Policies and Institutions to Support Carbon Neutrality in China by 2060

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1. Motivations underlying the research

An extensive and growing literature in environmental economics has focused on China's environmental policies, but only a limited set of studies has reviewed China's policies related to climate change, prompting this review paper. China's leadership has announced its aim to achieve CO_2 neutrality at the national level by 2060. This review examines the extent to which current policies and institutions would need to evolve to support deep decarbonization in the world's largest emitting nation.

2. A short account of the research performed

Here, we review the major developments in climate policies and institutions that are projected to drive transition in China's energy system. We ask how well matched these developments are to the goal of achieving CO_2 neutrality by 2060. Where relevant, we draw on other policy domains, such as energy management and local environmental protection, which offer insight into how policies and institutions can work together to support meaningful progress toward CO_2 neutrality. We further consider international dynamics.

China's international pledges have been reflected in plans and targets, which have been implemented via a combination of command-and-control and, more recently, market-based policies. The environmental economics literature on instrument choice has studied the interactions of various forms of climate policy instruments in a range of global contexts. Combinations studied include interactions between carbon pricing systems (carbon taxes or cap-and-trade) and sector-specific technology requirements or performance standards. This literature finds that combining instruments reduces cost effectiveness. However, precisely because they are more prescriptive, technology requirements and standards reduce uncertainty by defining what actions will be rewarded.

This review finds that China's climate policies often blend command-and-control and market mechanisms: in sectors or geographies bound by targets that are determined via the central planning process. This approach has roots in China's broader economic opening and reform process, in which markets initially played narrowly scripted roles and in many ways remain subordinate to state priorities. Applied to energy-related environmental policy, blending command-and-control and market-based instruments has at times faltered, for example, in the case of SO2 trading in the early 1990s. Aside from this brief experiment, until recently most of China's environmental policies have drawn heavily on command-and-control designs. However, over the past decade, a renewed emphasis on introducing market mechanisms in broader economic policy has been applied to climate policy, as a means of limiting costs, including the need for subsidies.

3. Main conclusions and policy implications of the work

Our policy review concludes with three observations. First, efforts in China to mitigate climate change have thus far largely delivered on targets set in national plans. None of these targets has been as ambitious as the country's 2060 carbon neutrality goal. Second, while command-and-control policies have been effective in providing clarity on who is responsible for specific climate change mitiga-

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tion actions, concerns about rising costs and weak incentives for firms to supply CO_2 reductions have led policymakers to rely increasingly on market-based instruments to encourage emissions reductions. Third, climate targets have proven easier to achieve when when responsibility is clearly assigned and when targets align with the near-term objectives of national plans. These objectives include maintaining steady economic growth, reducing industrial overcapacity, expanding clean energy industries, improving local air quality, and strengthening the nation's stature as a climate leader internationally. Although this multiplicity of targets may limit cost effectiveness in the near term, it will be important to generate early beneficiaries that can ensure the durability of the system and who stand to gain from a shift over time to expanded reliance on market mechanisms.

Modelling Net Zero and Sector Coupling: Lessons for European Policy Makers

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1. Motivation

Net Zero (NZ) is the name given to the policy target of reducing to zero (net) GHG emissions across the economy. In March 2020 the European Commission proposed a European Climate Law aimed at legislating for Net Zero across the European Union, this has recently (as of June 2021) become law having passed through the European Parliament and Council. While the prospects for electricity decarbonisation to 2030 are promising, the necessity of deep decarbonisation of the entire energy system by 2050 remains challenging.

Sector coupling is commonly understood as integrating the energy consuming sectors (such as buildings, transport, and industry), and optimising them with the energy supply sector. The joint decarbonisation of the electricity and gas sectors is seen as critical to the achievement of the NZ target in the European Union and the UK. What a NZ implies for energy and environmental policy can be clarified by appropriate energy system modelling.

2. Short account of the research

This paper seeks to discuss some of the policy implications which arise from the modelling of Net Zero GHG emissions in 2050 within a sector coupling approach. We draw on a major study of the EU-UK energy system in 2050 produced by the Centre for Regulation in Europe (Chyong et al., 2021), which involved stakeholders from both electricity and gas sectors in a year-long modelling exercise of the European energy system. While no model of the future is an accurate forecast, an optimisation model of the Net Zero energy system is very helpful in clarifying the role the modelled technologies might play in a future energy system under binding government policy targets. What our modelling highlights is that the achievement of Net Zero depends on the massive scale up of variable renewable electricity, biomethane, hydrogen and carbon capture and storage (CCS) technologies.

As with all scenarios, our modelling is not a prediction about the future, and we are not saying a priori that our reported scenarios are absolutely likely to come about or that any one scenario is more likely than another. We report our NZ scenario and our 90% GHG reduction scenario (relative to 1990) and show very significant changes to the European energy system relative to today. Our modelling allows us to discuss the potential magnitudes of future electrification, use of hydrogen, use of biomethane and the extent of carbon capture (with and without storage) to be explored. Specifically, the modelling produces magnitudes for the amount of sector coupling, which we take to encompass power-to-hydrogen (power-to-H2) as well as synthetic methane and synthetic diesel produced by combining hydrogen and CO_2 captured from bio-energy (i.e. e-gas and e-liquid).

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3. Conclusions for Policy makers

Our modelling highlights the following conclusions for policy makers and policy making.

The continuing roll out of renewable electricity supply (RES-E) is essential to any deep decarbonisation scenario and the required rate of roll out of wind is much higher than has previously been achieved. A striking consequence of the increased reliance on a renewables-based electricity system is that a substantial increase in electricity trading is envisaged.

Depending on relative costs and the depth of decarbonisation, electricity is required to be transformed into carbon-neutral gaseous or liquid fuels, which implies significant transformation losses compared to the route of direct electrification. Bio-energy with carbon capture and storage (CCS), otherwise known as BECCS, is an essential NZ technology as a source of negative emissions. Achieving NZ with this technology requires a large increase in the use of biomass. Hydrogen and biomethane have key roles in each of our NZ scenarios, given our currently available/envisaged technologies out to 2050, provided that the large increase in biomass availability turns out to be sustainable.

