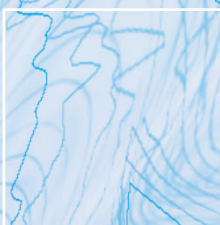
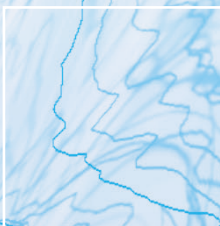
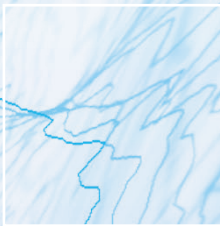
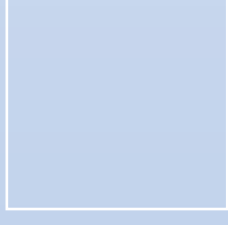
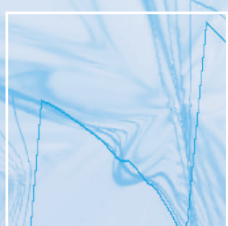
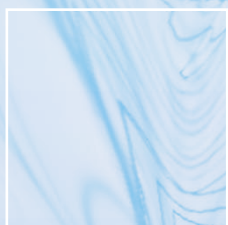




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# POLICY BRIEF

## *Sector Coupling: the New EU Climate and Energy Paradigm?*

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### Highlights

- To contribute to the achievement of the Paris Agreement 2°C, and potentially 1.5°C, objectives the EU needs a new energy paradigm. Sector coupling, binding together power and end-use sectors to integrate the rising share of variable renewable energy in the energy system, offers a new framework for this purpose.
- In order to translate the concept of sector coupling into the EU energy and climate policies, we propose to focus on four building blocks: infrastructure planning; system and market operation; regulatory framework; and research, development, demonstration and deployment.
- For infrastructure planning, the Ten-Year Network Development Plan (TYNDP) selection process should conclude with one integrated list of projects. Power-to-Gas installations, due to the system value and multitude of applications should become a part of this process and be eligible for the Connecting Europe Facility (CEF) funding.
- Regarding system operations, a more integrated system would require better correlation between the electricity and gas market design and price structure. Adjustments to the current electricity price structure may be necessary. The gas quality issues will require enhanced cooperation between upstream producers, end-use consumers and TSOs.
- For the regulatory framework, easing the unbundling rules for P2G in specific cases is worth considering, on the condition that the market test does not provide enough evidence for the development of P2G installations.
- The possibility of creating a single Target Model for both electricity and gas could be of interest.
- Research, development, demonstration and deployment is important for decreasing the capital costs of the new projects. Especially in the early stages, companies, industries and the whole sectors may benefit from the shared P2G or carbon storage infrastructure.



## 1. Introduction

The European Council conclusions from March 2018 invite the European Commission to publish “a proposal for a Strategy for long-term EU greenhouse gas emissions reduction” by the first quarter of 2019<sup>1</sup>. The discussions on the document replacing the 2011 ‘Roadmap for moving to a competitive low carbon economy in 2050’<sup>2</sup>, the so-called 2050 Roadmap, are underway. Whereas the introduction of any new binding climate policy objectives will require the European Council’s approval, a new roadmap is expected to determine the pathway allowing the European Union to contribute to the achievement of the Paris Agreement objectives.

The 180 Parties that have already ratified the Paris Agreement, including the European Union, are committed to the objective of limiting the increase in the global average temperature to well below 2°C and taking steps to limit the warming to 1.5°C above pre-industrial levels. The shift from 2°C to 1.5°C objective would require similar transformations in the production and the use of energy, yet the decarbonisation of the whole system would need to be accelerated and “more pronounced”<sup>3</sup>. In the 1.5°C scenario, the global GHG emissions need to peak no later than around 2020, be net-zero by 2050 (approximately 10 years earlier than in the 2°C scenario) and then become negative. It means that the use of fossil fuels

after 2050 should be offset by negative emissions, e.g. through the Carbon Capture and Storage (CCS).

