Selling Wind

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Renewable energy sources are increasingly important in electricity markets, and they have the potential to impact strategy and conduct in these markets. In 2018, wind energy was responsible for 6.5% of U.S. electricity generation, nearly doubling its market share and total production from five years prior. Renewable electricity is a critical component of global efforts to reduce carbon dioxide emissions, and its growth is expected to continue. Existing literature focuses on strategic behavior in electricity markets without substantial amounts of renewable energy, but few studies focus on how stochastic resource availability impacts strategic behavior and market power. Existing strategies for market power monitoring in electricity markets will be increasingly challenged by an influx of renewable generation, since regulators have imperfect information regarding energy availability from stochastic resources.

We offer a simple model to investigate how strategic firms sell electricity from renewable energy assets. Wind farms have stochastic production constraints: the total amount of energy they can produce at any time is uncertain *ex-ante*. We focus on wind energy, but the model is applicable to any asset with stochastic production constraints.

We focus particularly on the extent of resource heterogeneity—that is, the extent to which the production constraints of different firms or resources are correlated. As we show, an increase in dispersion (a decrease in correlation) improves welfare because it improves asset diversification, but *also* because it changes the conduct of firms and weakens their market power. We show that this insight is robust for any concave and downward-sloping inverse demand function. We first present the analysis for a simplified single-period electricity market with wind energy, and we extend the results to markets with multiple wind generators and traditional fossil-fuel generation.

We study strategic firms with private information regarding their realized energy availability, or "state." This energy availability is equivalent to a production constraint because it limits the extent of production by the firm in any given period. Since the resource availability of wind energy is uncertain, from an individual firm's perspective its competitors' production constraints are stochastic. However, the resource availability of wind farms is often correlated; firms can gain important information about their competitors' production constraints from the realization of their own resource availability. As such, the extent of heterogeneity (correlation) becomes an important factor that impacts strategic behavior, market power, and welfare.

We model producer competition as an incomplete information Cournot game with correlated types, where the type refers to the stochastic resource availability (production constraint) that is private information for each individual producer. We utilize a parameter d to represent the level of heterogeneity amongst wind producers; high d represents low correlation between resources. We link the extent of stochastic dependence to strategic behavior and welfare (in equilibrium), extending the existing literature on Cournot games with incomplete information.

As our model makes apparent, they key issue affecting market conduct is not just stochastic production constraints—it is that stochastic production constraints are *dependent* across firms. In

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reality, this dependence is true of both total energy output and also real-time errors versus day-ahead forecasts. As we show, the level of stochastic dependence or heterogeneity has monotonic effects on withholding and welfare.

The results provide clear insight to explain how stochastic dependence can impact welfare in imperfect electricity markets. Decreasing correlation in wind resource availability is beneficial for two reasons: First, it increases the diversification of resources, increasing the expected value of price times output. Second, it reduces strategic withholding, as it changes the information that a producer has regarding its competitors. The results of our model imply that imperfect competition in energy markets can affect investment in renewable energy, resulting in a system with sub-optimal levels of resource heterogeneity.

We also utilize the model to examine the effects of heterogeneity on collusion and on policies to prevent collusion. We investigate the effects of public sharing of high-quality weather forecasts, using the limiting case whereby the true realized energy availability of firms is monitored and shared. The results suggest an important dichotomy: information sharing through improved forecasting is socially beneficial, but it does not always improve producer profits. As such, it will not necessarily be undertaken by producers acting in their own best interest. We conclude that public forecasting—while beneficial—is unlikely to be enacted by market participants acting in their own best interests.

These results provide a framework for evaluating policies that impact investment and information-provision in imperfectly competitive markets, like electricity markets. The results can help us understand how policies that impact the dispersion of renewable energy resources, and thus the characteristics of stochastic energy availability, ultimately impact welfare in imperfectly competitive electricity markets.

Evaluating the Impact of Energy Poverty in a Multidimensional Setting

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Even in wealthy countries, there may be a portion of the population that is unable to purchase a basic set of goods and services based on energy use. According to the Building Performance Institute Europe, in 2012, about 10.8% of the European population was unable to maintain adequate warmth in their homes or were living in energy poverty. People exposed to energy poverty not only usually spend a high share of their income on electricity, oil, and gas; they also live in inefficient and unhealthy dwellings; and are exposed to severe consequences concerning health, social exclusion, and overall household welfare.