Fossil fuel prices do continue to make potentially significant differences, especially in determining the relative quantities of hydrogen produced from electrolysis (green hydrogen) vs. from steam reformation of methane with carbon capture and storage (blue hydrogen).

The successful scale-up of multiple technologies supported by appropriate policies will be critical for the achievement of any of our Net Zero scenarios. Scaling up new industries over which different EU member states have different preferences means that policy should both encourage learning from experimentation and harmonisation of arrangements across the EU. What our NZ scenarios show is that some massive scaling up of currently nascent technologies – e.g. hydrogen, CCS, biomethane - is part of Net Zero under a wide range of cost assumptions. While there may be lots of small injections of locally produced hydrogen, this is not enough on its own in any of our Net Zero scenarios. Our detailed modelling assumes that there are separate methane and hydrogen networks in 2050.

Finally, net zero raises big future issues as to how costs will be allocated to consumers.

Overall, net zero in Europe remains an extremely technologically challenging policy goal, involving the roll out of multiple new technologies at scale in a 30-year time frame. It requires policy to deliver three times the carbon reduction achieved in the last 30 years. Modelling clearly shows that wholesale failure to scale up any one of the key technologies on which our Net Zero scenarios depend – RES-E, biomethane, hydrogen or CCS – will fundamentally block the path to Net Zero, necessitating a currently unforeseen technological break-through. This is in addition to the fact that modelling shows the necessity of the extension of the single market in electricity and assumes uniformly high carbon prices and deep improvements in energy efficiency relative to business as usual.

New Transactions in Electricity: Peer-to-Peer and Peer-to-X

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Motivation

The electricity sector used to be characterised by transactions initiated by large and professional players: business-to-business at the wholesale level, and business-to-consumer at the retail one. This is changing due to the development of distributed energy resources (DER), including electric vehicles, and the digitalisation of the electricity infrastructure. Households, farms, small commercial activities and the like have today the ability to trade electricity and other related products peer-to-peer (P2P) or to offer those resources connected 'behind the meter' to business players (P2X).

P2P and P2X transactions open a new world in the electricity sector and have the potential to disrupt existing business models and regulation. Several initiatives are visible on the ground, but academic literature on the matter is still limited and an analytical framework able to capture the meaning and im-

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plications of these new transactions is largely missing. However, developing such a framework is vital in order to clarify the phenomenon and investigate the future of this emerging transactional space, whose ability to thrive in a highly regulated sector, where incumbents have significant power, is still unclear.

Short account of the research

P2P and P2X transactions call for a collection of empirical evidence on early implementation cases and the identification of typical forms that simplify the heterogeneous reality. In the paper, we initially distinguish three forms of P2P transactions and three forms of P2X transactions. The three forms of P2P transactions are peer-to-peer in sandboxes, peer-to-peer within platforms, and peer-to-peer in communities. The three forms of P2X transactions are peer-to-system, peer-to-grid, and peer-to-system with an integrator. We illustrate these six forms with case studies from the world of practice.

Then we simplify reality further by distinguishing only four fundamental 'families of transactions'. They are peer-to-peer with a third party, peer-to-peer within a community, peer-to-grid, and peer-to-system with an integrator.

Finally, the last part of the paper looks for a logical matrix of diversity and coherence in the functioning of this new world. We identify and discuss three pillars that look fundamental to enabling the new transactions. They are the 'matching loop', the 'pricing mechanism', and the 'delivery loop'.

Main conclusions and policy implications

There is no doubt that a new world of electricity transactions has emerged. It combines new players, which are of the same size as consumption units and have a non-professional nature, with new products or services originated from behind the meter of the traditional electric system. Representing a significant departure from the traditional electricity arrangements, these transactions look like heterogeneous, having not yet crystallised into regular forms of business models and governance. It is because they demand a sophisticated frame to work. First, a new type of matching loop to lower transaction costs, otherwise too high for small non-professional peers to handle. Second, a sophisticated pricing mechanism to provide peers with adequate incentives for investing in the relevant assets and operating them to offer attractive products or services to other actors. Third and final, a guaranteed delivery loop capable of ensuring the physical distribution of the product or service to the purchasing side.

The need of carefully aligning all these three pillars implies that P2P and P2X transactions are very sensitive to constraints and to the actual behaviour of traditional decision-makers like regulators, grid operators and market operators. However, P2P and P2X transactions are gradually getting a more favourable 'political economy' regime in those electricity systems characterized by large numbers of prosumers and electric vehicle owners.

To conclude, four families of transactions with peer look already capable of managing durably the particularities associated with the transaction of small quantities of energy, flexibility or storage. The variety of forms and the uncertainty about their future evolution is normal at this early stage, as it was in the 1990s and the 2000s when wholesale and retail trade of electricity began. It should not surprise but attract more attention. It may also happen that the world of B2B and B2C transactions could evolve in new ways able to perform P2P and P2X transactions.

Facilitating Transmission Expansion to Support Efficient Decarbonization of the Electricity Sector

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1. Motivations underlying the research

Over at least the next 30 years, achieving deep decarbonization targets for most electricity sectors will require replacing the bulk of fossil-fueled generators with zero carbon wind and solar generation along with energy storage. The best wind and solar resources are located in geographic areas that are often relatively far from the locations of the legacy stock of generating plants, their supporting transmis-

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sion infrastructure, and load centers. This situation raises a number of important questions. How much additional transmission capacity is needed efficiently to access these locations and utilize efficiently the wind and solar capacity that can be developed there? What are the barriers to facilitating the development of this transmission capacity? What changes in the approaches to stakeholder engagement, planning, regulatory, and financing arrangements can help to reduce these barriers? What can we learn from best practices in the U.S. and Europe to reduce these barriers?

2. Summary of research

The research documents that the best wind and solar resources in the U.S., the EU, and China tend to be remote from the existing stock of generating plants, remote from their supporting transmission infrastructure, and remote of demand centers. It goes on to examine several recent studies that use optimal electric power system planning models to identify transmission expansion needs in the U.S. and Europe efficiently to support deep decarbonization targets. While the results necessarily vary across model assessments, they all support the conclusion that significant transmission expansion is necessary to meet decarbonization targets efficiently.