In fact, the EU’s new long-term strategy would need to tackle some particularly challenging issues such as how to decarbonise the industrial sectors, especially carbon-intensive cement and steel; how to deal with difficult-to-decarbonise energy uses including aviation, long-distance transport, shipping, and the agricultural sector; and how to integrate the growing ratio of variable renewable energy into the energy system. Last but not least, it will need to consider the future role of the gas sector in EU long-term decarbonisation efforts.

There is a growing consensus that the change of such magnitude requires a new approach to the way we conceptualise and manage our energy systems. One of the concepts that is often quoted in the discussions is “sector coupling”.

## 2. Sector coupling and its benefits

The notion of sector coupling (SC) has been known for some time and there is already a vast literature aimed at finding the right definition and its main principles<sup>4</sup>. Here, the concept is understood as encompassing the “co-production, combined use, conversion and substitution of different energy supply and demand forms – electricity, heat and fuels.”<sup>5</sup> In other words, sector coupling binds together power and

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1. European Council meeting (22 March 2018) – [Conclusions](#), Brussels 23 March 2018, p. 3.
  2. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A roadmap for moving to a to a competitive low carbon economy in 2050. COM/2011/0112 final.
  3. Bill Hare et al., [Implications of the 1.5°C limit in the Paris Agreement for climate policy and decarbonisation](#), 2016, p. 4.
  4. Cf: T. Brown et al., Synergies of sector coupling and transmission extension in a cost-optimised, highly renewable European energy system, 2018. Martin Robinius et al., Linking the Power and Transport Sectors—Part I: The Principle of Sector Coupling, 2017. Katrin Schabe et al., Managing Temporary Oversupply from Renewables Efficiently: Electricity Storage Versus Energy Sector Coupling in Germany, 2013.
  5. [Renewable Energy Policies in a Time of Transition](#). IRENA, OECD/IEA and REN21, 2018, p. 93.



end-use sectors to integrate the rising share of variable renewable energy in the power sector<sup>6</sup>.

One crucial aspect of sector coupling is an indirect electrification of those energy processes that cannot be electrified directly (e.g. high-temperature industrial processes using hydrogen produced from renewable electricity). Moreover, sector coupling creates new links between energy carriers<sup>7</sup> and the respective transport infrastructure, as the excess electricity can be used to produce hydrogen (electrolysis) and synthetic methane (methanation) that can serve to provide energy service through technologies such as Power-to-Gas (P2G), Power-to-Liquid(s) (P2L) or Power-to-Heat (P2H). All the potential pathways are frequently referred to under the common name of Power-to-X (P2X)<sup>8</sup>.

As a result, sector coupling may offer advantages to the whole energy system. First, it will exploit the rising share of electricity. Currently, the excess renewable electricity is curtailed. However, sector coupling enables the use of the excess electricity in electrolyzers to produce hydrogen and synthetic methane, which can be stored on a large scale and over longer periods, constituting the source of seasonal flexibility. IRENA estimates that thanks to the large capacity of gas pipelines in Europe, even low blending shares would lead to the absorption of sub-

stantial quantities of intermittent renewable energy<sup>9</sup>. Second, blending hydrogen with natural gas is also a way to progressively decarbonize the gas grids and fully utilize the value of existing gas assets<sup>10</sup>.

The environmental benefits of sector coupling go beyond the gas networks. The hydrogen produced from the renewable electricity – or ‘green hydrogen’ – can replace fossil fuels in many end-use applications<sup>11</sup>. In transport, Fuel Cell Electric Vehicles (FCEVs) fueled by hydrogen could complement Battery Electric Vehicles (BEVs) in specific segments of the transport market, such as heavy vehicles or buses. In heavy industry, green hydrogen could replace hydrogen produced mostly from natural gas via Steam-Methane Reforming (SMR)<sup>12</sup>. It is estimated that in 2015 total global hydrogen demand amounted to 8 exajoules and 90% of the demand came from three sectors: chemicals (ammonia and polymer production), refining (hydrocracking and desulphurization of fuels), and iron and steel production<sup>13</sup>.

