Energy Network Innovation for Green Transition: Economic Issues and Regulatory Options

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ABSTRACT

In this age of low-cost capital and stimulus packages, is it the best time to heavily invest in tomorrow's energy networks and research infrastructure? In the academic literature it is widely acknowledged that innovation is key to decarbonising the energy sector and fostering sustainable development. However, post liberalisation has been struggling to promote R&D and innovation. Is this a case of business, regulatory, or policy failure, or are there other factors involved? In this paper, we discuss the reasons for slow uptake of new technologies in energy networks and propose some remedies for the European context, where innovation in the area of energy networks is crucial for the implementation of the Green Transition. The solutions to address this shortfall need to be considered in an overarching manner. The specific points raised here are based on incentive regulation, the establishment of competitive funding models like Ofgem's Low Carbon Network Fund, and a large European collaborative research hub.

KEYWORDS: Energy Network Infrastructure, European Green Deal, Innovation, Research and Development

1. BACKGROUND

The European Green Deal is an ambitious initiative launched in November 2019 and endorsed by the European Parliament in January 2020. It encompasses a series of policies to achieve the objective of making Europe the first climate-neutral continent by 2050. The EU's commitment to reach long-term full decarbonisation targets has been demonstrated before by endeavours such as the Ten-Year Network Development Plans (TYNDPs). These are scenarios jointly developed by the European Network of Transmission System Operators for Electricity (ENTSO-E) and the European Network of Transmission System Operators for Gas (ENTSOG). The interaction between electricity and gas is recent and still limited, but TYNDPs represent a prominent effort to comprehensively describe the interactions between these energy networks and appraise the development of new infrastructures in a future decarbonised hybrid energy system (ENTSO-E and ENTSOG, 2019).

The development of new technologies, along with economic incentives and behavioural changes, are key to effectively implementing the Green Transition towards an environmentally sustainable society. We cannot achieve the decarbonisation targets by only relying on the existing technologies and solutions. We need to develop new solutions through innovation.[1] Technological progress allows more ambitious targets to be set and achieved at lower cost. However, it is worth remembering that technological progress depends on research and development R&D spending and innovation endeavours.[2]

Energy R&D is lower than in comparable industries such as telecommunications (Idea to Value, 2020). This is perhaps because regulation has not been focused enough on the quality of service, and energy utilities have reduced investment in R&D in order to improve short-term profitability. The current levels of investments in innovation to decarbonise the energy sector, and in particular in the networks, are not sufficient for the challenges ahead. In order to promote and increase the effectiveness of innovation in the sector, the economic, regulatory, technical, and policy aspects and their interactions need to be analysed and better understood.

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[1] "An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations" (OECD/Eurostat, 2005, para. 146).

[2] "The term R&D covers three types of activity: *basic research, applied research and experimental development. Basic research* is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. *Applied research* is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. *Experimental development* is systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes" (OECD, 2015, p.29).

At the time of the liberalisation of the energy industry in the 1990s, when the primary objective of the reform programmes was to achieve cost efficiency, the importance of R&D and innovation was mostly downplayed. It was expected that the new competitive markets would efficiently determine the type and amount of R&D and innovation needed (IEA, 1999; USHR, 1998). However, this did not happen and a sharp reduction in innovation activities took place (Jamasb and Pollitt, 2015). This is evidenced by a decrease in the annual average of patent applications of major UK companies, namely, non-nuclear generation companies, the Electricity Council (posteriorly AEA Technology) and the UK Atomic Energy Authority, from 11 to 2.9, 10.5 to 2.6 and 108 to 9 in the period 1958-2009. With the emergence of the environmental concerns, new areas in need of innovation have evolved since the liberalisation of the energy sector.[3]

Some studies have examined whether the theoretical and empirical knowledge of the time could have predicted the subsequent collapse of innovative activities in the sector (Jamasb and Pollitt, 2008, 2011, 2015). These studies also found that the productivity of R&D in energy and innovative output seemed to have increased, possibly due to more emphasis on near-market and applied research. In recent years, while government RD&D (Research, Development, and Demonstration) spending has globally increased (but not for Europe), it is not keeping up with the pace of GDP growth (IEA, 2019a). Moreover, when looking at energy sector investments in general, we should remember that these can be in the form of "traditional" or "dumb" assets. Therefore, energy spending figures might not totally be reflecting expenditure in R&D and innovation. Thus, it becomes evident that energy utilities have reduced their R&D investment, which may be somewhat related to a lack of public spending.[4]

