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Juan Rosellón and his Contribution to the Academic Literature on Energy Economics*

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Abstract

This article reviews Juan Rosellón's contributions to Energy Economics, focusing on regulation and investment in natural gas and electricity transmission networks, electricity market design, and renewable energy integration. His work develops optimization-based regulatory frameworks that combine market incentives with welfare-maximizing objectives. Key contributions include hybrid merchant–regulatory mechanisms for network expansion, pricing schemes grounded in second-best theory, advances in nodal pricing and financial transmission rights, and the H-R-G-V incentive mechanism for transmission investment. More recently, his research addresses uncertainty, environmental externalities, storage, and large-scale renewable integration. Overall, Rosellón's work provides influential analytical tools for efficient, sustainable, and socially oriented energy policy design.

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1. Introduction

The scientific contributions of Juan Rosellón are fundamental to the theoretical and applied debate on the regulation of the energy sector. His work examines the relationship between the regulation of electricity markets, gas and electricity transmission networks, and the integration of renewable energies and social welfare.

Without a doubt, his decisive and central scientific contributions to the literature on Energy Economics revolve around optimization models for gas and electricity transmission networks and market design. Rosellón shows that the development of private transmission networks (merchant investments) offers greater efficiencies than transmission systems with regulated tariffs and, at the same time, allows greater flexibility, which facilitates their incorporation into a market system with nodal prices.

Rosellón's research provides a conceptual foundation for addressing investment challenges in electricity transmission. His studies serve as a reference for researchers and policy makers in the search for sustainable and efficient solutions. His contributions in this area encompass both theoretical advances and empirical evidence that ensure the efficiency of electricity markets and guarantee the sustainability of transmission networks and long-term social welfare.

A large part of the applications of regulatory frameworks and the empirical evidence found refer to Mexico. Rosellón analyzes the connection between electricity generation and the Mexican economy, showing that it is necessary to promote energy policies that stimulate investment in infrastructure. However, here we will focus only on his general conclusions and his contribution to the literature on energy economics.

This article is structured as follows. Section 2 analyzes Rosellón's work related to the regulation and expansion of natural gas networks. Section 3 examines his scientific contribution to topics related to regulation and incentives in electricity transmission networks. Section 4 covers Rosellón's research on the integration of renewable energies into power systems. Finally, Section 5 presents the conclusions.

2. Regulation and expansion of natural gas networks

The author develops different models aimed at promoting infrastructure investment and achieving an efficient expansion of gas pipelines. Rosellón's contribution aligns the goal of network expansion with the maximization of social welfare. His research develops regulatory schemes that foster efficient expansion, cost recovery, and pricing that remains competitive for users without affecting the most vulnerable sectors of society. Rosellón's work contains significant academic contributions for the design of public policies oriented toward maximizing overall welfare.

Rosellón's studies on the regulation and expansion of natural gas networks serve as a reference both for governments in Latin America and in Europe, where his regulatory models and commercial incentives prove applicable.

Rosellón's research not only offers solutions for the expansion of natural gas networks, but also serves as the foundation for a comprehensive regulatory framework that considers electricity networks and other sources of renewable energy. In this sense, Rosellón's work has motivated other authors to explore the applicability and relevance of his models in other sectors of the energy market, such as clean energies. His work on the regulation and expansion of gas networks addresses different points and solutions—complementary and alternative—that are detailed below.

2.1. Regulatory Mechanism for Private Transmission Networks

Rosellón proposes a mixed liberalized–regulated mechanism to incentivize the efficient expansion of gas pipeline capacity. The mechanism has a commercial component because it allows private companies to invest in infrastructure and then recover their investment and earn profits through tariffs. In other words, private companies charge additional tolls to those who use the expanded capacity. The mechanism is complemented by a regulated component involving the intervention of the regulator to guarantee efficiency, supply, and equity among consumers, especially the most vulnerable sectors. In particular, the regulator must assess whether bottlenecks exist or whether investment in infrastructure is required. If private initiatives fail to cover the demand for natural gas or to resolve congestion problems in specific areas, the regulator has the authority to intervene and require the expansion of the pipeline under a regulated scheme with guaranteed cost recovery, for example through the application of regulated tariffs.