We find that in both the U.S. and Europe transmission expansion is proceeding more slowly than would be desirable. The research starts with several case studies of several major transmission projects in the U.S and Europe, to help to identify the barriers these projects faced, and how the developers ultimately overcame the barriers or abandon the projects. These case studies are supplemented with a review of more recent planning, investment and regulatory experience in the U.S. and Europe, including the impacts of FERC Order 1000 and the EU Regulation on Trans-European Energy Networks (TEN-E). Comparing and contrasting U.S. and European responses to similar challenges yields useful suggestions for organizational, regulatory, planning, compensation and cost allocation reforms that can reduce the barriers to efficient expansion of transmission capacity.

The first barrier arises due to the limited geographic areas over which transmission planning has typically taken place. The EU has developed better institutions to identify attractive transmission projects over a large geographic area that encompasses the best wind and solar sites. The most important EU institution is ENTSO-E which serves, among other things, as an umbrella planning organization covering all of the transmission system operators (TSO) in the European synchronous network and neighboring grids. This leads to the recommendation that the U.S. (or the U.S. plus Canada) create a similar umbrella planning institution to facilitate interregional planning over much larger geographic regions than is the case today.

The second barrier, primarily in the U.S., is the failure to take all benefits of transmission expansion into account, especially decarbonization benefits. The U.S. lacks a comprehensive national decarbonization policy and some states have aggressive decarbonization commitments while others do not. Again, the EU has adopted detailed guidance for comprehensive cost-benefit analysis that include decarbonization commitments.

The third barrier arises due to the ways in which transmission developers are compensated for their transmission investments, increasing financing and project development costs. Three general compensation models are discussed along with their strengths and weaknesses. Actual transmission compensation practices in the U.S., the UK and the EU are then discussed. The research concludes that a hybrid compensation model, that integrates incentive regulation and competitive procurement with cost- of-service regulation is likely to reduce transmission development costs, while accommodating merchant projects more effectively.

The final barrier is opposition by stakeholder groups, going beyond classical NIMBY opposition. Drawing on the case studies and the literature on siting major infrastructure projects, the research identifies several actions that should be taken to better engage with stakeholders.

Transmission Network Investment in a Time of Transition

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Motivation

Because of unparalleled level of uncertainty in the electricity industry associated to the energy transition toward renewables, the problem of transmission planning is more complex than ever. Transmission investment remains fundamentally important, as a key facilitator of investment in new sources of generation. In this paper we review the literature on transmission network investment and regulation. We start with a review of the transmission planning task as carried out by a welfare-maximising planner and address the issues that arise in liberalised electricity sectors from the separation of generation and network investment. We further review the design of efficient financial incentives for a transmission planner, as well as the scope for merchant transmission investment and forms of competitive procurement. We also analyze the future challenges for transmission network investment in a time of energy transition, and even propose in an appendix a simple general stylized model for transmission planning.

Research Performed

In modern power systems the transmission network investment task is usually solved through an explicit optimisation algorithm. The algorithm takes as input the supply curve of every generator, the demand curve of each load, and the physical capability of the transmission network, and finds a combination of production and consumption for each generator and load which maximises the total economic welfare. The resulting locational marginal prices (LMPs) from this process send efficient signals for small-scale investment and dis-investment decisions at each location on the transmission network. However, even in sophisticated power systems, this optimal-dispatch process only operates every few minutes. On timescales shorter than the dispatch interval, it is common to rely instead on ad hoc or heuristic processes. Of course, there are many practical issues with the transmission planning task that make it more complex, such as computational intensity in the planning process, the handling of uncertainty and risk, and inefficiencies in the market and regulatory frameworks.

One of key question asked in the literature is whether it is possible to design a financial mechanism which provides incentives to the transmission company (TransCo) to both operate and invest in the network efficiently. In a market with LMPs, the TransCo will normally be the recipient of a merchandising (or congestion) surplus. In principle, the TransCo will face the correct incentives for the operation of, and investment in, the transmission network if it is granted a revenue stream equal to the total economic surplus received by the customers of the network (generators and loads). This idea can be seen reflected in the proposals of Léautier (2020) and Vogelsang (2020).

In the proposal by Léautier, the TransCo is made liable for the difference between the total economic welfare created by the transmission network in two scenarios: (a) the case

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where there are no transmission binding constraints; and (b) the case where there are binding transmission constraints. Léautier claims that, under this mechanism, the TransCo will have the correct incentives to expand the grid. However, there are concerns with Léautier's proposal, such as: in the presence of inter-temporal constraints, the concept of unconstrained dispatch is not clearly defined.

The H-R-G-V proposal described in Vogelsang (2020) alternatively proposes a two-part tariff for the TransCo. The variable part of the two-part tariff is the merchandising surplus, while the fixed part is restricted to be less than or equal to the total consumers' surplus. The H-R-G-V mechanism has various desirable properties, such as immediate convergence to social optimal investment in expanding a transmission network. However, there are also some concerns with this proposal, such as: how the TransCo obtains complete information on the supply and demand curves for all existing and future generation and load assets?

Given the hurdles of incentive financial mechanisms, can a merchant mechanism be created under which private entrepreneurs have an incentive to pay for upgrades to the transmission network? Several researchers have asked the question whether it is possible to link incentives for investment with the sale of Financial Transmission Rights (FTRs). Biggar and Hesamzadeh (2020) emphasise that generators with an upward-sloping supply curve (or loads with a downward-sloping demand curve) would like to construct a portfolio with a volume that varies with the supply curve (or demand curve), such as so-called 'Cap' or 'Floor' contracts. They point out that a financial intermediary could provide hedge contracts to market participants and to the system operator.

Conclusion and Future Challenges

A wide range of transmission investment issues, which also represent a list of challenges for policy makers and researchers, are likely to arise in a time of energy transition, including:

- The need to explicitly value flexibility through the real options framework;
- A deeper understanding of the appropriate handling of risk;
- The need to pay closer attention to the identity of the beneficiaries of transmission investment;
- The need to be clearer about the handling of the costs of stranded assets, and
- Resolving the role of market forces in wholesale power system operation and its impact on investment.