The main objective of this paper is to analyse the reasons for the slow pace of innovation in the energy networks and how this innovation can be incentivised and motivated. The remainder of the paper is organised as follows. Section 2 describes some aspects about innovation from a business and economic perspective. Section 3 discusses approaches to promote energy R&D and innovation in Europe. Section 4 contains conclusions.

2. INSIGHTS FROM THEORY

The propensity and drivers of innovation in regulated natural monopoly energy networks differ from those of firms operating in competitive markets. In economics, traditionally there is a difference between the views of Schumpeter and Arrow regarding the influence of competition on innovation. The Schumpeterian opinion is that monopolies favour innovation, while Arrow argued that competition favours innovation. It follows from the first viewpoint that monopolies could indefinitely enjoy positive profits and hence benefit from their R&D investment. If that is not the case, and monopolistic positions do not encourage innovation, then regulation should play an active role to address this drawback.

In order to understand the specific difficulties to maintaining energy R&D and innovation activities in the energy utilities, it is important to detail some relevant economic features of the energy sector:

- The energy sector is capital intensive and the sunk costs are very large.
- The economic life of the energy assets is typically long. In addition, energy R&D is costly and requires scale. Nevertheless, once rolled out on a wider scale, it can be more cost effective than traditional alternatives.
- Demand for energy is a derived demand, meaning that energy consumption is not an objective in itself, and individuals and companies only demand energy to fulfil energy services.
- Traditionally, and unlike gas, electricity has been a non-storable commodity that required matching generation to demand.
- Price elasticity is low, while income elasticity is high (in Least Developed Countries).
- Demand for energy in recent years has grown slowly or even slightly declined.
- However, the value of energy/electricity to the users has never been higher.
- Investment by energy firms in innovation can have substantial economic and environmental benefits.
- Firms engage in innovation for a variety of reasons.

Until the 1980s, neoclassical economics, exemplified by the Solow-Swan model (Solow, 1956; Swan, 1956), explained long-run economic growth based on the accumulation of physical capital and exogenous factors. The theory of endogenous economic growth set out in the mid-1980s established that economic growth is mainly driven by technological change, and started to consider it as an element internal to the growth dynamic (e.g. see Romer, 1990). The literature views this technological change as a three-step process (namely invention, innovation, and diffusion) that captures the deployment of new and thriving technologies (Schumpeter, 1939; Jaffe and Stavins, 1995). In particular, the second step in the technological change process, innovation, is normally identified as one of the foremost factors of business survival, competitiveness, economic growth, and employment (Cooke et al., 2000; Buesa et al., 2010). According to Grant and Jordan (2015) this concept can be defined as "the initial commercialization of invention by producing and marketing a new good or service or by using a new method of production" (Grant 2015, p. 367).

Although innovation is a means to economic growth, it is not an automatic and immediate step. In fact, the transition (or rather the gap) between invention and commercial application is commonly referred to as the 'valley of death' in the literature on technology innovation and

[3] It is noteworthy that the liberalisation of the sector might have led to some outsourcing of R&D. This implies, for instance, that part of the R&D spending relevant for energy networks can happen in companies that do not directly pertain to the energy utilities sector, and hence be 'counted' as spending in other industries (e.g., electronic and electrical equipment).

[4] This can be thought of as a 'crowding-in' effect. The crowding-in effect can be described as a situation in which public spending stimulates investment in productive capacity, which results in boosting real private spending (Friedman, 1978).