Rosellón constructs this mechanism through a two-level economic model. At the upper level is the regulator, who, as explained above, establishes the rules for expansion and additional tariffs, evaluates social welfare, and makes decisions when market failures are identified. At the lower level are the companies, which decide on their investments and operate with the goal of maximizing their profits subject to the rules established by the regulator.

Within this analytical framework, Rosellón establishes that the marginal cost of expanding pipeline capacity must be lower than the cost of congestion. He aligns the needs of consumers with the intentions of the companies making the investments. In this way, an efficient equilibrium is reached, characterized by the optimal allocation of resources and productive efficiency.

The mixed liberalized–regulated mechanism is highly relevant both in academia and in energy policy. This instrument constitutes an alternative for infrastructure expansion, distinct from fully centralized or completely liberalized approaches, and represents a meaningful contribution to the academic debate.

This contribution is taken up by Neumann et al. (2015) to promote the expansion of the cross-border natural gas transmission network in Europe. The mixed mechanism proposed by Rosellón helps resolve congestion bottlenecks, particularly in various cross-border areas such as the connections between Spain and France, the United Kingdom and Norway with other European countries, and among the Benelux countries.

Pipeline congestion limits the ability to respond efficiently to increases in demand. Rosellón's proposal provides a relevant tool to address an energy security and market integration problem in the European continent, as it improves competition and guarantees security of supply.

In short, Rosellón's proposal has a comprehensive approach. It combines the expansion of gas networks, the convergence of market prices, and improvements in welfare. The results of his research show that the application of the mixed mechanism generates a positive social 4 impact during the periods studied: consumer and producer surpluses increase, approaching optimal welfare levels.

2.2. The Efficiency of Investment in Gas Infrastructure

The structure of the gas market involves *lumpy* investments, characterized by requiring significant, large-scale expenditures, without the possibility of adjusting in small increments. This implies high initial costs and carries important risks of excess capacity, sunk costs, and intertemporal externalities. Consequently, marginal tariffs and free competition would not, in this case, be optimal. At the same time, dynamic programming models are difficult to apply because they depend on functions and parameters that are subjective or complicated to estimate precisely. In this context, it is not possible to reach the Pareto optimum through efficient pricing. Therefore, alternative solutions linked to the theory of the *second best* must be sought, taking into account constraints such as fixed or social tariffs and the risks of overinvestment or underinvestment.

Rosellón proposes a regulatory design that internalizes the externalities of lumpy investments. His proposal consists of moving away from marginal prices, allowing tariff distortions with the ultimate goal of financing gas infrastructure and avoiding risks associated with congestion.

This contribution can be found in Brito and Rosellón (2011), where tariff setting based on average cost is proposed instead of marginal prices. The authors suggest that the gas system can be regulated in a simple and transparent way, without significant welfare losses. In fact, this article shows that deviations from the first-order optimum are not significant given that gas demand is highly inelastic. Rosellón starts from the theoretical foundations of economic analysis so that regulation can adapt to the complexity of reality and serve as a valuable tool for public policy and regulatory authorities.

Rosellón's contributions are a notable reference in the academic field. Abada et al. (2013) build on Rosellón's work to study the natural gas market in northwestern Europe. For his part, Adamson (2018) evaluates Rosellón's proposal in his research on regulatory and investment differences between the natural gas and electricity sectors in the United States.

Rosellón's contributions, based on the application of second-best theory, once again highlight his concern with studying innovative approaches to regulatory policies that protect consumer welfare. His research focuses on consumer preferences, attempting to develop models that make it possible to balance the cost of transporting gas with the risk of pipeline congestion.