Last but not least, the sector coupling could decrease the need to use conventional power plants to provide system services, thus reducing the emissions and their adverse air quality impact, “partly resulting from the demand for flexible operation”<sup>14</sup>.

6. [Global Energy Transformation: A Roadmap to 2050](#). IRENA, 2018, p. 70.

7. *Ibid.*

8. Maroufmashat and Fowler distinguish as much as ten different “pathways” for P2G applications: A. Maroufmashat, M. Fowler, *Transition of Future Energy System Infrastructure; through Power-to-Gas Pathways*, *Energies* 2017, 10, 1089, July 2017.

9. *Hydrogen from Renewable Power. Technology outlook for the Energy Transition*, IRENA, September 2018, pp. 38-40.

10. J. Speirs et al., *A Greener Gas Grid: what are the options?* White Paper, Sustainable Gas Institute, Imperial College London, July 2017, p. 4.

11. *Hydrogen from Renewable Power*, *op. cit.*, pp. 38-40.

12. Currently, over 95% of hydrogen is produced from fossil fuels.

13. IRENA 2018, *op. cit.*, p. 14.

14. Michael A. MacKinnon et al., *The role of natural gas and its infrastructure in mitigating greenhouse gas emissions, improving regional air quality, and renewable resource integration*, *Progress in Energy and Combustion Science* 64(2018), p.65.



To sum up, sector coupling may contribute to the achievement of the EU climate and energy objectives – competitiveness, sustainability and security of supply – in a cost-competitive and publicly acceptable way. However, the integration of power generation with end-use sectors would require significant changes in the energy system. The authors believe that the implementation of a sector coupling policy framework should be based on four building-blocks: integrated infrastructure planning; system and market operation; regulatory framework; and research, development and deployment.

In the following sections the four pillars of sector coupling are presented. Each section consists of the analysis of the main challenges and current bottlenecks preventing closer integration, as well as the policy recommendations aimed at overcoming the barriers. Due to the limited length of this publication the focus is on the links between the electricity and gas sectors through Power-to-Gas technology. The paper will conclude with more general remarks regarding the role of sector coupling in the EU's long-term decarbonisation strategy.

### 3. Sector coupling building blocks

#### 3.1 Infrastructure planning

Sector coupling cannot be realised without integrated infrastructure planning. This is of particular importance for the electricity and gas infrastructure, which is characterised by high capital-intensity and a long-term pay-back period. In fact, the anticipated increase in the generation of electricity from

renewable sources requires massive electricity grid reinforcements and the increase in energy storage capacity to match the power supply and demand. However, in highly-integrated systems, existing natural gas networks could facilitate significant energy transfers in the form of molecules<sup>15</sup>. The cross-sectoral approach would ensure the best use of existing infrastructure and prevent unnecessary and costly infrastructural investments.

The long-term planning of gas and electricity infrastructure in the European Union is governed under the Ten-Year Network Development Plan (TYNDP) framework. The TYNDP is a non-binding document that builds upon national and regional investment plans with the aim to provide a coherent outlook of the pan-European energy infrastructure and to identify potential infrastructure gaps<sup>16</sup>. The plan is updated every two years and consists of the following elements: the modelling of the integrated network; scenario development; a European supply adequacy outlook (for gas TYNDP) and a European generation adequacy outlook (for electricity TYNDP)<sup>17</sup>; and the assessment of the resilience of the system.

Although the procedures for the establishment of the TYNDP for electricity and gas look very similar, currently the processes are separated and conclude with two separate lists of electricity and gas projects, published by ENTSO-E and ENTSG, respectively. Moreover, both sectors use different cost-benefit analysis (CBA) Methodologies, which are a crucial instrument for the TYNDP, Projects of Common Interest (PCIs) selection and serve as a reference for investment requests and financial support.

15. Maurits Kreijkes, Synergies on the Dutch gas infrastructure: Hydrogen and the changing function of the Dutch gas infrastructure. TU Delft Repositories.