Fossil natural gas exit – A new narrative for the European energy transformation towards decarbonization

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1. Motivations underlying the research

This paper discusses the potential role of fossil natural gas in the process of the energy transformation in Europe on its way to decarbonization. Mainstream conventional wisdom has it that natural

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gas, perhaps in combination with other gases, should maintain an important role in the energy mix, first, as a "bridge fuel", and then through a gradual transition toward "decarbonized gases". However, when considering the ambitious climate targets of the EU and the subsequent need for far-reaching decarbonization, in combination with technical constraints and the results from our own energy system modeling, we arrive at a contrasting result: The disappearance of fossil natural gas and its corresponding infrastructure is the next logical step of the transformation process in Europe. The paper provides a review of the issues at stake and deconstructs the dominant narrative through a detailed technical description of different energy gases and their real climate effectiveness, as well as results from energy system modeling. We conclude that the phase-out of fossil natural gas in Europe needs to be completed towards 2040 in order to comply with climate targets and provide planning reliability for policy-makers and the industry. We develop an opposing narrative of a natural gas exit, by positing that the EU objectives of decarbonization are to be taken serious, and then rejecting the hypothesis that "methane can decarbonize". Our argument relies on a critical analysis of energy gases, and it is supported by modeling evidence on the European energy mix under decarbonization.

2. A short account of the research performed

The paper describes the transformation process of the European energy system over the last decades. From a focus on market restructuring, liberalization, and competition, the focus has shifted to environmental aspects and decarbonization. Clearly, while the former benefitted the natural gas industry, the latter disfavors it, due to its relatively large contribution to greenhouse gas emissions through CO_2 and methane (CH_4). In Section 3 we provide an overview of the technical aspects of fossil natural gas and other energy gases and find that arguments how to "decarbonize" methane are flawed. In Section 4, we place this analysis in the energy economic context and provide model-based analysis of a gradual phase-out of fossil natural gas from the European energy mix in the coming decades; this rests on the assumption that nuclear power is not economically available, and that there be no breakthrough of carbon capture or other carbon dioxide removal technologies.

3. Main conclusions and policy implications of the work

Our analysis has implications, both for concrete business and policy decisions, but also at the more general level of the new narrative:

- Fossil natural gas is a CO_2-intensive fossil fuel, the climate and other adverse effect of which have been hidden so far, by the focus of the climate debate on the phasing out of coal, and the narrative of "clean" fossil gas as an important bridge of the low-carbon energy transformation. However, taking into account the entire production chain, from production, long-distance transportation, and (often incomplete) burning in motors and turbines, the greenhouse gas impact of methane in many cases resembles that of coal (by unit of energy produced), and in some cases even exceeds it. Today, over two decades of attempts to generate "clean" fossil fuels, the illusion of large-scale, technically and economically available CCTS should not be upheld.
- Some energy gases may remain in the future, also in a 100% renewable system. Hydrogen, locally produced from 100% renewables may be needed for seasonal storage of excess electricity and locally reconversion on cold days with little wind and sun. In addition, hydrogen may be needed for specific industrial applications that cannot be converted to electricity (e.g. steel production or the chemical industry). The failed history of global LNG markets (Jensen 2004; Neumann 2009) suggests not to bet on "globalization" of other gases, such as synthetic fuels or hydrogen.
- As a long-lived asset, and a system good with heavy interlinkages to upstream, downstream, and side stream activities, fossil gas exit will not happen overnight, but rather on a time span of about two decades. Thus, private and public decisions need to be taken to address natural gas exit in the short term, e.g. through imposing an adequate price on carbon, but also in the long term, e.g. by prohibiting new fossil gas-fueled new heating (such as in the Netherlands from 2025 onwards).
- Just like for coal, phase-out plans for fossil natural gas will have to be developed. These plans should include phase-out periods with clear end dates for fossil natural gas production and usage in

order to enable planning security and to avoid stranded assets and compensation payments. No fossil hydrogen infrastructure including CCTS should be developed: It takes too long to build, will lock-in natural gas production, and will result in stranded assets when natural gas is phased out.

- More generally, risks of stranding assets are imminent. The current situation, where an industry doomed to disappear starts to sink investments to assure short-term survival, is not new, but observed worldwide. The risk, however, both for outside investors and the state/European regulators, is that the fossil natural gas industry invests in what will become stranded assets. The most prominent example is the € 10 bn. North Stream 2 pipeline connecting Russia to the EU, which is not necessary to assure European supply security, let alone to make a return on investment (Neumann et al. 2018). Smaller investments fall in this category as well, such as new LNG terminals on the shore of the North Sea (Brauers, Braunger, and Jewell 2021) and new natural gas power plants (Gerbaulet et al. 2019).

Electric Vehicles Rollout—Two Case Studies[a]

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There is much speculation about the rollout and impact of electric vehicles, but so far there is little experience due to the fact that, in most countries, the penetration is limited. This paper presents two cases where electric vehicles are sufficiently important for some lessons to be drawn on the consequences for energy systems and markets.

Backed by an attractive subsidy scheme, Norway leads the way in electric-vehicle sales, with a 55.9 per cent share of new registrations in 2019. Norway was also the leader in terms of share of electric vehicles in the total stock, with a 12 per cent share. The Netherlands has seen fluctuations in the market share of electric vehicles due to changes to its subsidy scheme, but in 2019 it reached 15.1 per cent; the stock share reached 2.5 per cent.

We first consider drivers for the uptake of electric vehicles. Given that all countries have access to the same car models and technologies, yet the speed of adoption differs, local factors must be important. We look at a number of such factors, including incentive schemes—taxes and subsidies—development of charging infrastructure and urban development features.

We next study how electric vehicles are used. Do they fully replace traditional cars or are they mostly supplementary? Who is likely to buy an electric vehicle and for what needs? Are there specific geographical patterns in the adoption of electric vehicles?