2.3. The Role of Shadow Prices in the Gas Market

Rosellón's work stands out for the exploration of tools and concepts from general economic theory that can be applied to his main field of study, namely the regulation of energy markets. The author seeks to integrate diverse regulatory, economic, and social concepts with the aim of developing precise instruments for energy market regulation. These practices are reflected in his constant search for new economic methodologies that can provide solutions to the structural and regulatory problems of the energy market. At the same time, this reflects his concern for promoting public policies aimed at maximizing social welfare.

In Ramirez and Rosellon (2000), the implementation of the Netback rule by the Mexican Energy Regulatory Commission is supported through economic analysis. This rule—an application of the Little–Mirrlees rule—links the local market with the U.S. market and proves efficient in setting the price of natural gas. In addition, the authors study the implications of the regulatory approach for Pemex's marketing activities. The criteria of the Energy Regulatory Commission incorporated Rosellón's contributions and required that the gas price take into account associated logistics and transportation costs.

Rosellón proposes the application of the Little–Mirrlees rule in the energy market. This rule establishes that the evaluation of public projects must be carried out using shadow prices instead of market prices, since the latter do not reflect the true social cost as a consequence of distortions generated by taxes, subsidies, monopolies, and other externalities. Therefore, if market prices are used, this can generate failures and discourage the investments necessary for the expansion of networks to prevent congestion and ensure proper supply for consumers. Brito and Rosellón (2005) demonstrate that the rule is Pareto optimal. The authors propose a theoretical welfare economics approach to tariff regulation and the expansion of infrastructure investments.

Rosellón highlights the usefulness of the Little–Mirrlees rule for correcting tariff distortions in energy markets and for controlling the appropriate level of private investments for the expansion of gas pipelines or electricity networks. He applies this criterion in different research projects related to electricity and gas markets, for example when developing the two-level regulatory optimization model for lumpy investments, which is an application of second-best theory (Brito and Rosellón, 2011).

Brito and Rosellón (2005) suggest using international reference prices to regulate the price of natural gas, through the application of the Little–Mirrlees rule. The authors argue that in this way prices reflect the economic value of the resource in a global market. In this study, they show that the application of the Netback rule is optimal for the natural gas market in Mexico.

The study uses a general equilibrium model in an open economy to demonstrate that the Netback rule is Pareto optimal. The model takes into account different particular situations: consumers may choose between natural gas and alternative fuels, their spatial distribution along the pipeline is considered, and concentrations of consumers that generate "mass points" are identified. In this way, Rosellón develops a model that incorporates limitations in transmission capacity and the potential bottlenecks that may arise from a lack of or inefficient infrastructure.

The authors warn that the application of the Netback rule generates a public policy challenge. In the case of Mexico—a market that has been the focus of much of Rosellón's research—they raise the need to separate the transmission and marketing activities of Pemex in order to guarantee network capacity and eliminate situations of market power that prevent the entry of competitors, just as European regulation establishes. Otherwise, capacity will be insufficient, the market will not balance, the rule will not work, and Pemex will obtain additional rents derived from bottlenecks. However, this market-oriented approach faces political and institutional barriers to carrying out the reform, despite its clear effects on allocative efficiency and consumer welfare improvement. In this sense, Rosellón identifies tensions between some economic objectives of energy price regulation, such as efficiency and competition, and the constraints that political and governmental institutions may impose.

Although the research focuses on the Mexican natural gas market, its findings are also relevant for other vertically integrated industries. In this sense, Rosellón provides a robust theoretical framework that justifies the regulation of natural gas prices under certain specific conditions of the energy market.

The academic literature incorporates Rosellón's contributions by considering international prices as a reference for regulating internal prices in the natural gas market. Indeed, Ascari (2021) highlights the work of Brito and Rosellón (2005) in his research on different methods to regulate the price of natural gas that guarantee affordability, promote economic security, and ensure security of supply. In addition to world prices, this article considers other strategies such as setting maximum prices and cost-based regulation. Ascari (2021) also values the theoretical perspective of Rosellón's study for the regulation of gas prices in vertically integrated industries and the importance of adapting the regulatory approach to the specific conditions of each market.