TABLE 1. SUMMARY OF RELEVANT ECONOMIC

Relevant issues from an economic perspective	Implications for TSOs and DSOs
Technological change as a driver of economic growth	Public role to promote R&D efforts
Valley of death in innovation	Focus on widespread application of inventions
Prevalence of market failure in energy R&D	Promotion of open innovation
Increase in consumer surplus and economic and social benefits	Adoption of a 'value-based' approach in innovation funding
Vertical disintegration and relationship between firms' size and R&D	Coordination to organise large R&D project initiatives R&D
Short-term network price controls	Incentive-based rather than cost efficiency approaches

Note. Summary of relevant economic issues to the case of TSOs and DSOs in Europe.

transfer (Grubb, 2014). In the context of energy networks, an innovation gap may arise due to the long processes for network companies to trial and then adopt new innovative solutions. This presents challenges for start-ups' finances in the early years. Despite this problem in the central phases of the innovation chain, R&D is essential if we aim to stimulate and manage the process of growth.[5] Although it can imply an advantage in a competitive market setting, R&D also has some characteristics of public goods and can lead to market failures (Ferguson and Ferguson, 1994). These failures can be described in terms of the difference between public and private discount rates. In R&D and innovation, private discount rates are higher than public discount rates due to outcome uncertainty and the capacity of private investors to capture the benefits (Jamasb and Pollitt, 2015).

Energy R&D investment is no exception to this issue, but presents some specific features worth describing. Indeed, for reasons related to the characteristics of a liberalised sector presented above, the occurrence of market failure in energy R&D is prevalent. For instance, Transmission System Operators (TSOs) and Distribution System Operators (DSOs) are regulated businesses that cannot gain competitive advantage from innovation, unless incentive-based regulation based on Opex, incentivises them to do so. In that context, an 'open innovation' system in which both internal and external R&D may generate value for the companies can be an appealing option from the society point of view.

Prior to liberalisation of the sector in the 1990s, the energy sector was generally seen to provide a public service. After the reforms, energy was considered as a commodity and utilities, including network companies, reduced their R&D investment due to regulatory uncertainty. Recently, the perception of energy has been gradually changing from a commodity to a service, which may also have an impact on R&D spending (Jamasb and Llorca, 2019). As mentioned above, the demand for energy has recently stagnated or even dropped, but the current nature of energy services delivered has greatly increased the value of the energy for users (and hence consumer surplus). R&D usually attempts to yield technological progress in a cost-efficient way. However, considering the increase in consumer surplus and the economic and social benefits from a system perspective, a value-based approach to investing in R&D and innovation should be adopted.

The unbundling of the energy sector implies the vertical separation of the sector in competitive (generation and retail) and regulated (transmission and distribution) segments. The potentially competitive and regulated activities of the utilities sector represent rather different challenges for R&D and innovation (Jamasb and Pollitt, 2008, 2011, 2015; Jamasb et al., 2008). It is noteworthy that unbundling has likely reduced the economies of coordination in the electricity sector. The presence of vertically integrated utilities not only involves some economies of coordination, but it also increases the size of the utilities, which implies the possibility of larger R&D expenditure. Generally, only large firms and organisations can undertake substantial energy R&D. This is evidenced by the literature, which shows a positive correlation between firms' size and R&D expenditure (Cohen and Klepper, 1996). The vertical separation of energy utilities after liberalisation reduced the size of the utilities, which seems to be one of the reasons for the decline in energy network innovation. Moreover, in the absence of competitive markets, regulated monopolies cannot become bankrupt. In regulated firms, lower efficiency relative to their peers does not always have immediate consequences. On the other hand, in a perfectly competitive market even small differences can force the worst performing firms out of the market altogether.

The concept of induced innovation in the innovation literature on the energy sector can be viewed as the counterpart to endogenous growth in the macroeconomic literature. It is a key innovation policy issue because it is not only a contributor to economic growth, but has also become a crucial factor for achieving sustainable development and low carbon energy use. In regulated networks it is therefore important to promote innovation. However, in general, the short-term nature of network price controls can mean that reducing R&D investments is an effective way of improving short-term profitability, although this may come at the expense of networks in the long term, as innovation will be implemented at a much slower rate (Bauknecht, 2011).

In conclusion, there is a range of concepts from the economics literature that may be relevant when discussing the slow pace of innovation in energy networks. Table 1 attempts to summarise the most relevant of these, and presents possible repercussions for the TSOs and DSOs in Europe.