16. [Regulation \(EC\) No 714/2009](#) of the European Parliament and of the Council of 13 July 2009 on conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC) No 1228/2003 (Art. 8 points 10 and 11), [Regulation \(EC\) No 715/2009](#) of the European Parliament and of the Council of 13 July 2009 on conditions for access to the natural gas transmission networks and repealing Regulation (EC) No 1775/2005 (Art. 8 points 10 and 11).

17. Please note that under the Art. 45 of the [Proposal for a Regulation of the European Parliament and of the Council on the internal market for electricity \(recast\)](#) a European generation adequacy outlook has been deleted.



In this light, the publication of ENTSOs Scenario Development for TYNDP2018 should be welcomed as a positive development<sup>18</sup>. For the first time, ENTSOs worked together on a document providing the overview of potential developments in the European energy system up to 2040. It means that as of this year the electricity and gas infrastructural projects will be assessed against the same future scenarios.

In addition, the ENTSOs continue to work on the “interlinked electricity and gas market and network model including both electricity and gas transmission infrastructure”<sup>19</sup>, *de facto* sector coupling. This year, ENTSO-E and ENTSG launched the Focus Study, the results of which will become the basis of the Interlinked Model. The Model will be a part of the CBA Methodologies and will apply for the project assessment starting from TYNDP2020.

Moving from the European to the regional and local perspective, the availability of local infrastructure has a tremendous impact on the deployment of technologies such as P2G<sup>20</sup>. Before taking the investment decision the companies need to assess the following factors: the connection to the electricity grid and the closeness to the renewable energy sources, and curtailed energy; the connection to the gas network and gas storage facilities; the proximity to potential buyers/end-use consumers; the demand for by-products (e.g. oxygen); finally, the local planning, permit procedures and requirements and the public acceptance. More coordinated planning at local level will gain growing importance as the EU energy system becomes increasingly decentralised.

As the works on the final Interlinked Model are ongoing, the authors would like to highlight the following:

- The Interlinked Model should not only provide the right instruments to map and assess the interactions between the electricity and gas projects, but also the right tools to eliminate projects whose construction can be avoided in the integrated energy system.
- The new P2G installations should be included in the TYNDP. It is also worth considering whether the P2G infrastructure could be eligible for the funding under the Connecting Europe Facility (CEF).
- In the more distant future, the TYNDP processes for electricity and gas should be fully integrated resulting in one TYNDP list prepared jointly by ENTSOs.
- At the national and local level, the MSs should make sure that the national planning incorporates the timely construction of the associated infrastructure. For instance, extension of electricity grid to connect to the sites with newly-developed decarbonised production units such as P2G facility or biogas-fueled combined heat and power (CHP) plants.

### 3.2 System operation and market rules

The rules enabling the proper functioning of the highly integrated energy system are the second pillar of the sector coupling. There are two main challenges: economic – current electricity price structure; and, technical – the gas quality considerations that could constitute a barrier to cross-border trade.

18. [TYNDP 2018 Scenario Report. Main Report](#). March 2018.

19. Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009, Art. 11(8).

20. Power to Gas system solution. Opportunities, challenges and parameters on the way to marketability. DENA, November 2015.



With the gradual electrification of end-use sectors, the access to low-cost clean electricity will become one of the key concerns for the hydrogen producers, the industries using hydrogen as a feed-stock or fuel, and for electrified heat. McKinsey&Company estimated that at current commodity prices the CCS is the cheapest option for decarbonisation. However, with the renewable electricity prices dropping below 50 USD/MWh, using electricity for heat or hydrogen generation becomes more economical than CCS<sup>21</sup>. It should be noted that this level of prices has been already achieved in Sweden, where the power sector is based on hydropower and nuclear power.

In many EU countries the regulated components of electricity price – that is the elements that do not relate to the supply of electricity such as grid fees, taxes and levies – constitute a significant part of the electricity bill. For instance, it has been estimated that in Germany taxes, levies and surcharges constitute 54% of a total power price, whereas the regulated grid fees account for almost a quarter of the price (24.7%). This leaves only 21% of the price set by the market<sup>22</sup>. In cases where the P2G installations are considered as the end-users and thus obliged to pay the full grid fees, it may constitute a considerable barrier to build a robust business case.