Finally, we consider the impact of electric vehicles on the power system. The relative increase in electric energy demand, and the associated impact on the grid and the overall power system, will depend on a number of factors. These include the size of the electricity system, charging behaviour—for example where and when charging takes place—the current state of the electricity infrastructure as well as the ability of the system to respond to increased demand.

Our research indicates that the uptake of electric vehicles has so far essentially been driven by financial and other benefits offered to potential buyers. These benefits are stronger in Norway than in The Netherlands and the market share of electric vehicles in correspondingly higher.

Most owners of electrical vehicles prefer charging at home or at work. Hence, a partial electrification of the vehicle fleet may be achieved even with limited public charging infrastructure, but the market will then be limited to buyers with access to private charging who travel mostly locally. For increased

a This article is based on Baldursson, von der Fehr and Lazarczyk (2019), a study written for the Centre on Regulation in Europe (CERRE, www.cerre.eu). The study and this article reflect the views of the authors only; it may not reflect the view of CERRE or its members.

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penetration of electric vehicles public infrastructure is needed. In both cases studied, infrastructure has tended to follow the development of electric vehicles and, so far, lack of charging facilities do not seem to have hindered further growth of the fleet.

The impact on the electricity industry in general and electricity networks in particular has so far been limited in Norway and The Netherlands, even given the relatively high penetration of electric vehicles. In most countries this is likely to be different when the majority of the car fleet is electric: in many countries in Europe—including The Netherlands—full penetration of battery electric vehicles would imply a doubling of household electricity consumption. Even if full electrification of the car fleet would take place over decades, this could put a strain on electricity infrastructure. Depending on how charging infrastructure develops, local effects could be even stronger, leading to an overloading of distribution infrastructure in certain locations at specific times. Smart charging solutions—incentive driven or command-and-control based—must then be adopted to change charging behaviour in order to ease local strains on networks and reduce peak electricity demand. The case study of The Netherlands indicates that relatively simple measures may be utilised to affect charging behaviour.

Electric vehicles not only pose challenges for the power system, but also create opportunities. The average non-commercial vehicle is parked more than 90 per cent of the time which creates the potential to use the batteries of electric vehicles as storage. In the aggregate, a large fleet of plugged-in electric vehicles forms a huge storage facility. If infrastructure is available to connect most stationary cars to the grid, and if smart charging technology is in place, there is a technical potential to harness this storage. If this technology is successfully brought to the market, electricity sourced from electric vehicles could provide flexibility and balancing services when needed. This would be of crucial importance for the power system, especially in a system with a high share of variable renewable energy (wind and solar). Hence, electrical vehicles themselves may become part of the solution as storage if vehicle-to-grid technologies are successfully deployed. But technology alone is not sufficient; a change in charging behaviour is also needed if this potential is to be harnessed. For this to happen, vehicles need to be plugged into the grid while they are parked, the vehicle-to-grid technology has to be developed and in place, and market agents—aggregators—need to be operating and to have entered into contracts with electric vehicle owners for the use of their (mobile) batteries.

Policies for supporting the adoption of electric vehicles for individual use tend to be considered mostly from the environmental perspective. The case of Norway indicates that it is also necessary to consider them as a part of transport policy, including consideration of issues such as road congestion and incentives for using public transport.

Empower the consumer! Energy-related financial literacy and its implications for economic decision making

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1. Motivations underlying the research

Untapped energy savings potential in the residential sector are a barrier to achieving ambitious national energy-efficiency targets. In fact, they may lead to substantial welfare losses. Among the several

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potential causes for consumers to not invest in energy-efficient appliances and equipment, which—over their lifetimes—are often also the cost-minimizing choices, are consumers' limited energy-specific knowledge and investment skills. Consumers' decisions to invest in energy-using durables represent a type of intertemporal decision, for which it has been observed in other domains that consumers are myopic or inattentive to costs arising in the future. Previous research in different countries has shown that large shares of the population are unaware of the savings they could realize by replacing their electric appliances by more energy-efficient ones.

Yet, investments in energy-using durables require not only awareness of future operation costs but also a combination of specific knowledge and skills: information about the energy consumption and the lifetime of appliances as well as of possible new, more efficient, appliances that could replace the old ones. Furthermore, consumers need to know the cost of electricity and make assumptions on how frequently they plan to use their appliances. Eventually, they need the skills to process all this knowledge in order to identify the possible savings from replacing their appliances by more energy-efficient ones. Research shows that these processing costs are relatively high for a substantial share of individuals. In combination with the lack of energy-specific knowledge and skills, this might represent an important barrier to households' energy conservation.

2. A short account of the research performed

To clarify the focus of our analysis, we summarize the various existing definitions of the term 'energy literacy' as well as its relation to the concept of 'financial literacy'. Moreover, we propose an integrated concept of literacy that we call 'energy-related financial literacy'. This concept combines both (1) the energy cost-specific knowledge households need in order to take informed energy-related decisions and (2) the set of skills needed to process this information and take optimal intertemporal investment decisions. We hypothesize that the combination of these elements is a better predictor of cost-efficient energy-related investment decisions than a standard financial literacy measure.

Using data from a large sample survey carried out in three European countries, we first present key facts about individual's financial literacy (as measured with the standard "Big Three" questions) and energy-related financial literacy. We document a substantial lack-of energy cost-specific knowledge among the respondents in our sample. Using multivariate regression analysis, we then study the determinants of energy-related financial literacy, with particular emphasis on the role of gender. The results provide evidence for a substantial gender gap in energy-related financial literacy, consistently with the evidence for financial literacy.

We then explore the role of financial literacy and 'energy-related financial literacy' for the adoption of energy-efficient technologies. Focusing on the adoption of energy-efficient light bulbs, we exploit data on actual investment decisions rather than hypothetical choices. The results of the econometric analysis show that energy-related financial literacy is positively associated with the adoption of energy-efficient light bulbs. Specifically, consumers with high energy-related financial literacy are associated with a 5 percent higher share of LED light bulbs at home. In contrast, we do not find an influence of financial literacy on lighting efficiency.