Brito and Rosellón (2010) suggest continuing to apply the Netback rule to the natural gas market in Mexico. In this country, the price of natural gas uses the Texas gas price as a reference, adjusted for transmission costs. It is assumed that the Texas market is competitive and similar in characteristics to the Mexican market. The authors take into account that the Texas market experienced bottlenecks in previous years, which generate quasi-rents that distort natural gas prices. However, despite these market imperfections, the study shows that it remains optimal to continue using the Netback rule to define pricing policy in Mexico, since under this criterion both economic valuation costs and opportunity costs are considered.

Rosellón's research constitutes a relevant theoretical framework for application in other energy markets beyond Mexico, since it provides a model that can be replicated to evaluate the efficiency of energy pricing policies. Krane (2015) builds on Rosellón's work to analyze the political and economic implications of energy subsidies in the Gulf monarchies. The author points out that such subsidies have led to massive domestic consumption that threatens exports and economic sustainability. Unlike the application of the Netback rule in Mexico, proposed by Rosellón and noted by Krane, in those countries the assumptions of the Little–Mirrlees rule are not considered to control the distortions generated by subsidies, which implies serious economic deterioration.

Likewise, Cordano et al. (2013) also highlight the importance of Rosellón's research on the Netback rule for setting natural gas prices in terms of the opportunity cost of international trade. The authors emphasize that the Netback rule is optimal for maximizing social welfare beyond the competitive conditions of the reference market and the determination of the arbitration point that defines transmission costs.

In conclusion, Rosellón's work includes the application of economic analysis to the design of efficient and equitable energy policies. This approach allows market failures to be corrected and private investments to be strategically directed. His work is not limited to the case of Mexico, but also provides a theoretical framework for its extension to other energy markets where the maximization of social welfare is pursued through energy regulation.

3. Regulation and Incentives in Electricity Transmission Networks

One of the most relevant topics in the literature on energy economics concerns the regulatory design of electricity transmission networks. The main objective is that transmission capacity be able to meet the supply and demand requirements of the electricity market. Rosellón develops incentive schemes to promote efficiency in investment in transmission networks, a fundamental aspect of the three pillars of the energy trilemma: security of supply, affordability and social equity, and environmental sustainability. His theoretical models and practical applications, based on optimization methods, highlight the existence of divergent regulatory approaches in the design of electricity transmission networks.

Rosellón argues that regulation must not only be efficient but also aligned with the interests of the different actors in the energy market. Indeed, public energy policies must guarantee supply, foster business competitiveness, and promote a framework of social welfare and sustainability.

His very prominent contribution on electricity transmission networks—possibly the most important—addresses all aspects of the system: market design, network design, the FTR market, issues of uncertainty, and the construction of the Hesamzadeh-Rosellón-Gabriel-Vogelsang (H-R-G-V) theoretical model, which provides an integrated solution to the new model of electricity system operation in which each of the parts responds to market criteria synchronously and as a whole (Khastieva et al., 2019). Without a doubt, Rosellón's contribution in this field is one of the most important—if not the most important—in the literature on energy economics.

3.1. Nodal Prices

In Rosellón's work, his support for the use of nodal prices stands out. These are set at each specific node of an electrical network, such as generating plants, substations, consumption centers (cities or factories), or interconnection points between lines. That is, each node has a different price depending on the network's conditions. The nodal price at a specific node equals the marginal cost of delivering an additional unit of electricity at that point,8 considering the cost of generating electricity, energy losses in transmission lines, and network congestion when lines reach their capacity limit.

In the context of electricity transmission networks, nodal prices are used to identify congestion and losses in the network, and they are key in markets such as those of the United States and Mexico. Indeed, electricity prices in these markets take into account not only generation costs but also supply and demand at each node, energy losses in transmission, and network congestion. In Mexico, nodal prices were implemented starting with the 2014 energy reform, which improved the efficiency of the electricity market and provided locational signals.