It should be noted that in some EU countries – France, the United Kingdom, Denmark and also Germany – partial exemptions from grid fees, electricity taxes or levies for electrolyser operators are already in place. However, the exemptions are

based on the condition that electrolysers operate in a system-beneficial mode, that is, they do not consume electricity during the system peak load<sup>23</sup>. For example, in Denmark electrolysis is not considered as an end use, but a “special process”, and as a result gains the lowest possible electricity tax rate<sup>24</sup>.

The electricity system can also benefit from the possibility to store green gases, mostly hydrogen and biomethane with the use of already existing natural gas infrastructure and potential newly constructed hydrogen infrastructure. This would make it possible to match electricity supply and demand, which will become increasingly challenging with the rising share of intermittent renewable sources. Despite the already existing storage options such as pumped hydro storage or batteries, hydrogen and other low-carbon gas storage seem to be the most suitable for large-scale and long-term storage including seasonal backup and the reserves stored for energy security reasons<sup>25</sup>.

On the other hand, the quality considerations could prevent higher ratios of hydrogen and synthetic methane injected into the gas pipelines and transported to the final consumers. Even though blending is technically possible, the technical and regulatory problems arise with higher hydrogen content. The studies show that the higher content may be harmful to transmission and distribution pipelines, compressors, and storage facilities, gas metering (currently used chromatographs are not suitable to measure hydrogen) and the end consumers – gas turbines have not been designed to operate on a fuel rich in hydrogen<sup>26</sup>. The low hydrogen concentrations up to

21. McKinsey&Company, Decarbonization of industrial sectors: the next frontier, June 2018, p.8.

22. E. Thalman, B. Wehrmann, [What German households pay for power](#), Clean Energy Wire Factsheet, 5 June 2018.

23. Study on early business cases for H2 in energy storage and more broadly power to H2 applications. Final report. Prepared for the Fuel Cells and Hydrogen 2 Joint Undertaking, June 2017, pp. 69-75.

24. [Framework conditions for flexibility in the Gas – Electricity interface of Nordic and Baltic countries. A focus on Power-to-Gas \(P2G\)](#), Flexible Nordic Energy Systems, June 2017, p. 8.

25. J. Moore, B. Shabani, A Critical Study of Stationary Energy Storage Policies in Australia in an International Context: The Role of Hydrogen and Battery Technologies, *Energies* 2016, 9, 674.

26. M. W. Melaina, Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues, NREL, March 2013.



10-20% are, with some exemptions, acknowledged to be safe for the operation of pipelines or require only minor adjustments. Some of the problems can be solved by retrofitting and using argon to detect hydrogen in gas meters<sup>27</sup>. Nevertheless, the implications of the increased hydrogen content in the transmission and distribution system would need to be further examined.

### Recommendations

- One of the measures that could strengthen the business case of P2G applications is to implement adjustments to the current electricity price structure. Offering the discounted grid tariffs for reversible electrolysis or tax exemptions for electrolyser operators producing green hydrogen, and provided their operations provide benefits to the functioning of the electricity system is one of the potential solutions that is relatively easy to implement. Another possibility is to exempt the green hydrogen producers from RES support levies, on the grounds that this solution creates incentives to decarbonise non-power sectors such as: industry, transport or heat.
- Also, the electrolysers should be eligible to participate in ancillary service and capacity markets, which could constitute an additional revenue streams for the operators of such facilities.
- Electricity grid connection. In cases, where the electrolyser operators are obliged to pay full con-

nection fees, splitting these costs between P2G operators and TSOs is worth considering.

- Enhancing the cooperation between upstream producers, end-use consumers and TSOs could be at least an interim measure to deal with gas quality issues. It should be noted that the gas quality resulting from the increased content of renewable gases will probably remain a local issue. That is why setting the European or even national gas quality standard would not always be the optimal solution.
- More research is needed to assess the cost associated with the pipeline system modifications required in specific EU regions at several hydrogen blend levels and to test the impact of hydrogen on the end-use systems, such as household appliances and power generation apparatus (e.g. turbines).