3. Main conclusions and policy implications of the work

Our analysis documents that, while the majority of the respondents in our sample perform quite well in standard financial literacy questions, a substantial lack of energy cost-specific knowledge prevails. The empirical analysis also shows significant heterogeneity in energy-related financial literacy scores among respondents. Importantly, we document a substantial gender gap in our measure of energy-related financial literacy, with males scoring higher levels of the index, consistent with the evidence on the gender gap in financial literacy. We also find that our measure of energy-related financial literacy is a better predictor of cost-efficient investment decisions than financial literacy, which suggests that standard financial knowledge alone is not sufficient to ensure optimal energy-related investment choices.

Our results inform models of consumer behavior for the choice of energy-consuming durables about the importance of considering limited energy-specific knowledge and skills to perform an intertemporal investment calculation. Further, they point towards the promotion of energy-specific and financial education programs as a mean to address consumers' lack of energy-related knowledge and skills and increase the adoption of energy-efficient durables. This is important to reach energy-efficiency goals since the decision of adoption of durables have implications in the long-run electricity consumption. Such programs would be even more relevant in the light of the prevailing energy poverty within several EU Member States, which is often associated with further problems such as poor health of household members.

Incentive Regulation of Electricity and Gas Networks in the UK: From RIIO-1 to RIIO-2

Tooraj Jamasb[a]

1. Motivations underlying the research

During the initial post-liberalisation years in the UK, the regulation of electricity and gas networks was mainly focused on improving cost efficiency, quality of service, and network energy losses. By the 2000s, changes in the policy and technological landscape had brought about new regulatory possibilities and priorities. The UK energy regulator Ofgem faced challenges related to smart meters and networks, distributed generation, access charging methodologies, new business models, electric storage technologies, fuel poverty, and environmental concerns. This meant that regulation of energy networks has also implications for the wider energy systems, consumers, and the society.

As the regulatory and operating context of energy networks is dynamic and constantly evolving, achieving a multitude of economic, environmental, social and policy objectives is a challeng for the sector regulators. In 2010, Ofgem replaced its approach to energy network price control and incentive regulation with a Revenue-Incentive-Innovation-Output (RIIO-1) model. As part of the preparations for the second output-based network price controls (RIIO-2), Ofgem is revisiting the RIIO-1 model. RIIO marks a transition from cost-efficiency focused regulation to an output-oriented framework. RIIO-1 ends in March 2021 and Ofgem is considering modifications for RIIO-2 effective from 2021 (2023 for electricity distribution).

The motivation for revising the incentive mechanisms of the next price control of energy networks under the RIIO-2 framework is evident in Ofgem's Decision Document: "*When returns fall well outside ex ante expectations, particularly across all companies in a sector, we think it is more likely due to network companies exploiting information asymmetry, forecasting errors, or due to a poorly calibrated price control mechanism*." (Ofgem, 2019).

2. A short account of the research performed

The possible changes to the RIIO model can affect the incentives, conduct, and output delivery of the energy networks in the short- and long-run. This paper is an economic assessment of the incentive properties of the main changes to RIIO energy network regulation model.

This paper reviews the incentive areas that influence the performance of the next version of RIIO-2. The assessment is guided by the principles of regulatory economics and evidence in the literature, we discuss key aspects and incentive properties of the regulation model under revision by the regulator.

We examine the main potential revision areas in the output-based RIIO-2 regulation for gas and electricity transmission and distribution network price controls considered by Ofgem. The changes concern several areas of price controls and incentive mechanisms. These changes include: (i) shorter price control periods, (ii) adjusting cost of equity (CoE), (iii) Return (on equity, RORE) Adjustment

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Mechanism (RAM) and profit sharing, (iv) Replacing the Information Quality Incentive (IQI) scheme with Business Plan Incentive (BPI), Totex Incentive Mechanism (TIM), and Sharing Factors, and (v) Blended Sharing Factors (BSF) as targeted incentives.

3. Main conclusions and policy implications of the work

RIIO-1 has been the longest network price control (8 years) in the UK. RIIO presents an innovation in utility regulation by attempting to reflect the changing nature of the role and services of the utilities. There are also indications that under RIIO-1 most companies have earned high ROREs.

This has motivated the regulator to revisit the framework for RIIO-2 and a set of changes are being considered. The combined effect of the proposed changes in the regulation model is, however, difficult to determine and will depend on the details of implementation. The main sources of the excess RORE in RIIO-1 are (i) significant Totex underspend, (ii) over-performance in some targeted incentivised areas, and (iii) real price effects during the regulatory period.

The optimal length of price control is a longstanding issue in regulation and there is no clear answer to it. Uncertainty is a key factor in determining the benefits of a longer price control. The IQI can be eliminated. Instead of incentives based on forward-looking business plans, benefit sharing based on historical information and own assessments can be considered. The Totex Incentive Mechanism (TIM) and Blended Sharing Factors (BSF) are key components of RIIO. These incentive mechanisms can also reduce their reliance on information provided by the companies. The use of targeted incentive mechanisms should be limited to critical areas where performance improvement has a high priority. The return adjustment mechanism (RAM) should be a mechanism of last resort. When other incentive mechanisms are well-calibrated the need for RAM will be reduced. Incentive regulation models can quickly become complex. Simpler models will have the advantage that the effect of a given incentive change can be tracked.

The lessons of experience from the RIIO models in the UK are also relevant for energy regulators in other countries and can inform their design of incentive regulation of energy networks.

Biomethane for Electricity in Mexico: A Prospective Economic Analysis

Hector M. Nuñez[a]

1. Motivations underlying the research

Mexican's new administration (2019–2024) has changed priorities from supporting a competitive electricity market and giving priority to renewable energy sources (RES) to bringing the energy industry back under government control. However, nonconventional RES in Mexico have made some progress during the recent years, contributing 10% of the total generation in 2019. In the case of bioenergy, it contributed with 0.54% of the total supply. Biomass can be converted to electricity in several ways, and the most used in Mexico is direct combustion, followed by biogas generation for either combustion or electricity. However, the alternative – transforming biogas into biomethane (BM) and selling it to current and future natural gas (NG) power plants – is not used in the country. NG is the main fuel used for electricity generation in Mexico and the country imports more than half of the NG required to satisfy domestic demand, and the electricity sector claims most of that. This dependence on foreign NG could be alleviated by sustainable domestic BM production, which could use the same infrastructure as NG and be stored in salt caverns and aquifers. In this sense, BM is different from other RES because it would compete with imported NG rather than domestic electricity production.