Energy poverty has been initially seen as an aspect of income poverty. Gradually, a consensus has emerged about the importance of considering it as a distinct phenomenon that should be separately analyzed. Recent advances in the economic analysis include the use of multidimensional energy poverty indicators, the consideration of subjective welfare measures, and the use of both 'objective' and 'subjective' measures of energy deprivation.

Building on the extant literature, we propose an analysis of individuals' life satisfaction where objective and subjective measures of energy poverty deprivation are jointly considered within

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a multidimensional approach. To assess the impact of energy poverty on subjective well-being (SWB), we first subsume a set of available indicators in a single multidimensional energy poverty index (MEPI) providing information at the individual level. This is achieved by adapting to energy poverty analysis (and the data at hand) the methodology used for multidimensional poverty index by the UNDP. While the aggregate multidimensional indicators are used for descriptive analysis, the individual-level MEPI is used in econometric analysis. Considering subjective indicators of energy poverty makes this kind of index trivially endogenous in its relationship with SWB. We suggest estimating the individual-level relationship between SWB and the MEPI using a bivariate ordered probit model (given the ordinal nature of our MEPI and the life satisfaction variable) with exclusion restrictions. Provided that an opportune set of instruments is available, this solution is adequate to face a general set of endogeneity problems related to unobservable factors even in a cross-sectional environment.

We build the multidimensional indicator and carry out our empirical analyses by using the Italian version of the European Union Survey on Income and Living Conditions. We first provide an explorative analysis that shows the potential from using the multidimensional index to identify energy poverty, while pointing at the same time to differences with respect to traditional monetary indicators of fuel poverty. Subsequently, we econometrically assess the relationship between subjective well-being and the individual level MEPI by identifying the causal relationship between energy poverty and life satisfaction by means of exclusion restrictions referred to the year of construction of the dwellings. The results not only confirm theoretical predictions, by detecting a significant negative relationship between subjective well-being and the intensity of energy poverty, but also point to the capability of multidimensional indicators in explaining the impact of energy poverty on subjective well-being *vis-à-vis* classical affordability measures (which, in our exercise, do not detect any significant effect). These effects are detected even when considering a MEPI restricted to the subset of objective indicators, but the predicted negative impact is substantially smaller. Thus, accounting for subjective perception is relevant not only for the identification of a larger group of deprived individuals, but also for assessing the intensity of the phenomenon. Concerning the planning of policies identifying and supporting energy poor people, our findings point to the importance of complementing the available data on energy expenditures with information on the dwelling's inefficiency and perceived thermal discomfort.

A Risk-Hedging View to Refinery Capacity Investment in OPEC Countries

Hamed Ghoddusi[a] *and Franz Wirl*[b]

Investing in the downstream sector to export refined products, as opposed to the export of crude oil, is an appealing and popular policy slogan in many oil-producing countries, including OPEC members. To better highlight the attraction of the slogan, Figure 1 shows the ratio of the refinery capital to oil production capacity for a set of OPEC versus non-OPEC G20 countries. One observes that the ratio is much higher for non-OPEC countries, which then grants of the question of whether OPEC countries should also invest in the oil refinery industry? This is a crucial energy

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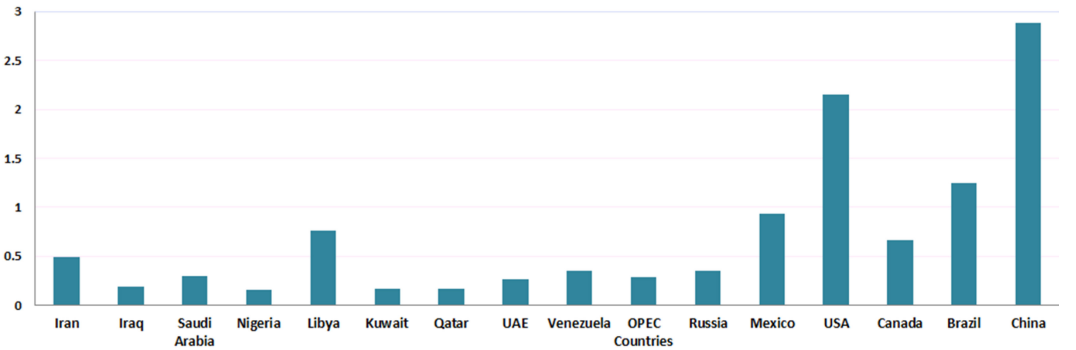
policy question for such economies, on which, unfortunately, very little recent academic literature exists.

