, directly below wind projects). In this case, the project can be considered as a pure gas production. As such, it is independent from the electricity wholesale market and does not constitute a relevant gas/electricity interlinkage.

Power-to-gas can/could be operated to satisfy a given need of gas (e.g. a given hydrogen consumption in a specific industrial complex). In this case power-to-gas activation is driven by the needs of the industry and the installation can be considered as a pure electricity consumer (with specific characteristics depending on the gas use). As such it does not create a relevant interlinkage between gas and electricity systems.

Power-to-gas can be operated based on the electricity wholesale market price. In this case its capacities are activated when the electricity price is lower than the price of gas in the gas network times the efficiency of the P2G technology (and including the potential savings in CO2). This creates a direct interlinkage between both systems which can lead to several constraints / issues on volume, gas exports/imports or storage.

Similarly, power-to-gas capacities operated for network purposes could be dynamically taking into account local congestions (and local surplus of electricity). As such it creates a direct interlinkage between both systems.

Interaction in the presence of power-to-gas (2)

Effects of P2G on project assessment in areas with a high share of P2G

Assessment of electricity projects	Assessment of gas projects
Price-driven power-to-gas capacities are competing with exports and/or storage for the use of cheap electricity, since they reduce the volume of electricity available for exports or storage and increase the local price of electricity. Hence, the benefits brought by electricity interconnections which export electricity from an area with P2G is generally reduced by the presence of price-driven P2G. In some cases, there can however be synergies between P2G and interconnectors (or storage assets), in situations where P2G would create surplus of gas in an area.	As a gas source, power-to-gas can reduce the needs for additional import capacities in the area and needs to be taken into account when assessing gas infrastructure projects. This requires P2G projects of several hundred MW to materialise. If the gas production from P2G is too high to be absorbed by the system (i.e. it creates surpluses), it can increase the value brought by gas interconnection projects. We expect this case to be quite exceptional, for example in the case of large wind farms coupled with electrolysers, which are not expected to be dynamically driven (and thus will not create interactions)

Interaction in the presence of power-to-gas (3)

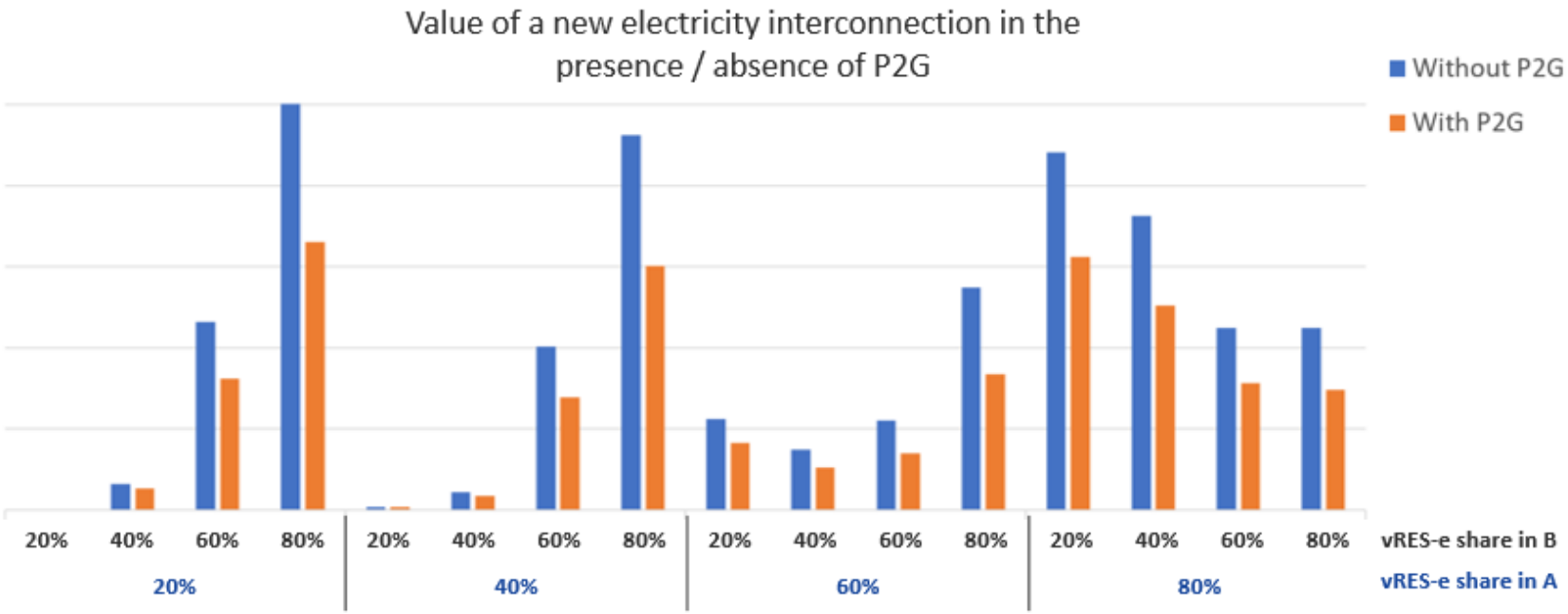
The interactions between gas and electricity systems in the presence of **dynamically driven** P2G depends on the following key parameters:

- The capacity of P2G compared to the capacity of low variable-costs generation (RES-e, nuclear)
  - If P2G capacities are not significant, their effect will remain very low.
- The share of generation with low variable costs in the system (RES-e, nuclear), and the flexibilities in the electricity system
  - The volume of cheap electricity will greatly affect the potential volume of surplus, taking into account the flexibilities (storages) of the electricity system.
  - The volume of surplus directly affects the strength of the interaction
- The presence of gas surpluses due to P2G
  - If power-to-gas generation is such that it creates gas surpluses (taking into account gas exports and storage capacities), there can be an interaction with gas projects.
  - This in unlikely to occur at short-term but could become relevant in the future, e.g. in 2040.

Interaction in the presence of power-to-gas (4) - Illustration

In order to assess at what level of RES-e share the interaction became significant, we have performed simulations of a model representing 2 areas with market-driven P2G and various share of RES.

We compare below the value of a new electricity infrastructure in the presence/absence of P2G.



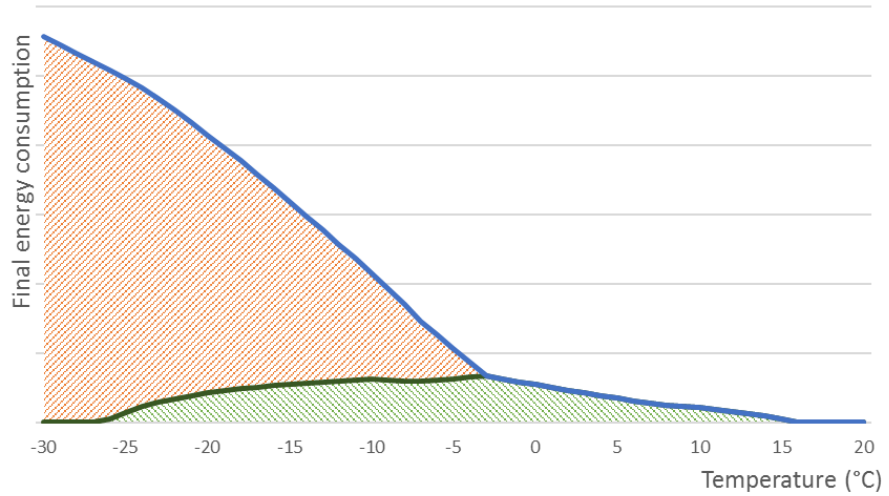
Interactions in the presence of hybrid consumption technologies

Interaction in the presence of hybrid technologies

Hybrid consumption technologies (HCTs) refer to energy consumption means that can be satisfied by gas or electricity depending on their hourly prices. In this section we have focused on hybrid heat pumps (HHP), currently the most developed HCT. The findings are then derived to all types of hybrid consumption we might encounter in the future.