Additionally, political, regulatory, and economic uncertainties may affect the level of R&D spending in specific energy sectors or technologies that are worth being mentioned. We illustrate below how these uncertainties

[5] R&D represents the efforts to achieve technological progress through the three-step process defined before.

would impact investment in hydrogen-related infrastructure, which is expected to play an important role in the Green Transition (European Commission, 2020).

- General uncertainty regarding the national and European political agenda and strategies that can affect certain technologies or fields of research more than others (e.g. methane pyrolysis or blue hydrogen).
- Uncertainty regarding cost recovery, since a predictable framework is not in place (e.g. no regulatory framework for a hydrogen network, such as the Gas Directive for (natural gas) pipelines).
- Regulatory barriers like unbundling rules, third-party access, and tariffs (e.g. are TSOs allowed to operate a power-to-gas facility as a pilot project?).
- Uncertainty about the market demand and market behaviour, if there is no political signal and regulatory intervention (e.g. impact of the EU Emissions Trading System – EU ETS – prices and economic development).

3. HOW TO PROMOTE ENERGY R&D AND INNOVATION IN EUROPE?

A report prepared for the European Commission and the Energy Infrastructure Forum 2019 recognises that there is a significant degree of similarity between national regulatory models for energy network infrastructure in the EU with respect to security of supply, but large differences regarding innovation (Ecorys et al., 2019). They identify four groups of countries regarding their regulatory approach to innovation: those in which there are explicit high level references to innovation (e.g. in legislation), those in which the explicit references are at low level (through various regulatory instruments), countries in which an efficient and economic development of the network is promoted but without explicit reference to innovation, and finally countries with no evidence of support.

National regulators and transmission systems operators have found that there is scope for improvement in terms of incentivising innovation through the regulatory models. A recent report stated that innovation is understood as "putting 'innovative' transmission infrastructure investments into practice" (Ecorys et al., 2019, p. 17). The main barriers identified in the report are: (i) lack of incentives to encourage socially beneficial projects, (ii) bias towards Capex, (iii) no specific provision for innovation, (iv) high project risks and sanctions for not meeting deadlines, (v) disincentives to investment due to smart grid developments, and (vi) absence of comprehensibility. Moreover, some bespoke solutions for improvement are proposed for the different Member States. These country-specific solutions are based on a combination of options that include: (i) making it explicit that TSOs have a duty to consider innovative solutions, (ii) carrying out Social Cost Benefit Analyses (SCBAs) for large or controversial projects, (iii) consulting on projects and National Development/Investment Plans with stakeholders, and (iv) considering Opex-based solutions.

Overcoming the previously mentioned barriers requires that the proposed solutions should not be considered in isolation, but within a broader perspective and consistent with current legislation.[6] In our opinion, we need a new European energy R&D infrastructure ecosystem and an innovation ecology, established through collective and interactive efforts to facilitate the development of new innovative ideas and value creation, which will likely imply changes in the current business and regulatory models.[7] Governments must take a lead to transform the world of energy regulation and face the present challenges (IEA, 2019b). Ensuring universal access to clean and affordable energy and cutting carbon emissions are some of the challenges that will require strong energy investments and policies from governments. In this section, we first elaborate on how we can rearrange the European energy R&D infrastructure ecosystem. We then provide an overview of how we can rearrange the regulatory incentives for investments in network innovation.

3.1 REARRANGING THE INNOVATION FRAMEWORK AND ECOLOGY

Innovation and R&D in the energy sector are a multi-faceted activity and involve different types of actors, with the energy network utilities being only one of these. Due to the high costs and range of innovation efforts, some companies are involved in R&D externally to share risks with other companies and reduce uncertainty (Cohen and Sanyal, 2008). Costa-Campi et al. (2019) identify four innovation objectives for energy firms: innovation in processes and products, reduction in environmental impact, and fulfilment of regulatory obligations. They find that both external and internal R&D are used to deliver the regulatory and environmental objectives, while advanced machinery (such as the acquisition of computer hardware or land and buildings) is procured in order to improve innovation in processes.

In addition, preservation and dissemination of generated knowledge in innovation is very important. Do we know how much we actually know? We do not seem to. Energy R&D is costly and precious, and yet much of the results are not known to the scientific community.[8] This seems to call for developing incentive mechanisms and statutory obligations for the retention and dissemination of generated knowledge.