Figure 1: Ratio of Refinery to Upstream Capacity



Among many possible arguments in favor or against downstream investment by OPEC countries, we take a risk-hedging view to the problem. Our paper offers theoretical models for a vertical integration strategy within an oil-producing economy. The first theoretical model highlights the trade-off between return and risk-reduction features of upstream/downstream sectors. We then introduce a dynamic model that focuses on the volatility of total budgetary revenue of each sector.

Guided by our theoretical framework, we run an extensive empirical analysis using historical time-series of crude oil and refined product prices. The empirical analysis suggests that the average markup in the refining sector is significantly smaller than the profits in the upstream (see Figure 2 for the histogram of net refining margins).

However, the near-zero correlation between changes in the upstream and downstream profits, motivates downstream investment as a hedging instrument.

Finally, the dynamic model suggests that the more stable and mean-reverting refining margins provide a partial revenue cushion when crude oil prices are low. We discuss the risk-hedging feature of the refinery industry when the crude oil market faces supply versus demand shocks.

European Industries' Energy Efficiency under Different Technological Regimes: The Role of CO_2 Emissions, Climate, Path Dependence and Energy Mix

Eirini Stergiou[a] *and Kostas Kounetas*[b]

As a part of national efforts to achieve green development and mitigate GHCs emissions, European industries have perceived the huge potential benefits from adopting energy saving policies and environmental friendly technologies following European as well as country specific policies. A clean and energy saving manufacturing sector has been targeted as a key area for Europe, particularly, since the launch of Energy Efficiency Directives 2012/27/EU and 2018/2002/EU. Thus,

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building up an energy efficient European industry can benefit European countries to improve their welfare with greater levels of energy independence and security, achieve the underlying objective of cost minimization and face successfully the threat of energy rising prices. Additionally, it can evolve into a valuable asset for reducing CO_2 emissions, fulfilling Kyoto protocol and Paris Agreement (2015), enhancing industry competitiveness and promoting economic growth through continual innovation (European Commission, 2011).

On the basis of the above mentioned, a detailed estimation of total factor energy efficiency estimates, at a European industry level is essential for policy makers, economists, environmentalists and scholars. Moreover, it is important to evaluate and detect possible factors that affect total factor energy efficiency scores. Less immediate for this research, but equally important from a production theory perspective, is to incorporate in our total factor energy efficiency estimations the presence of CO_2 emissions and examine the convergence-divergence hypothesis. Finally, this research aims at enlightening the role of technological heterogeneity and any country hierarchies in the benchmarking process revealing specific idiosyncrasies at national and European level. The adopted methodology operates in three stages. In the first stage we adopt a fully non-parametric approach to perform benchmarking on total factor energy efficiency scores across industries using Data Envelopment Analysis (DEA) and Directional Distance Function (DDF). In the second stage, econometric approaches provide us a concrete evaluation as whether some groups of variables are likely to increase energy efficiency with respect to the different technologies. Finally, in the third stage, we proceed with a convergence analysis for our total factor energy efficiency estimates.

Our results are important for the analysis of governmental policies regarding energy efficiency and the environment such as carbon taxes. Regarding total factor energy efficiency, our results reveal that small-scale economies exhibit a persistent high performance. In addition, the results regarding its determinants suggest that path dependence phenomena have a strong presence, revealing technological lock-in, climatic characteristics occurs, while energy mix displays linear and non-linear relationships. Finally, regardless of the method employed, there is a strong evidence of conditional and unconditional convergence for total factor energy efficiency scores.

Under Pressure! Nudging Electricity Consumption within Firms. Feedback from a Field Experiment

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The development of behavioral economics has raised interest for non-price energy conservation policies. The impact of nudges on households' pro-environmental behaviors has been studied in this perspective. Originally conceived as a public policy, nudges have recently been developed in the private business sphere to influence employees' decision-making. We seek to address this issue with the help of a field experiment on employees' energy use.