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On the other hand, known production costs in Mexico are still very high, while market NG price projections are significantly lower for the next years. However, it is well documented that new renewable energy industries significantly reduce processing costs in the medium and long term.

In this context, this paper carries out a normative analysis of the welfare and environmental impacts of first- and second-best policies to incentivize BM domestic production to substitute part of the NG for power plants, in the presence of import dependency and externalities in the NG-for-electricity market, comparing them with outcomes obtained under current policy.

2. A short account of the research performed

This work constructs a stylized partial equilibrium model of the NG/BM for-electricity sector in Mexico to undertake the mentioned normative analysis. This optimization model simulates the formation of simultaneous equilibrium by maximizing the social surplus derived from production and consumption of a set of products related to the NG/BM-for-power subject to material balance equations and resource availability. The social-surplus function includes the NG for-power market in Mexico as well as the excess of supply of NG from the rest of the world.

Electricity plants are the direct consumers for this analysis. The model considers BM from the organic fraction of municipal solid waste and activated sludge from municipal wastewater treatment facilities. These two sources are confined at significant amounts, with a constant flow to specific sites, which makes them viable for medium-term implementation. For projections, BM and NG are assumed to be perfect substitutes to generate blended NG/BM-for-power.

The socially optimal scenario for Mexico considers the effects of imposing a commensurable carbon tax on emissions from NG. This policy provides a normative benchmark for comparison of the extent to which the mandate to blend BM in NG and status quo policies are second best in terms of their social welfare outcomes and differ in the incentives they provide for NG/BM mix, production, and consumption decisions relative to the first-best policy.

Results show that under the status quo policy, there is no BM production and Mexico imports most of the total NG required for the electricity sector. Under a mandate policy, total NG/BM demand decreases slightly given that BM producers would not produce a larger amount because they are not able to bear production costs. Under the carbon tax policy scenario, total NG demand declines further while BM demand increases and reaches the highest level of all three scenarios – up to 2.8% of the total projected NG/BM demand in the country. This first-best policy yields the largest total social welfare and NG producers get the lowest welfare gains due to the carbon tax. The mandate policy reports higher welfare than the status quo, basically explained by the larger environmental damage under the latter policy.

3. Main conclusions and policy implications of the work

Externalities due to GHG emissions from NG consumption and not-value-added residue disposal are key welfare justifications for intervention by the Mexican government in the NG-electricity market. Results show that BM can generate about 6,000 GWh per year, which can incentivize domestic industry when building the plants and job creation will be permanent and intensive. It is thus paramount that any policies the country implements to promote BM be seen as sustainable.

Nevertheless, selecting the status quo policy scenario reflects the value the government places on revenues from the national electricity company, which is the main NG consumer, and indicates the low priority given to environmental goals. A mandate policy targets slightly more environmental and BM producer gains than the status quo, but significantly less than a first-best policy.

Key assumptions made in this analysis are that i) there will be a considerable reduction in BM processing costs in the medium and long term; ii) that competitive market conditions will prevail; and iii) that conditions in the NG market can be predicted with reasonable certainty. Hence, government should also promote policies to help assumptions i) and ii), such as investing in the biotechnology researching sector and fostering conditions for market competitiveness and spillovers from other activities.

Aiming for carbon neutrality: which environmental taxes does Spain need by 2030?

Jorge Blazquez,[a] Jose Maria Martin-Moreno,[b] Rafaela Perez,[c] and Jesus Ruiz[d]

1. Motivations underlying the research

On December 2019 the European Commission presented the Green Deal, a strategic plan with the ambition to achieve climate-neutrality by 2050. As part of this strategy, the Commission aims to reduce greenhouse gas emissions by at least 55% below 1990 levels by 2030, as an intermediate target. Consequently, in the next years European policymakers should design a set of policy instruments to significantly curb emissions. However, the direct impact of energy policies, international prices of fossil fuel, and economic activity on carbon emissions is no easy to address.

In this new ambitious policy context, Spain is seeking to pass a new climate law to cut its emissions to net zero by 2050. The current Spanish strategy for a long-term decarbonization sets a reduction of 23% in greenhouse emissions in 2030. The aim of this paper is to find the level of taxes on fossil fuels and on carbon consistent with targets for 2030 set by the current strategy (23%) and by EU commission (55%). The level of these taxes might provide a useful benchmark for policymakers, given the ambitious carbon target pointed out by the European Commission.

Our study uses a general equilibrium model where the government, to achieve its environmental target, taxes the consumption of oil, coal and natural gas, focusing on the long-run impacts. We identify the optimal mix of taxes on fossil fuels to curb emissions and to achieve a specific carbon target in a competitive equilibrium framework. We compare the optimal tax-mix to a standard carbon tax. Previous studies focused on the optimal tax on a specific fossil fuel, but, to best of our knowledge, there is a gap regarding optimal taxes on oil, natural gas and coal simultaneously.

2. A short account of the research performed

We use a general equilibrium model for a decentralized small open economy with a representative household, competitive firms, a government, and an external sector. These interact actively by trading final goods, foreign bonds, and three primary energy inputs: oil, natural gas, and coal. This model focuses on carbon emissions from energy use. In this theoretical framework we define the optimal tax-mix as the combination of tax rates on fossil fuels that minimizes the negative impact on household welfare in the steady state while achieving, at the same time, a specific target of CO2 emissions.

The aim of this paper is to provide a benchmark for policymakers, focusing on two carbon targets: the one set by current Spanish strategy for a long-term decarbonization and one the one set by the European Commission plan in 2030, which imply a decline in the level of emissions of 23% and 55%, respectively.