Rosellón demonstrates that nodal prices improve the operational efficiency of the electricity system, allowing prices to reflect the real costs of electricity generation and transmission. In addition, they allow better infrastructure planning and encourage investment in generation located near consumption centers. This contribution by Rosellón can be found in Kunz et al. (2016), where a complete nodal representation of the German electricity system is employed. This article demonstrates that the allocation of financial transmission rights (FTRs) can be more effective in compensating for the distributive impacts derived from the transition to nodal prices compared to other allocation alternatives.

As the authors explain, Germany employs a zonal pricing system that generates inefficiencies due to internal congestion. To resolve this issue, Rosellón suggests a transition toward nodal prices. This proposal is especially relevant in a context where there are political and economic concerns about the redistributive effects of changing the pricing regime. By integrating economic analysis with institutional design, Rosellón provides pragmatic solutions to implement nodal prices without generating strong resistance from the government and from certain consumer groups that might oppose the system. This proves useful both for countries in transition and for developed systems that seek to improve their efficiency and equity, especially those integrating high volumes of renewable generation. He also manages to integrate the nodal pricing system with incentive-based regulation. The author demonstrates that this solution is effective in achieving an optimal development process of electricity transmission networks in terms of social welfare, maximizing consumer and producer surplus while reducing congestion costs.

In Zenón and Rosellón (2017), it is shown that the electricity market in Mexico must evolve toward a nodal pricing system that reflects the local costs of generation and transmission. Furthermore, it is necessary to replace the regressive subsidies of the system prior to the Electricity Reform, which benefited higher-income sectors to the detriment of poorer and middle-income populations. In other words, the proposal is to replace the regressive subsidies inherited from the previous system with a more efficient and transparent alternative that uses prices reflecting generation and transmission costs while simultaneously protecting the most vulnerable consumers. Rosellón's proposal is particularly interesting in the context of the 2013 Mexican Electricity Reform, which seeks a balance between market openness, economic efficiency, and distributive justice. This article also warns that the lack of linked incentives for transmission companies could limit the achievement of greater economic efficiency in the electricity system.

In a later contribution with Kunz and Kemfert (Kunz et al., 2017), Rosellón reinforces the idea that nodal prices efficiently reflect the marginal costs of generation and transmission. Nodal prices allow the identification of congestion areas in the network, promoting greater operational efficiency of the system. This contribution appears in a model that optimizes the economic dispatch of the Mexican electricity system and integrates nodal prices determined based on marginal costs at each network node.

The authors again demonstrate that the nodal pricing system improves the economic efficiency of the electricity market, as it incentivizes electricity generation in optimal locations and fosters investment in transmission by companies. In this article, it is explained that the nodal pricing system must be combined with mechanisms that mitigate potential adverse distributional impacts on society. In this sense, the allocation of FTRs allows compensation to market participants harmed by the new prices, especially the most economically vulnerable sectors. Ultimately, this proposal introduces efficient prices without generating distortions and maintains the political and economic viability of the transition toward a more competitive and transparent electricity market.

Rosellón's work is recognized in multiple studies on the design of electricity markets in Europe. In this regard, Eicke and Schittekatte (2022) cite the work of Kunz et al. (2016) as a key reference supporting the use of nodal prices and FTRs to address congestion and inefficiencies in the zonal model used in Europe.

Rosellón's contributions on nodal prices are central to the literature on energy economics. His work offers a conceptual and applied framework that encourages policymakers to design public policies that correct market failures, expand the electricity grid, and promote a more efficient allocation of resources.

3.2. Merchant Regulation Models and Long-Term Financial Transmission Rights

In the conventional scheme, investment is largely planned and financed by the State or the system operator. By contrast, in merchant regulation of the electricity sector, investments in transmission lines are carried out by private agents who assume the economic and financial risk of the project. In return, investors do not receive regulated revenues from the government but instead recover their investment through market-derived revenues calculated from the differences in nodal prices between points of the network and through the settlement of FTRs.