Our field experiment was conducted at 47 French office-sector companies located in the PACA Region. All participating companies were equipped with a Building Management System, allowing us to obtain their daily energy consumption distinguishing electricity consumption for

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heating from electricity consumption for other uses. The field experiment lasted 12 weeks. During the 4 first weeks, the companies' electricity consumptions were simply observed. Then, 3 treatments were tested during the 8 remaining weeks. Each site was randomly assigned either to one of the 3 treatment groups or to the control group. Each treatment was tested alone during the first 4 weeks. During the last 4 weeks of the experiment, the first treatment was maintained alone, and the last 2 treatments were coupled with the first one.

The first treatment provides information on good energy consumption practices with the help of stickers. The other two treatments were intended to activate two different social norms in employees' electricity conservation decisions. The second treatment, using a "descriptive social norm" (i.e. "what others do"), consists in weekly reports comparing the electricity consumption of the site with the consumption of the other sites participating in the experiment. The third treatment, using an "injunctive social norm" (i.e. "what others praise"), delivers weekly messages linking electricity consumption to the natural and human consequences of global warming.

Using more than 3,700 observations, our difference-in-difference econometric analysis suggests that private environmental nudges have no significant impact on workers' energy conservation when implemented alone. However, they become significant as soon as they are combined with another nudge. In particular, the combination of injunctive norms and stickers had significant effects on the consumption of electricity at company sites participating in the experiment. We interpret this result as follows: moral appeal and social comparison nudges raise individuals' awareness but (unlike stickers) do not necessarily provide the necessary means or knowledge to act and improve energy conservation.

Incentives for Vertically Integrated Firms in the Natural Gas and Electricity Markets to Manipulate Prices

Nathalie Hinchey[a]

This paper examines the potential for vertically integrated firms that own assets in both the natural gas and electricity markets to manipulate natural gas and electricity prices through the withholding of natural gas pipeline capacity. An integrated firm theoretically could increase the price it receives in the electricity market by withholding pipeline capacity to the wholesale natural gas market, thereby reducing wholesale supply of natural gas and potentially increasing generation costs for electricity through higher natural gas prices.

A key criteria in assessing whether an integrated firm's allocation of pipeline capacity between the wholesale and retail markets constitutes manipulation relates to whether the allocation is profit maximizing on a stand-alone basis, i.e., the allocation maximizes the firm's profits in the natural gas market without considering its profits in the electricity market. In short, allocation that reflects profit maximization on a stand-alone basis is not evidence of manipulative behavior while allocation that does not reflect profit maximization on a stand-alone basis could be such evidence.

I develop a theoretical model that examines the incentives to allocate pipeline capacity to the wholesale natural gas market, which supplies the power generation sector, and the retail natural gas market. I find that an integrated firm may choose to allocate more pipeline capacity to the retail market than the wholesale market in order to reduce the probability of paying fines from failing to

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adequately meet retail demand, to increase its profits in the wholesale natural gas capacity market or to increase its profits in the electricity market. In order to prove a manipulation has occurred, it must be shown that the last case is true and the first two cases had little effect on the allocation decision. I further find that when pipeline constraints do not bind, and there is at least one firm with enough contracted capacity that its supply of pipeline capacity is required to meet demand, it is easier to detect manipulation.

Locational (In)Efficiency of Renewable Energy Feed-In Into the Electricity Grid: A Spatial Regression Analysis

Tim Höfer[a] and Reinhard Madlener[b]

In order to mitigate climate change, governments all over the world have started a sustainable transformation of their energy generation systems. The associated introduction of renewable energy sources (RESs) into the energy system has led to a significant transformation of the energy sector in numerous countries worldwide. While most energy systems can accommodate moderate shares of variable renewables, severe challenges, such as grid imbalances or massive curtailment of electricity generation, occur at higher shares. Germany, as one of the forerunners in transforming the energy system ("Energiewende"), has already experienced such challenges in the past. A major reason for these challenges is that variable renewables, such as solar and wind energy, are located in regions with favorable weather conditions, which, in Germany, have a quite low energy demand. This leads to an imbalance of electricity supply and demand. Further stress factors for the energy system originate from the rising share of intermittent electricity production and the direct infeed of the produced electricity into the distribution grid. These changes in the electricity generation require an expansion and reinforcement of the electricity infrastructure. However, due to public resistance, this expansion and reinforcement is lagging behind. As a result, a local overstress of the electricity infrastructure can occur in times of high renewable electricity production. In order to still balance electricity supply and demand, system operators often need to reduce the production output of renewable and conventional power plants. In 2017, the system operators reducted 5,518 gigawatt-hour (GWh) of renewable energy output—the so-called *RES curtailment*. This accounts for approximately 2.9% of the total electricity produced by renewables. The associated costs for RES curtailment totaled €610 million in 2017.