Hybrid heat pumps systems are used to produce heat and composed of an electrical heat pump component and a gas boiler functioning as back-up. Due to its cost, the heat pump component is usually dimensioned to cover only a fraction of the heat demand and usually functions in priority given its low variable costs..

At very low temperatures, heat pump efficiency and capacity decrease.
The gas back-up covers most of the heat demand



At higher temperatures, the electric heat pump covers most or all of the heat consumption

Figure 6 – Operation of a temperature-driven hybrid heatpump. Back-up (red) and heat-pump (green) consumption. Source: Artelys

Interaction in the presence of hybrid technologies (2)

Hybrid heat pumps can create interactions between gas and electricity systems

If the hybrid heat pump is "temperature-driven", the electric heat pump always functions in priority. In this case, the interlinkage between gas and electricity systems is low as both consumptions can be considered independently from each other and are independent from the infrastructure.

If the hybrid heat pump is "price-driven", the gas back-up is activated in replacement of the heat pump when the heat generation cost of the boiler is lower than the heat generation cost of the heat pump, i.e. when :

$$\frac{\mathrm{GasPrice}}{\mathrm{boilerEfficiency}} \leq \frac{\mathrm{electricityPrice}}{\mathrm{heatpumpCoefficientOfPerformance}}$$

This can occur if the electricity prices are very high.

In this case, switching to the gas back-up to avoid the additional electric consumption of the heat pump can be beneficial to the electricity system, by reducing the stress at peak electricity hours and thus reducing the needs for additional capacity (typically OCGT or interconnections). This however requires having enough gas to switch.

Interaction in the presence of hybrid technologies (3)

Effects of HHPs on project assessment in areas with a high share of HHPs

Assessment of electricity projects	Assessment of gas projects
If the HHP is temperature driven, there is no dynamic adaptation of the consumption so there is no interaction. A single system analysis is sufficient.	If the HHP is temperature driven, there is no dynamic adaptation of the consumption so there is no interaction. A single system analysis is sufficient.
If the HHPs are price-driven and there are no significant constraints on the electricity system (i.e. the prices are not frequently very high), the HP component is used in priority. In this case, adding interconnection capacities will not affect the consumptions. HHP consumption has thus the same effect as any consumption.	In the case of price-driven HHPs, if there are no significant constraints on the electricity system (i.e. the prices are not frequently very high), the HP component is used in priority and the volume of electricity consumption switched to gas remains too low to be significant compared to he overall gas consumption of the HHPs.
If the switch between gas and electricity is significant, then adding electricity interconnections can reduce the need for the gas back-up.	If however the switch between gas and electricity becomes significant and creates constraints on the gas system, then it can have an effect on gas infrastructure assessment : indeed, adding new gas infrastructure could in this case allow a more frequent use of the gas boiler component.

Interaction in the presence of hybrid technologies (4)