These revenues are known as congestion rents and arise when there is a price difference between two nodes generated by transmission capacity limitations. In a market operated with nodal prices, where electricity costs less at the source node and more at the destination node, an economic rent is generated by multiplying that price difference by the amount of energy transmitted.

FTRs, for their part, grant their holders the right to receive payments for the differences in nodal prices between two different points in the electrical network. That is, if the price at the starting node (A) is lower than at the destination node (B), the holder of an FTR from A to B 10 receives a gain proportional to the price variation and the number of megawatts of electricity covered by their right. These congestion revenues are collected by the system operator (CENACE in the case of Mexico) and are used to pay FTR holders.

Normally, FTRs are issued and managed by the market operator, who conducts periodic auctions to allocate the rights to interested participants. These auctions generate resources that are allocated to network maintenance or expansion. FTRs are purely financial products because they act as a hedge against the risk of price variations between nodes without granting the physical right to transmit electricity.

Moreover, the settlement of FTRs occurs ex post, considering the actual price differences observed. This provides economic security to investors and improves the transparency of the system. However, they can also be transferred and traded in secondary markets before expiration. Therefore, the rights can generate liquidity for their holders and allow them to adjust their exposure to congestion risk over time. Each FTR has a defined term, which may be daily, monthly, annual, or other, depending on market design, and ceases to generate payments upon expiration.

FTRs resemble contracts for differences (CfDs) because both provide financial protection against price variations. However, there are also important differences between these two instruments. FTRs serve to compensate for nodal price differences between points in the network, whereas CfDs cover the difference between a fixed price and a spot price in a day-ahead market where all purchase and sale operations are negotiated. Moreover, FTRs are administered by the system operator, backed by congestion revenues, which differentiates them from traditional CfDs that are usually the result of contracts awarded in auctions—for example, for renewables—or bilaterally agreed upon between parties.

Rosellón studies the expansion of transmission networks through merchant regulation models based on the allocation of long-term financial transmission rights (LTFTRs). Unlike traditional regulatory models that focus on the costs of the electricity system, Rosellón proposes an alternative incentive-based approach that promotes private investment by transmission companies without direct state regulation by the government.

The author demonstrates that merchant transmission models can be combined with incentive-based regulation, allowing transmission operators to recover their investments through congestion rents and the sale of LTFTRs, aligning market interests with social welfare. In this regard, Kristiansen and Rosellón (2006) show that the merchant mechanism drives transmission network expansion and protects consumers and generators by granting them transmission rights that guarantee financial stability against nodal price changes. Indeed, FTRs make it possible to capture congestion rents and, through these benefits, recover investments without establishing regulated tariffs or granting public subsidies to all consumers. Furthermore, the model considers certain limitations of the electricity system, such as the existence of multiple nodes, physical constraints, and strategic agents. Therefore, the system proves useful for designing public policies aimed at promoting market competition and expanding electricity networks.

Rosellón's contributions regarding the design of mechanisms based on FTRs have been highlighted by influential authors in the electricity market literature. Hogan (2012) recognizes that the regulatory models proposed by Rosellón, particularly those that integrate FTRs with investment incentives, enhance economic efficiency and promote transmission network expansion. This author, considered one of the pioneers of the nodal pricing model, cites Rosellón's work as a fundamental part of the theory on FTRs and network expansion.

Likewise, the merchant approach combines commercial instruments, such as LTFTR auctions, and regulatory components to ensure that investments are efficient and benefit all market participants. Indeed, Hogan et al. (2010) define transmission capacity in terms of LTFTRs and combine a regulatory approach with commercial investment incentives for the purpose of transmission expansion. One of the main contributions of this alternative is its ability to adapt to different conditions of the electricity system. When congestion is high and additional rents can be captured from such congestion, the model allows expansion to be financed in a merchant way. However, when investments cannot be attracted—for example, in areas with low electricity demand but high strategic value—the mechanism allows for regulatory participation to complete expansion. Thus, the model proposed by Rosellón offers a flexible and realistic solution that overcomes the limitations of unreviewed merchant approaches or conventional regulatory criteria. Rosellón's contribution integrates both perspectives in order to achieve more efficient, equitable, and sustainable transmission network planning.