In this context, our study aims at identifying the main drivers for curtailing renewables and at explaining the regional variability of RES curtailment costs. More specifically, we analyze the RES curtailment costs of four distribution system operators (DSOs) in Germany in the period 2015–2017 by means of an econometric model. To further refine the analysis, the DSO regions are partitioned into 1,111 subregions based on substations on the high-to-medium voltage level. To this end, we apply a Voronoi tesselation, which allocates all renewables and conventional power plants to the closest substation.

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In order to investigate RES curtailment costs, we apply a two-step Heckit sample selection model, which accounts for non-randomly selected variables. The selection equation is a binary choice model that estimates the probability of occurrence of curtailment in a subregion associated with different types of renewables, conventional power plants, and the prevalent load. This analysis considers all subregions of the respective DSOs. In contrast, the outcome equation considers only those subregions that experienced curtailment costs in each year of the period 2015–2017. The latter model aims at monetarizing the effects of different types of renewables and conventional power plants on RES curtailment. The model corrects for cross-sectional dependence by combining a spatial econometric model and a correlated common effects model. The analysis is conducted once using the installed capacities and once using the generated electricity of various types of renewables. The generation technologies considered are wind and solar power as well as biomass, hydroelectric, and conventional power plants.

The investigation of RES curtailment costs in Germany shows that only a very few subregions account for the majority of total curtailment costs. Of all subregions considered, only a quarter experienced RES curtailment in the period 2015–2017. The applied selection equation indicates that an additional megawatt (MW) of the capacity of wind energy, solar power, and biomass power plants increases the likelihood of occurrence of curtailment in a subregion by 0.3% each. When taking into account the generated electricity instead of the installed capacity, the numbers vary but also indicate a positive impact of these renewables on RES curtailment (wind energy systems and biomass power plants +0.07% per GWh and PV systems +0.5% per GWh). A further result is that higher electricity demand in a subregion decreases the probability of occurrence of RES curtailment (–0.04% per GWh). The outcome equation shows that only wind energy systems have a significant effect on RES curtailment costs in the subregions considered. In contrast, all other power plants and the prevalent load do not exert a significant effect. Increasing the installed capacity of wind energy systems by one MW raises the curtailment costs in a subregion by 0.7%. Similarly, one GWh of additional electricity produced increases the costs by 0.2%. In the most affected subregions, which are located mostly in northern and eastern Germany, this increase is associated with RES curtailment costs of approximately 28,250 €/MW and 8.10 €/MWh. In other words, in the examined period between 2015 and 2017, the yearly RES curtailment costs in the affected subregion induced by an additional MW of capacity of wind energy amounts to approximately 1.8% of the average overall costs of wind energy systems in Germany. The costs associated with the generated electricity equals approximately 9.2% of the remuneration tariff for wind turbines. These costs are passed on to the consumers in the region concerned.

The results imply that an uncontrolled deployment of renewables, especially of wind turbines, induces additional costs due to the overstress of the electricity infrastructure. These costs need to be internalized by the operator of renewable power plants in order to enable a welfare-enhancing deployment of renewables. A welfare-enhancing deployment implies that all costs associated with the electricity generation and transmission are internalized. A possible policy regime to achieve a welfare-enhancing siting of renewables would be to set regionally varying price signals that account for congestion in the transmission and distribution grid. In addition to steering the siting of renewables, a further instrument to enhance social welfare might be to promote flexibility options in regions with a high amount of curtailed electricity. Such flexibility options comprise, among other things, energy storage systems, electric vehicles, or power-to-heat and power-to-gas applications.

Vertical Separation of Transmission Control and Regional Production Efficiency in the Electricity Industry

Yin Chu[a]

Deregulation in the electricity industry has been one of the major market restructuring transformations in the U.S. over the past few decades. Before deregulation, the U.S. electricity industry was comprised of many local natural monopolies that are vertically integrated from transmission control, generation to retail distribution. Typically, deregulation activities may consist of a combination of multiple aspects. In order to evaluate the impacts of restructuring for policy recommendations, researchers must disentangle these channels, which is generally a difficult task.