This model simulates energy consumption of Spain using historical data and market dynamics. The main conclusion is that there is the need for a substantial increase in fossil fuel taxes to achieve both carbon targets in the long run (23% or 55%). When we compare the actual tax mix with the optimal one, the misalignment for coal and natural gas is evident: for coal the tax rate should increase from the current 100% to around 460% or 760% depending on the target, and for natural gas should increase from the current 60% to around 130% or 260%. Contrarily, the current taxation of oil, 130%, is not so different from the model optimal, around 81% or 180% for each target. Alternatively, the two emis-

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sions cut targets could be achieved with a carbon tax in 2030 around 40 or 150 euros per ton of carbon dioxide (€/tCO2), respectively.

3. Main conclusions and policy implications of the work

In the new European climate strategy for 2030, Spain should reduce its carbon emissions significantly, around 55% in the next decade. This study, based on Spanish economic data, suggest that the domestic prices of fossil fuels need a substantial increase to achieve the carbon targets for 2030. This increase can be achieved through higher taxes on fossil fuels or by means of a substantially higher carbon price. We estimate that taxes on oil should increase around 50 percentage points to achieve a 55%-cut in emissions, taxes on natural gas should between twofold and fourfold, and taxes on coal, between fivefold or sevenfold, depending on the target. We also find that, alternatively, the carbon tax needed to achieve a 55% reduction is around 150 €/tCO2, similar to previous findings for other countries.

This study suggests that, for Spain, carbon taxes are an appropriate policy instrument to achieve the carbon target for year 2030 for three reasons: its simplicity, it penalizes the negative externality, and it is -almost- identical in terms of welfare losses to the optimal taxes on oil, natural gas, and coal.

The Cost of Finance and the Cost of Carbon: A Case Study of Britain's only PWR

David Newbery[a]

The article argues for the critical importance of the cost of finance for decarbonising the economy, and demonstrates this by calculating the cost of CO_2 abatement from Britain's only operational PWR nuclear station, Sizewell B. It computes this cost using a Regulatory Asset Based model, whose efficacy in reducing the weighted average cost of capital (WACC) has been demonstrated in the financing of long-lived regulated utility assets like transmission and distribution networks. The resulting cost of decarbonisation is then compared with commercial financing (assuming, as is doubtful, that would be possible for nuclear power) and with keeping the station in public ownership at the social discount rate. Moving from a WACC of 3% real to the UK Government's typical WACC of 8% more than doubles the cost of carbon saved.

The advantage of studying Sizewell B, commissioned in 1995, is that we know its build and operating costs. A second objective is to show that its cost of abating CO_2 compares favourably with the social cost of carbon and the alternative ways of decarbonising electricity available. This incidentally sheds some light on the logic of the Central Electricity Generating Board's then proposed nuclear power programme, derailed by privatization, and the consequential lost economies of replication – issues that are germane to the UK's current plans for future nuclear power stations.

This is particularly important as the standard argument against nuclear power (other than dread of massive accidents, and its association with the bomb) is that it is too expensive compared to the now rapidly falling costs of renewables. By examining the particularly expensive example of a first-of-a-kind nuclear power plant, it argues against that view, based on a tried and tested method of lowering the WACC used to set prices for regulated utilities. The evidence also allows us to speculate on a counterfactual in which decarbonisation had been taken more seriously in the early 1990s, when Britain's embryonic nuclear programme was abandoned under free market pressures. Successor stations could then have been built at lower cost.

The UK has now committed itself to Net Zero by 2050, and various bodies, such as the Commission on Climate Change and the National Infrastructure Commission are publishing pathways for the energy sector to meet that target. Almost without exception, where these reports give costs, they do not draw attention to the cost of financing the investments (the WACC), and where they do, the default

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assumption appears to be that these will be financed at the kinds of hurdle rates used by private companies investing in liberalised electricity markets. Thus the National Infrastructure Commission assumes almost all WACCs at around 9% real. However, one characteristic shared by all zero and low-carbon energy technologies is that they are very capital intensive and many are very long-lived, so the cost of capital is a main determinant of their life-time costs. This can matter when choosing the best portfolio of techniques to deliver the target, favouring shorter-lived technologies such as wind over longer-lived technologies such as nuclear power and carbon capture and storage. This article argues that the tendency to assume high hurdle rates is both damaging (in exaggerating the costs of decarbonisation), potentially dangerous (in the choice of techniques) and unnecessary, in that there are better methods of financing such investments that dramatically reduce the WACC.

One tried and tested method of reducing the WACC is to apply the Regulated Asset Base (RAB) model adopted for privatized network utilities and with a successful 30-year record of delivering low WACCs in the UK. This article applies that model to the last nuclear power station commissioned in the UK (Sizewell B, SZB, on the east coast of Britain) to ask whether it was a cost-effective way of decarbonising electricity. This is particularly important as the standard argument against nuclear power (other than dread of massive accidents, and its association with the bomb) is that it is too expensive compared to the now rapidly falling costs of renewables.

This article calculates the cost per tonne of CO_2 abated to displace fossil generation. The assumption on which this calculation is based is that in the absence of an adequate carbon price, new nuclear power was not commercially viable. Just as zero-carbon renewables required (and obtained) contractual support, SZB would have required a long-term contract at above market prices. The simplest such contract would be a long-term Contract-for-Difference (CfD) with the terms periodically revisited in quinquennial price controls under the RAB model of the privatised utilities, using the WACCs then applied to network utilities. At low values of the WACC the cost is $£_{2019}$36/tonne CO_2 abated and $£_{2019}$43/t. CO_2 at the high WACCs, compared to the roughly £40/t. CO_2 paid by GB generators in 2019 (of which £18/t was the additional Carbon Price Support tax). By April 2021 the EU Emissions Allowance price alone was just over £40/t. (US $57/t.)

The other striking observation is that the full cost of SZB (including First of a Kind costs) at $£_{2019}$4,290/kW is less than the $£_{2019}$5,340/kW estimated for the proposed second EPR planned for Sizewell C. If instead Britain had built both Hinkley Point C and SZC at the cost of a Nth-of-a-kind PWR, the saving would have been $£_{2019}$9-18 billion.