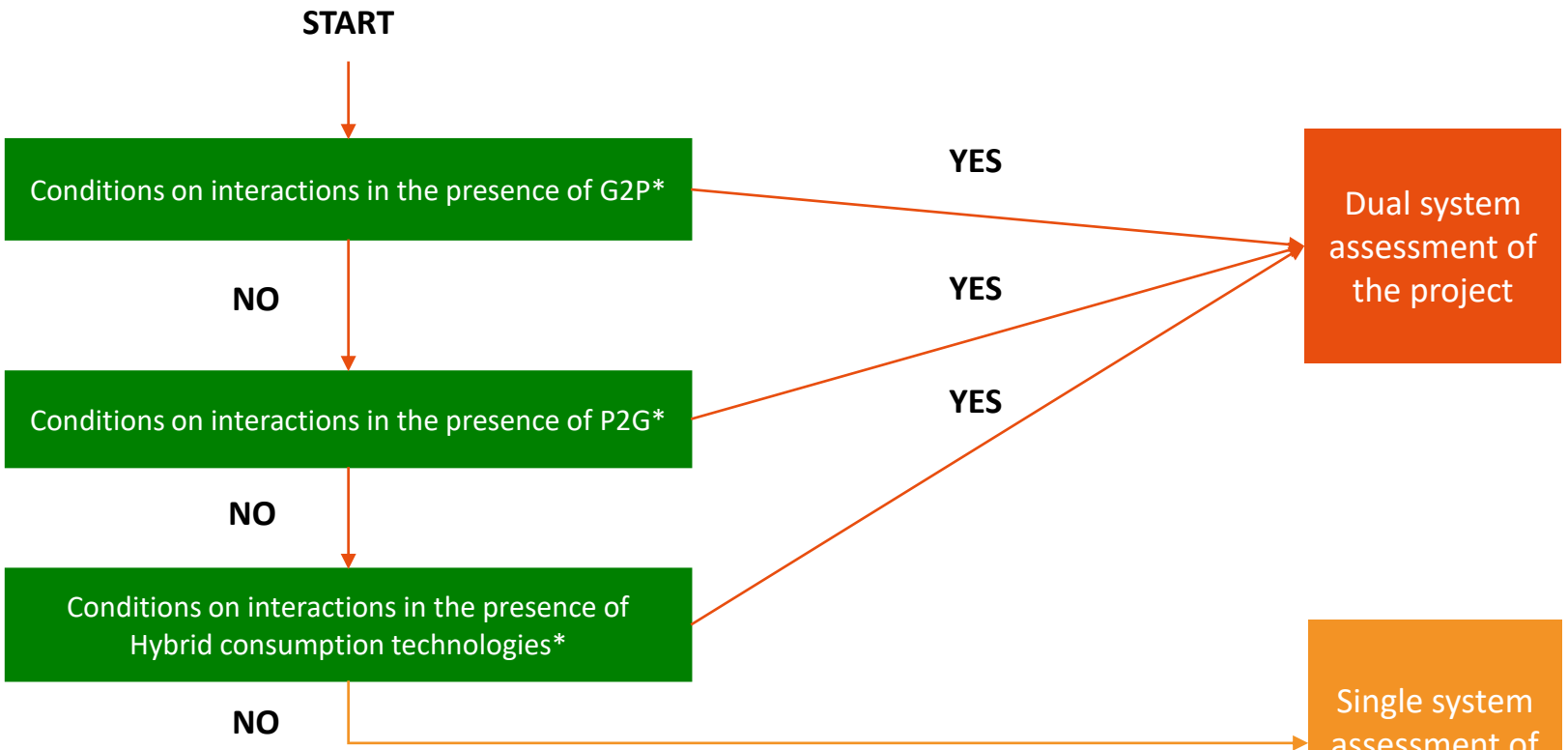
The interactions between gas and electricity systems in the presence of price-driven HHP (and other HCTs) depends on the following key parameters:

- The share of this consumption in comparison to the overall gas and electricity consumption
  - Indeed, if the price-driven HCTs remain low in volume, there will not be a need for a dual system assessment.
- The arbitrage opportunities between gas and electricity for the considered technology, depending on the efficiencies of the gas and electricity components
  - Indeed, if like the hybrid heat pumps, one component is preferred to the other, the dynamic switching between gas and electricity will remain marginal and will not generate interactions between gas and electricity that could require a dual system assessment.
  - The interactions starts occurring if the volume switched between carriers is frequent. For hybrid heat pumps, this occurs when there are significant constraints on the electricity system.
  - On the other hand, the switching to gas could be prevented if there are constraints on the gas system leading to a higher price (the arbitrage is thus not profitable)

Back to the screening methodology

Overview of the proposed screening methodology

Given the previous findings, the screening methodology for a given project in a given scenario could be structured as follows:



* To be checked for both connected areas, for an interconnection project

Conditions on interactions in the presence of G2P

For new gas and electricity infrastructure, the following conditions have to be checked to assess if there is an interaction due to G2P:

1. Existence of a significant amount of G2P in the gas system
   - An interaction is more likely to appear if the gas consumption for G2P is higher than 5% of the total gas consumption.
   - The threshold on this condition has been qualitatively assessed but could be reviewed after the use of the screening methodology on real projects.
2. Presence of gas constraints related to the use of G2P
   - An interaction occurs between gas and electricity only if there are constraints on the gas system (congestions, storage constraints or supply source dependence issues) due to the presence of G2P. This can be checked for instance with simulation results from the scenario building step.
3. Presence of electricity flexibilities to avoid gas consumption from G2P
   - If the flexibility of the electricity system can avoid to use G2P (possibly at a higher cost), there is an interaction between gas and electricity systems that requires a dual system assessment for a new asset.
   - One possibility to assess this flexibility could be to use simulation results of the TYNDP scenario building step and the indicators provided in this exercise. For instance, if LOLE is already high when using G2P, it means there is no available flexibility.