### 3.3 Regulatory framework

The sector coupling will not be possible without changing our approach towards the energy sector regulation, as the technologies linking electricity and gas sectors require the adoption of a set of coherent rules.

One of the challenges that frequently arises in the discussions regarding the cross-sectoral integration are the current unbundling rules. According to the proposal for a Recast Electricity Directive<sup>28</sup>, Power-to-Gas falls under the category of energy storage<sup>29</sup>.

27. M. Chaczykowski, A. J. Osiaacz, Power-to-gas technologies in terms of the integration with gas networks, *Trans. Inst. Fluid-Flow Mach.* 137(2017), pp. 85–103.

28. [Proposal for a directive of the European Parliament and of the Council on common rules for the internal market in electricity \(recast\)](#).

29. Art 2(47) of the Recast Electricity Directive defines the “energy storage” in the electricity system as: “deferring an amount of the electricity that was generated to the moment of use, either as final energy or converted into another energy carrier”. This definition may be considered as not detailed enough; however the General approach adopted by the Council on 20 December 2017 proposes a more detailed definition, which leaves no doubt that P2G facilities should be considered as energy storage. In the Art 2(47) ‘energy storage’ in the electricity system is defined as “the conversion of an amount of the electricity that was generated into a form of energy which can be stored, the storing of that energy, and the subsequent direct use or reconversion of that energy back into electrical energy or into another energy carrier and use of that reconverted energy at a later moment than it was generated”. Please note that the General approach is not a binding document, but a negotiating position allowing the Council to start negotiations with the European Parliament.



In principle, the proposal does not allow either transmission or distribution system operators to own, develop, manage or operate energy storage facilities<sup>30</sup>. The exemptions are possible only in limited cases. As a result, the Member States may allow the derogation from unbundling rules to P2G projects only if the following conditions specified in the Art. 36(2) and Art 54(2) of the Recast Electricity Directive are met:

- other market participants have not expressed their interest to own, develop, manage or operate a P2G facility following the non-discriminatory tendering procedure;
- the P2G facility in question is necessary to fulfil TSO's or DSO's obligations under the Electricity Directive to ensure system safety, efficiency and reliability and are not used to sell electricity to the market;
- the NRA grants its approval after assessing the need for such derogation and taking into account the abovementioned conditions;
- the Recast Electricity Directive presents an opportunity to reverse the status quo resulting from the application of the derogation decision, if the public consultation performed at least every five years reveals the interest of other market entities to invest in storage facilities, the system operators are obliged to cease their activities.

The above-mentioned proposal will be discussed in the coming months and is still subject to revision. However, the provisions in the current form open the door for the system operators to own, develop, manage or operate energy storage facilities, including P2G installations. This may happen by way of derogation from unbundling rules granted by the NRA if storage facilities are necessary for TSOs and DSOs to fulfill their tasks and there is no interest from the market participants to invest in such facilities.

30. Art. 36 and 54.

31. European Gas Target Model – Review and update, ACER, January 2015, p. 7.

The authors believe that the Electricity Directive proposal in the current form determines the right balance between the unbundling rules, which are the cornerstone of the EU energy markets' liberalisation, the interests of system operators and the market entities. As a matter of fact, the provisions strengthen the role of the national regulators, as by granting derogation decisions they can enhance or limit the pace of the construction of the new facilities.

Apart from the rules on unbundling, creating cross-sectoral regulation suitable for a more integrated energy market is tempting. Currently, there are two separate sets of regulation dealing with electricity and natural gas markets, respectively. It seems that both markets would benefit from more integrated regulation, especially if sector coupling becomes the new normal.

The potential starting point could be the integration of non-binding rules such as Electricity and Gas Target Models. Interestingly, the need for closer cooperation between electricity and gas sectors as a consequence of the higher shares of renewable energy source generation affecting both markets has been already recognised in the updated version of European Gas Target Model. The 2015 Gas Target Model proposes the introduction of a legally-binding obligation on gas and electricity TSOs to cooperate with each other, *inter alia*, through a better exchange of information and “a cooperative review of gas and electricity industry timelines” and the TYNDP process<sup>31</sup>.