Pringles et al. (2015) mention Rosellón's research on mechanisms that combine merchant and regulatory approaches to promote transmission network expansion in the Peruvian electricity system, highlighting its relevance in promoting efficient investments in transmission networks.

Following the same line of research, Rosellón also fosters efficient and long-term expansion of electricity transmission networks through economic regulation approaches. The author proposes a price-cap mechanism with Laspeyres weights, which redefines transmission output in terms of FTRs. This scheme incentivizes investments aimed at reducing congestion, increases consumer surplus, improves the profits of transmission companies, and promotes the convergence of nodal prices toward marginal costs. Furthermore, the model's results approximate those of a social welfare maximization scheme. Rosellón and Weigt (2011) apply the approach using a simplified network of northwestern Europe (Germany, France, Belgium, the Netherlands, and Luxembourg) and show that the application of the incentive mechanism is compatible with private investment in electricity markets organized with FTRs. The authors propose a dynamic approach to transmission network expansion, incorporating intertemporal investment decisions and changes in market structure and congestion conditions. The viability of hybrid mechanisms and tools to improve coordination between public planning and private investment in electricity systems is reaffirmed. Along these lines, Clastres (2011) cites the incentive mechanism and highlights its relevance in promoting efficient investments in smart transmission networks.

Rosellón's contributions are related to efficient, flexible, and economically viable expansion of electricity transmission networks. His mechanisms are innovative because they combine market signals, incentive-based regulation, and financial tools such as LTFTRs, which 12 consider the private interests of consumers and producers while also taking into account social welfare. Through merchant models, hybrid mechanisms, and dynamic incentive schemes, it is possible to overcome the limitations of traditional electricity transmission network planning models.

3.3. H-R-G-V Mechanism (Hesamzadeh, Rosellón, Gabriel, Vogelsang)

The H-R-G-V mechanism is among Rosellón's most important contributions to the academic literature on energy regulation and markets (Hesamzadeh et al., 2018). As explained earlier, nodal prices are determined by the conditions at each node of the electricity network. Electricity transmission companies are responsible for building and maintaining the networks and charge a regulated tariff for their use. Finally, the regulator sets the tariffs according to the need for network expansion between different regions, using nodal prices as a signal to detect these requirements. The H-R-G-V mechanism offers an optimal solution because it identifies nodal prices, proposes a regulated tariff scheme, and incentivizes transmission company investments.

The mechanism combines regulatory criteria with commercial incentives, from a multilevel optimization approach, to align the interests of electricity transmission companies with social welfare and to promote efficient investments without resorting to state subsidies.

The H-R-G-V model proposes a two-level optimization: at the upper level, the transmission company makes investment and pricing decisions; and at the lower level, the (independent) system operator manages network operations. Its structure is based on a hierarchy of decisions: at the upper level, the transmission company chooses its investment decisions and sets network access prices; at the lower level, the system operator manages the economic dispatch of the network based on nodal prices. This structure incentivizes companies to make investment decisions that are efficient from the perspective of the system as a whole, since their revenues depend on the actual use of the network and not on fixed regulated compensation. Moreover, company investments promote social welfare by ensuring efficient operation of the electricity system.

Hesamzadeh et al. (2018) demonstrate that the H-R-G-V mechanism achieves optimal levels of investment and efficiency in the transmission system, surpassing the limitations of other regulatory approaches such as price-cap or revenue-cap regulation. This research shows that transmission companies make investment decisions closer to the social optimum when operating under the H-R-G-V mechanism. The total system cost is lower compared to other regulatory methodologies, and problems stemming from underinvestment or overinvestment in the transmission network are reduced. Likewise, the mechanism helps lower long-term transmission network development costs, benefiting end consumers and improving system reliability by ensuring adequate network investment.