IF

G2P consumption >= 5% * gas consumption

AND

G2P creates gas SoS issues or congestions

AND

Presence of electricity flexibilities

THEN

Dual system assessment of the project

Conditions on interactions in the presence of P2G

The following conditions have to be checked to assess if there is an interaction due to P2G:

1. **Presence of a significant amount of dynamically operated P2G in the electricity system**
   - An interaction is more likely to appear if the P2G share is significant compared to the capacities of low-variable costs electricity generation
   - The threshold is based on quantitative analyses using Crystal Super Grid modeling. The case simulated cover a wide range of possibilities but are not exhaustive so the threshold could be reviewed after the use of the screening methodology on real projects.
2. **Presence of a substantial generation of low-variable costs technologies (nuclear, vRES-e)**
   - An interaction occurs when the share of low variable costs generation (vRES-e or Nuclear) is significant in comparison with the consumption, taking into account the consumption of storages.
   - This condition could be assessed using the results of energy mix of the TYNDP scenarios building step
3. **(only for gas projects) Quantity of P2G superior to the absorption capacity of the gas system**
   - If the P2G generation is such that there is surplus gas in the area, there is an interaction that requires a dual system analysis
   - This can be assessed after the scenario building step using the simulations of the gas model.

IF

Dynamically operated P2G capacity >= 5% of (Nuclear + vRESe) capacity

AND

$$\frac{\text{vRESe yearly Generation} + \text{Nuclear yearly Generation}}{\text{Electricity yearly consumption (incl. pumping)}} \geq 60\%$$

AND
(for gas projects only)

P2G Gas production + local gas production + imports ≥ exportable gas + storable gas + consumption

THEN

Dual system assessment of the project

Conditions on interactions in the presence of HCT

The following conditions have to be checked to assess if there is an interaction due to hybrid consumption technologies :

1. Presence of a significant amount of dynamically operated HCT in the electricity and gas systems
   - An interaction is more likely to appear when the dynamically operated HCT share is significant compared to the gas and electricity consumption, i.e. more than 5% of electricity or gas consumption. This threshold is based on quantitative analyses.
   - Given the current and forecasted deployment of hybrid technologies (especially for dynamically operated technologies) we anticipate that these constraints will not be met very frequently. .
2. Frequent arbitrage between gas and electricity consumption in the HCT
   - The interaction created by HCT occur only if the trade-off between using gas or electricity is a close call. Usually (e.g. for hybrid HPs) this will not happen.
   - This condition can be verifiable by looking at the efficiencies of gas and electricity components of hybrid technologies.

IF

Significant quantity of dynamically operated HCT

AND

Frequent arbitrage opportunities between gas and electricity

THEN

Dual system assessment of the project

Example of application of the methodology* (1)

Reference situation:

Areas	Total gas demand [TWh]	G2P demand [TWh]	Presence of gas constraints	Presence of electrical flexibilities	P2G capacities [GW]	Nuke + vRes capacities [GW]	Nuke + vRes production [TWh]	Electrical demand [TWh]	HCTs (Heat pumps) [GW]	Arbitrage gas – electricity opportunities
A	480	55	No (from simulations)	Yes (from simulation)	5	140	420	460	Negligible	-
B	45	8	No (from simulations)	Yes (from simulation)	1	11	14	60	Negligible	-

Application of the methodology*:

Interactions in the presence of G2P?

	Condition 1.1		Condition 1.2		Condition 1.3	
IF	Significant quantity of G2P in the system	AND	Presence of gas constraints	AND	Presence of electricity flexibilities	
In A:	TRUE		FALSE		-	→ FALSE
In B:	TRUE		FALSE		-	

Interactions in the presence of P2G?