### Recommendations

- A set of non-binding guidelines for NRAs to make the decisions regarding the granting of a derogation from unbundling rules could be helpful. The Guidelines should on the one hand support the role of system operators in constructing and oper-





ating energy storage facilities, based on the fact that some technologies are in their early deployment phase, but on the other hand they should guarantee the necessary level of competition in the market.

- The definition of ‘energy storage’ in the Recast Electricity Directive should be clarified. Potentially, the definition of Power-to-Gas could be included in the new electricity and the upcoming gas package.

### 3.4 Research, development, demonstration and deployment (RDD&D)

The research, development, demonstration and deployment of the most promising technologies is the last pillar on which the sector coupling is founded, as it is the only way to achieve the robust and affordable low-carbon energy system<sup>32</sup>.

It has been proven that innovation and the production scale-up could lead to capital cost reduction by as much as 30% and the creation of new (business) opportunities<sup>33</sup>. But the achievement of the GHG reductions beyond 80% would require not only that the technologies are developed, but also that they are ready to be commercialised at an opportune time. According to the study on sectoral integration ordered by the European Commission, the review of the technological developments providing a clear indication of which (technological) strategy to follow should take place within the next decade. In fact, achieving the net-zero emissions energy system around 2050 would require that the modifications of the current energy systems are well-advanced a decade before, that is around 2040<sup>34</sup>. This claim is based on the observation that the high investment

requirements make it impossible to continue the development of certain options over a prolonged period. In fact, in the long-term perspective only a handful of technologies will achieve the required economies of scale and will dominate in the energy market.

### Recommendations

- In the following years, more effort should be made to decrease the capital costs via innovation and the deployment of technologies at different scales, with a focus on technologies that provide multiple energy services such as Power-to-Gas.
- The industry should take a more active role in decarbonisation efforts identifying the synergies between the industrial decarbonisation and the decarbonisation in other sectors. A good example is a joint AkzoNobel and the Dutch TSO - Gasunie project to build a 20MW electrolyzer in the northern part of the Netherlands<sup>35</sup>.

## 4. Conclusions

In order to keep up with its international climate commitments under the Paris Agreement, the European Union will need to define the pathway towards achieving net-zero emissions energy system by 2050. The new EU long-term emissions strategy expected to be published this autumn will be a significant step.

The deep decarbonisation of the whole energy system including the gas sector, industry, transport and heating would require more integrated policy and regulatory frameworks. The notion of sector coupling, based on linking together power and end-use sectors to integrate the rising share of VRE, is well-suited for this purpose. It is a solution that

32. Steven J. Davis et al., Net-zero emissions energy systems, Science 360, eaas9793, 29 June 2018, p. 7.

33. O. Schmidt et al., Future cost and performance of water electrolysis: An expert elicitation study. International Journal of Hydrogen, Energy Volume 42, Issue 52, 28 December 2017, Pages 30470-30492.

34. Sectoral integration-long-term perspective in the EU Energy System. Final report. Asset project. February 2018, p. 11.

35. Bart H. Meijer, [Akzo and Gasunie plan to build Europe's largest green hydrogen plant](#), Reuters, 9 January 2018.



offers not only the environmental benefits but also seems to be one of the most cost-competitive, and politically and socially acceptable options.

Putting this notion into practice would require the focus on four equally important building blocks: infrastructure planning, system and market operation, regulatory framework, and continuous investments in the research, development, demonstration and deployment. In this paper we have presented a list of recommendations addressing the key challenges in these areas.

Finally, although sector coupling could be good strategy for a successful energy transition in Europe, we need also to remember that “(...) a successful transition is one that holistically considers three aspects - or layers - of the system: technical [flow of energy between source and load], economic [monetary flows between different market participants], and institutional [flows of information and division of roles and responsibilities].”<sup>36</sup>

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36. Status of the Power System Transformation: System integration and local grids. OECD/IEA, 2017, p. 83.



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