Exploiting a unique electricity market, the Southwest Power Pool (SPP), this study examines the welfare implication of one specific aspect of restructuring overlooked by previous literature: vertical separation of transmission control. The necessity of separating transmission function from other activities is largely grounded on the principle that an electricity market functions effectively only under the condition of non-discriminatory transmission access. A vertically integrated firm who operates both power plants and transmission facilities would have the incentive to discriminate against generators of their non-integrated competitors when providing the transmission services. Despite the extensive theoretical analyses and great policy relevance, there have been relatively few empirical studies on the efficiency impacts of the vertical separation. This study represents an intellectual endeavor to fill this gap.

In this paper, I investigate the impact of vertical separation of transmission control on regional production efficiency. If it is the case that vertically integrated utility producers engage in transmission discrimination and over-utilize their own generating assets, outside lower-cost options would be potentially underutilized. This would lead to an inefficient allocation of regional production resources. Thus, the divestiture of transmission control, which is handed over to a third, impartial party (called Regional Transmission Operator), could potentially enhance wholesale competition, incentivize under-utilized cost-efficient generators to produce more, and improve regional production efficiency accordingly.

I measure regional production efficiency through the sensitivity of unit utilization with respect to average costs. The implicit logic is that the utilization of generators in a market where units are dispatched more efficiently should be more responsive to their own average costs. I employ the difference-in-difference strategy and compare the average cost sensitivity of unit utilization in SPP with that in a control region, where no market restructuring activities ever took place. If the utilization of generators in SPP becomes on average more cost responsive, it would provide evidence of efficiency gains in regional production. I utilize an 8-year monthly panel of detailed micro-data at the generating unit level in the empirical work.

Based on robust results, I fail to find significant market wide evidence of improvement in regional production efficiency associated with the vertical separation of transmission control. However, looking into subgroups of generators, I find mixed evidence of cost savings via reallocation of production resources: (1) coal units are dispatched more efficiently after the restructuring, indicated by an increase in the cost sensitivity of unit utilization by 8%-11%; (2) such efficiency gains are not found for two types of gas units with different combustion technologies and cost efficiency.

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This study offers useful information for policy makers. First, it helps to better understand how to choose the optimal package of deregulation policies in electricity markets. Due to high implementation costs of deregulation, policy makers of traditionally regulated markets may favor a minor level of restructuring such as the vertical separation of transmission control. This study suggests that the efficiency improvement associated with it is limited. To achieve sufficient efficiency gains, restructuring needs to go beyond it and incorporate more aspects such as establishing market-oriented mechanisms to facilitate information revelation. Second, this study is also informative on the cost-and-benefit debates about vertical integration and separation in other network industries. The evidence of improvement in regional production efficiency indicates pre-existing discriminatory use of electricity network, which is also a major concern in other network sectors such as gas, telecommunications, etc. I find that the benefits associated with enhanced competition are at most moderate. Therefore, if the separation of the network is costly to implement, then improvement in regional production efficiency alone may not justify the policy change.

Optimal Allocation of Variable Renewable Energy Considering Contributions to Security of Supply

Jakob Peter[a] and Johannes Wagner[b]

Recent cost reductions suggest that the cost-optimal decarbonization of the electricity sector will to a substantial part be based on variable renewable energy sources (VRE). Electricity generation from VRE differs from dispatchable power generation in its pronounced dependency on weather conditions. These weather-induced variations show spatial dependencies and are not perfectly predictable. Accordingly, there arise important implications for reliability of supply in power systems as electricity is only storable at comparatively high cost and the supply-demand balance has to be maintained at all times in order to prevent outages.

Reliability of supply has always been a major concern in electricity systems as outages incur high economic losses. With increasing shares of VRE, reliability issues gain further importance due to the variability, spatial dependency and imperfect predictability of electricity generation based on VRE and the resulting risk of unavailability during times of stress. VRE resources are typically less correlated on a wider geographical scope, which reduces fluctuations because of imperfectly correlated generation patterns at different locations (balancing effects). Hence, markets can benefit from these balancing effects via interconnections and cross-border cooperation. Envisaged reliability levels can thereby be reached at lower costs compared to reliability measures restricted to national borders. Against this background, the following research question arises: What is the optimal mix and allocation of VRE capacity in order to benefit from balancing effects both in generation and contribution to security of supply to reach an envisaged reliability target?