[6] The pieces of legislation also need to be consistent with each other. There are some updates taking place in 2020 which are relevant for energy network innovation and need to ensure that consistency. These revisions will be based on previous legislation:
- Smart Grid Indicator/Electricity Directive, Directive (EU) 2019/944 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944&from=EN);
- Energy Efficiency Directive, Directive (EU) 2018/2002 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2002&from=EN);
- Trans-European Networks for Energy (TEN-E) regulation, Regulation (EU) No 347/2013 (https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0347&from=en).

[7] Ideally, R&D projects should be in line with an overall EU research strategy to avoid unnecessary projects and costs. To avoid these issues, projects should be approved by an independent and competent authority that checks if the R&D projects can contribute to the overall strategy.

[8] This should not be a surprise considering that an important amount of applied research and technological developments may go under industrial secrets that are not publicly available.

[9] There are some existing exceptions such as BRIDGE, which is a European Commission initiative to establish links between Horizon 2020 projects in the fields of Smart Grid and Energy Storage with the aim of overcoming barriers to innovation. ERRA (Energy Regulators Regional Association) can be seen as another attempt to address knowledge sharing by bridging national and EU funded research.

Nevertheless, this aspect of research has not received enough attention, because the financial and scientific benefits to researchers are limited.[9]

The high costs of energy infrastructure along with lack of knowledge preservation can be used as arguments to bolster organisational and collaborative research for energy networks, and in particular the creation of a permanent large European hub for energy research, perhaps with a network of some regional branches.[10] In the UK, some research organisations have been established for a limited number of years (e.g. 8, 10 or so). However, these then tend to disappear over time. The loss of institutional memory can be staggering. Although much knowledge continues to reside in the individual scientists and engineers, these can be forced to move to other areas. This highlights the relevance of implanting knowledge transfer processes in the organisational culture of research centres and the energy firms themselves. However, there are some other examples of successful permanent research organisations that can be used as a reference.

The Electric Power Research Institute (EPRI) is an American non-profit organisation that performs R&D activities in the electricity sector. It involves more than 1,000 organisations and utilities from more than 38 countries (EPRI, 2020). Some of these companies are European, which seems to suggest that these European members and even others could also be attracted to a European research organisation. Another example is the Central Research Institute of Electric Power Industry (CRIEPI). It is a Japanese non-profit organisation that also conducts R&D in the electricity sector and research on social aspects through some dependent laboratories. With more than 660 research staff and an operational budget of 29.3 billion yen in 2020 (about EUR 250 million), it also has international outreach via technology transfer, training, and education (CRIEPI, 2020).

As we have mentioned before, unbundling has diminished the economies of coordination in the energy sector, and with them the size of the utilities, which implies lowering the possibility of larger R&D expenditure. However, in the US and Japan, where many utilities are large and vertically integrated, we find research hubs like EPRI and CRIEPI.[11] Even though one would expect these research hubs to be more needed in an unbundled (e.g. EU) than in a vertically integrated setup (e.g. USA and Japan), the reality is that this type of organisation has not yet materialised in the European context. Moreover, the non-profit nature of these organisations is likely to be a significant factor, since these might be more easily accepted by regulators and utilities.

The collaborative approach of a permanent research hub contrasts with the alternative of funding support models such as Ofgem's Low Carbon Network Fund (LCNF), where utilities and projects 'compete' for their own and others' share of R&D allowance. In competition-based mechanisms for funding the best research efforts, e.g. Ofgem's LCNF mechanism, utilities allocate a share of their revenue to a collective innovation fund. They then take part in a competitive bidding process to fund their proposed innovation projects. This mechanism combines current spending with a competition mechanism. The regulator needs to decide on the allowed share of revenue to be spent on innovation.

The LCNF was one of the three mechanisms[12] that were set in place to promote innovation in the British electricity sector as part of the fifth Distribution Price Control Review (DPCR5) that was running in Great Britain from 1 April 2010 to 31 March 2015 (Rious and Rossetto, 2018). The LCNF £500 million programme was divided into two tiers of funding: one to allow distribution utilities to recover part of the spending on small-scale projects, while the second was to host a yearly competition for the allocation of up to £64 million to partly fund a small number of flagship projects.