	Condition 2.1		Condition 2.2	
IF	Significant quantity of dynamically operated P2G	AND	Significant share of low-variable costs electricity generation	
In A:	FALSE		-	→ FALSE
In B:	TRUE		FALSE	

Interactions in the presence of HCTs?

	Condition 3.1		Condition 3.2	
IF	Significant quantity of dynamically operated HCT	AND	Frequent arbitrage opportunities between gas and electricity	
In A:	FALSE		-	→ FALSE
In B:	FALSE		-	

Single system assessment of the project

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* The application of the methodology to real situations may require adaptation or adjustments from the ENTSOs

Example of application of the methodology* (2)

Reference situation:

Areas	Total gas demand [TWh]	G2P demand [TWh]	Presence of gas constraints	Presence of electrical flexibilities	P2G capacities [GW]	Nuke + vRes capacities [GW]	Nuke + vRes production [TWh]	Electrical demand [TWh]	HCTs (Heat pumps) [GW]	Arbitrage gas – electricity opportunities
A	95	3	Yes (from simulations)	Yes (from simulation)	0	4	15	48	Negligible	-
B	11	1	Yes (from simulations)	Yes (from simulation)	0	1	5	16	Negligible	-

Application of the methodology*:

Interactions in the presence of G2P?

	Condition 1.1		Condition 1.2		Condition 1.3
IF	Significant quantity of G2P in the system	AND	Presence of gas constraints	AND	Presence of electricity flexibilities
In A:	FALSE		-		-
In B:	TRUE		TRUE		TRUE

→ TRUE

Dual system assessment of the project

Interactions in the presence of P2G?

	Condition 2.1		Condition 2.2
IF	Significant quantity of dynamically operated P2G	AND	Significant share of low-variable costs electricity generation
In A:	-		-
In B:	-		-

Interactions in the presence of HCTs?

	Condition 3.1		Condition 3.2
IF	Significant quantity of dynamically operated HCT	AND	Frequent arbitrage opportunities between gas and electricity
In A:	-		-
In B:	-		-

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* The application of the methodology to real situations may require adaptation or adjustments from the ENTSOs

Summary

- The study has identified 3 main sources of interlinkages : gas-to-power, power-to-gas, and hybrid gas/electricity consumption technologies.

- The effect of these technologies on gas/electricity interactions has been analysed and the effects of these interactions on project assessment have been qualitatively and quantitatively evaluated.

- Given this analysis, a structure of the screening methodology has been proposed.
  - The methodology relies on conditions relative to key parameters of the interactions taking place in areas with a significant quantity of G2P, P2G or hybrid consumption technologies

  - These conditions involve country-specific scenario parameters (assumption or single-system simulation results) for which thresholds have been qualitatively or quantitatively assessed.

Final words

On the basis of the recommendations provided by this study, the next steps for the ENTSOs will be to:

- Test and adjust the screening methodology to ensure that it is producing the expected results when confronted to real cases

  We expect that the conditions on G2P will be the ones that will trigger a DSA in most cases:

  - Indeed, conditions on HCTs will not be frequently met: most scenarios do not consider a large deployment of hybrid technologies in the coming years. Moreover, the interaction only takes place if HCTs is price-driven
  - Conditions on P2G are rather strong, and could be met in some areas especially at the 2040 horizon
  - Conditions on G2P could be met more frequently in areas with a gas-intensive electricity mix, provided there are electricity flexibilities in the area (storage, interconnections, DSR)

- To design a methodology to carry out the dual system assessment of relevant projects

Thank you for your attention!

Contact

maxime.chammas@artelys.com

christopher.andrey@artelys.com

Artelys Crystal SuperGrid

Key features

- Bottom-up optimal dispatch tool
- Capacity expansion planning
- Multi-energy (power, gas, reserves, etc.)
- Built-in library of indicators
- Intuitive user interface

Used for

- Assessment of infrastructure projects
- System adequacy assessment
- Design of optimal flexibility portfolios
- Multi-energy scenario building
- Energy policy impact assessment