Typically, generation patterns of wind and solar power plants at different locations are positively correlated. Therefore, the ability of one unit of VRE generation capacity to substitute firm capacity, which is referred to as its capacity value (or capacity credit), declines as the share of VRE in total generation increases. Nevertheless, economic long-term simulation models for electricity markets, which are widely used in scientific and political practice, often assign fixed exogenous

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capacity values to wind and solar generation and neglect cross-border effects for reasons of simplification and computational tractability.

Against the described backdrop, this paper develops a new methodology to endogenously determine the contribution of VRE to security of supply in a long-term partial equilibrium model for electricity markets. The proposed methodology builds on an iterative approach, which captures the non-linear dependency of the capacity value of VRE on installed capacity and its spatial distribution considering cross-border cooperation via interconnectors. The methodology therefore determines cost-minimal investment into power plants taking into account electricity generation as well as provision of security of supply of VRE, while keeping computational tractability in a large-scale application. After introducing our methodology, we apply it in a first step to a simple two-country example. Building on that, we extend it to the European electricity system to determine an optimal decarbonization pathway until the year 2050, starting from the existing power plant fleet. Our analysis focuses on wind power, however the presented approach can be applied to all VRE technologies. We build the analysis on a new dataset, which is based on meteorological reanalysis data featuring a high spatial and temporal resolution. The data is therefore well suited to optimally capture the stochastic properties of wind generation and the resulting contribution to security of supply.

We show that the proposed methodology is capable to endogenously determine the capacity value of wind power in large-scale investment and dispatch models for electricity markets. The results of the large-scale application imply that wind power can substantially contribute to security of supply in a decarbonized European electricity system cooperating with respect to reliability, with an average wind power capacity value of 13% in 2050. Additionally the results show that the capacity value of wind power is heterogeneous across different regions and years, which is a result of varying wind conditions as well as increasing total installed capacities and technological innovation over time. Existing modeling approaches, which typically assign constant exogenous capacity values for wind power, therefore result in inefficient levels of dispatchable capacities, which are required to guarantee security of supply in electricity systems with high shares of VRE. In our application for the European electricity system, the additional yearly costs for firm capacity provision when applying exogenous fixed wind power capacity values of 5% compared to endogenous capacity values amount to 1.5 and 3.8 bn EUR in 2030 and 2050, respectively, which represents additional costs of 3% and 7%. Finally our results suggest that European market integration can substantially improve the contribution of wind power to security of supply due to cross-border balancing effects.

Peak Load Habits for Sale? Soft Load Control and Consumer Preferences on the Electricity Market

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In Sweden and elsewhere in Europe, electricity markets are changing and the transformation is characterized by three key factors: (i) deregulation of electricity markets, (ii) new technologies with respect to generation, distribution and use, and (iii) substantial changes in the production mix as a result of energy and climate policy as well as changes in relative production costs for different technologies. These factors in combination with a relative rigid demand side characterized

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by daily and seasonal use patterns, and consumers that are not exposed to the time of use marginal generation cost, have raised concerns about security of supply.

In line with these observations, attention has been brought towards demand flexibility and demand side management. So far, demand side management in Sweden has targeted large industrial electricity consumers at moments of imminent power shortages. The balancing of intermittent power production, however, requires more adaptable resources that can be activated at short notice during all times of the year, and the household sector in general, and detached and terrace houses in particular, may have a large potential in this context.

In this study we estimate Swedish household's willingness to accept load restrictions for electricity use during peak hours using a stated preference approach. Two types of load restrictions are considered: "soft control", which refers to a temporary restriction in the maximum possible load (in watt) for high-power appliances and installations; and "hard control", which refers to a complete loss of power for a 30-minute period during peak time. The resulting monetary compensation for the "soft" load control can be interpreted as the value of potential lost load (VoPLL), whereas the monetary compensation for complete loss of load corresponds to the value of lost load (VoLL).

The results reveal that demand response relying on behavioral change is costly in the sense that households require a high compensation for accepting restrictions. That is, the risk of not being able to, say, make dinner at the usual time may be very disruptive for the household, and this disruption is very costly, according to the results. One policy implication that follows immediately from the results is that specific policies aiming at stimulating behavioral changes probably will be very ineffective and/or costly. This implies that demand response through curtailment actions may be less cost-effective than supply response and/or automation and passive response.