3.2 REARRANGING THE REGULATORY INNOVATION INCENTIVES

Utilities regulation is generally performed through two alternative approaches: cost-based (such as rate-of-return) and incentive-based (such as price cap) regulation. Rate-of-return (or cost-of-service) is a type of regulation in which companies are allowed to recover their costs of production plus a rate of return on capital. This type of regulation is often criticised because it does not provide the companies enough incentives to operate efficiently. Moreover, rate-of-return regulation leads to the Averch-Johnson effect, which means that utilities can have excessive capital accumulation. Incentive regulation, in the form of a price or revenue cap, implies strong incentives for cost reduction and improving the companies' performance. However, even some types of incentive regulation schemes can lead to capital accumulation. Kuosmanen and Nguyen (2020) point out that the Nordic-style revenue cap model constrains the level of revenue and is equivalent to rate-of-return regulation. They formally demonstrate that the system is exposed to the Averch-Johnson effect.

Conventionally, energy network regulation has been focused on standard short-term cost-efficiency improvements, and hence R&D efforts and innovation have not been explicitly promoted. Although innovation can be costly at the pilot phase, it often results in significant cost savings and efficiency in the long-term. In that line, some authors suggest that regulatory models should shift to an approach that incorporates further mechanisms for achieving long-term goals (Cambini et al., 2014). Moreover, from a risk perspective, it is important that incentive mechanisms consider the risk profile of an innovation endeavour to avoid network utilities focusing their activities only on low-risk 'normal' efficiency improvements (Poudineh et al., 2020). In addition, innovation in energy networks is often perceived by energy firms to have high costs and risks. Newbery et al. (2019) discuss the use of a Regulated Asset Base (RAB) model to overcome the problem of financing long-term low-carbon generation assets that require low funding costs.[13] However, it should be mentioned that RAB models may lead to a bias towards Capex investments.

[10] A somewhat similar idea is posed by Skillings (2020). He proposes the establishment of an EU 'Clean Economy Observatory' that would have a critical role in fostering innovation. It would mainly serve two purposes: promoting 'learning by doing' and identifying 'pathway critical challenges' (breakthrough innovation).

[11] There is no energy research hub at European level. It must be said that there are already similar organisations at national level in Europe, e.g., SINTEF (Norway), VITO (Belgium), TNO (Netherlands) or VTT (Finland). However, both the scale and the degree of specialisation of these organisations (not only focused on energy, but also on other sectors such as health or chemistry) greatly differ from EPRI and CRIEPI.

[12] The other two were the Innovation Funding Incentive (IFI) and the Registered Power Zones (RPZs).

[13] RAB represents the part of capital accepted by the regulator to receive a return.

TABLE 2. REGULATORY MECHANISMS TO STIMULATE INNOVATION

Issue	Costs for innovation are incurred now while benefits are uncertain and only materialise in the longer term (short-term thinking and risk-aversion)				Innovation benefits can go beyond grid cost reduction (externalities)
Total (can be combined)	**Output-based**				**Output-based**
	RAB-based approach	**WACC-based approach**	**Cost-pass through**	**Competition for funding**	
Explanation	Include R&D and innovation spending in regulatory asset base	Increasing the return on investment to compensate for the risk	Spending on R&D and innovation is a current expenditure	Tender for grants of an innovation fund	Improving outputs can foster innovation as a means to gain rewards
Example	In GB, it is applied to infrastructure projects and discussed for new nuclear projects	In Italy, some smart grid projects receive ad ditional WACC	In Norway DSO R&D expenditures are added to the allowed revenues	In GB, there is an annual Electricity Network Innovation Competition (NIC)	Automation can have an effect on quality-of-service incentives

Note. Regulatory mechanisms to stimulate innovation. Source: Own elaboration based on Meeus et al. (2012), Bauknecht (2011), CEER (2017) and Newbery et al. (2019).

In addition to the approach of organising a competition for innovation funding discussed earlier, we distinguish three input-based regulatory mechanisms that are commonly used to facilitate expenditure on R&D and innovation: RAB, Weighted Average Cost of Capital (WACC) or cost pass-through.

- An RAB-based approach to innovation expenditure simply includes the R&D and innovation spending in the regulatory asset base of the utility. But the issue that follows is how the RAB is to be remunerated, i.e. how is the appropriate WACC to be determined.
- A WACC-based approach can attempt to distinguish between the capital used in innovation/innovative assets and other forms of capital (i.e. investment in more conventional assets) to fairly reflect the perceived higher risk of innovation investments.
    - o The RAB and WACC approaches implicitly assume that the capital spent on innovation is in the form of equity or debt. Distinguishing between the different types of capital and their costs for inclusion and calculation of the WACC is inherently difficult for the regulators.
- On the other hand, a cost pass-through approach to spending on innovation implies that spending on R&D and innovation is a current expenditure funded by the rate payers through network charges or perhaps energy prices; the regulated entity does not receive any rate of return on these expenses.

As some innovation benefits can go beyond grid cost reduction, some regulators complement input-based with output-based mechanisms. Improving the relevant outputs can foster innovation as a means to gaining rewards. Table 2 summarises the discussed regulatory mechanisms and provides some European examples in which the different approaches are applied.

There are several methods by which innovation can be funded and accounted for.

- Government funded – Due to the global nature of benefits and co-benefits of decarbonisation, the government or taxpayers pay for the cost of innovation in utilities.
- Utility funded – Costs of innovative activities can be treated as disallowed costs. Under this model, the firm only incurs innovation costs if the efficiency gains from these expenditures exceed the costs of them (Poudineh and Jamasb, 2015).
- Rate payer funded (1) – Innovation costs are allowed as Opex. This approach or variations of it are common and preferred by regulators.

- Rate payer funded (2) – Innovation costs are allowed as Capex and part of the RAB. Networks are capital intensive and innovation has implications for the quantity and quality of their investments. Therefore, it is sensible to include the innovation costs of utilities in their RAB, as with their other capital investments. This is also consistent with how firms in competitive markets engage in multi-year research programmes. In order to achieve the low carbon future, we need to be consistent and consider technology enabling R&D as investment in enabling future solutions. Energy networks and new technologies are capital intensive. Also, cost of capital for public spending is low, thus further reducing the difference between the private and public discount rates.

4. DISCUSSION AND CONCLUSIONS

Innovation is key to decarbonising the energy sector and fostering sustainable development. However, post liberalisation, it has been difficult to promote R&D and innovation in the energy sector. In this paper we have discussed the reasons for the slow uptake of new technologies in the energy networks. We have described economic characteristics of the network utilities sector and proposed some recommendations to encourage innovation in the sector. We have discussed the use of regulatory mechanisms (RAB, WACC, and cost pass-through), the creation of competitive funding models, and the establishment of a European research hub. To complement these main points, there are some final remarks that we would like to add.

- We can adopt a more 'value-based' approach to innovation funding and incentives rather than a cost efficiency approach. The value of the energy benefits of green energy to the modern economy and society increases with our dependence on these. The value of innovation in energy networks must be viewed in a system benefit perspective and incentivised accordingly. Furthermore, this value indeed goes beyond the energy sector and serves economic and social objectives.

- Innovation stimulus spending packages should be viewed as investment opportunities for the future economy rather than essential one-off spending. It makes economic sense to adopt a long-term view and direct these innovation efforts at renewing the existing infrastructure and as an investment opportunity to create value in the future. Interest rates are at historically low levels, making the current economic climate suitable for long-term investment in energy R&D and innovation. Also, social discount rate in innovation is lower than private discount rate. In addition, societies can socialise/spread the spending and the risk among large numbers of rate payers and taxpayers.

- We should note there are limits to the role of regulators in promoting R&D or innovation in networks. Regulators have limited reach, mandate, and experience to reach out to other R&D/innovation actors outside of the utilities sector such as equipment manufacturers. If the right institutions and organisations are not out there, the regulators tend to use the utilities as the vehicle of R&D and innovation, but this can have limited reach.

- Spending on innovation may or may not be enough. However, before addressing that, we need to visit the organisation of R&D and innovation. If the structure is not sound, simply increasing the R&D and innovation budgets will not be sufficient. Also, an increase in R&D capacity will need to be gradual and built up over time. Sudden spending increases before the capacity is in place will be inefficient and wasteful.

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