The authors use the H-R-G-V mechanism to estimate the value of energy storage and assess the impact of incentive regulations. They demonstrate that the regulator must ensure, through an incentive scheme, that transmission network investments also take into account assets not 13 directly related to the networks, such as energy storage. This allows more efficient and favorable results for the system as a whole. This major contribution constitutes one of the most debated and complex issues within regulatory doctrine. Moreover, it helps address the challenges regulatory design faces with the development of storage and offshore wind energy. In the same vein, Khastieva et al. (2019) validate the H-R-G-V instrument for the joint planning of transmission and storage investments through two applied cases of different scales, which proves its usefulness in real-world scenarios. In the article co-authored with Khastieva et al. (2019), Rosellón argues that the regulator must ensure, through mechanisms such as the H-R-G-V, that investment decisions consider nontraditional technologies that can enhance system efficiency, such as storage.

The academic impact of Rosellón's work is also reflected in his participation in applied and advanced studies, such as the nodal-level direct current load flow model developed in Germany. Egerer (2016) analyzes the regional imbalances occurring in the system and suggests that Germany could foster incentives for transmission investment following Rosellón's proposals. This shows the applicability of the H-R-G-V model in European contexts, thereby consolidating its relevance both in economic theory and regulatory design.

Rosellón also demonstrates that the H-R-G-V incentive mechanism is effective in promoting private transmission investments that maximize society's overall welfare. Through this mechanism, companies are motivated to make optimal investments that reduce network congestion and incorporate renewable energy sources.

Khastieva et al. (2020) apply the H-R-G-V model as an effective regulatory tool to promote transmission infrastructure investments. The authors suggest that the development of the mechanism can influence how regulators design and implement incentive policies in electricity systems of different countries. The article explains how the mechanism incentivizes optimal network investments, allowing bottlenecks caused by congestion to be minimized. It also facilitates the entry of clean generation sources such as wind and solar, thereby supporting the energy transition.

The literature recognizes Rosellón's very important contributions in relation to the H-R-G-V mechanism. Joskow (2024) argues that policymakers should consider this mechanism when developing regulatory proposals related to transmission network operations. Joskow's consideration underscores the relevance of Rosellón's work.

The H-R-G-V mechanism represents a structural contribution to regulatory theory due to its theoretical rigor, its ability to adapt to different institutional and technological conditions, and its orientation toward social welfare. The H-R-G-V mechanism not only reflects Rosellón's academic rigor but also his ability to translate economic theory into practical solutions that address real challenges of modern electricity systems.

3.4. Impact of Uncertainty

Rosellón's work also includes studies related to the impact of uncertainty on the planning of electricity transmission networks. This issue is especially relevant in the context of the energy transition because the level of production from renewable sources depends on natural resources that are highly volatile and variable.

Rosellón proposes stochastic optimization models and mixed-integer linear programming (MILP), whose ultimate goal is to maximize the return on transmission network investments while taking into account technical and economic constraints and assuming the future risks and opportunity costs involved in such financial decisions (Khastieva et al., 2020). In other words, MILP allows for optimal decision-making in infrastructure investments. Rosellón demonstrates that companies can use these models to define the timing and location of new transmission lines, connect new renewable energy sources to the network, design installation, and anticipate network capacity. In all cases, the approach considers different flexible scenarios to adapt to the uncertainty associated with the use of renewable energy, demand growth, and other uncertain factors.

These contributions are key because they make it possible to solve complex problems using standard computational tools that are relatively easy to apply in the real world. As is well known, MILP is used to optimize problems with continuous and integer variables as well as linear constraints. In the context of transmission networks, system operators must decide which lines should be built to minimize costs and maximize efficiency. That is, network expansion is the problem, while the decision to build a line is an integer variable, and the volume of transmitted energy consists of continuous variables.

Traditionally, transmission network planning relied on deterministic optimizations that did not adequately account for the uncertainty associated with renewable sources. However, Rosellón introduces uncertainty into investment planning through a stochastic approach that combines government regulatory decisions with the challenges inherent to energy generation from intermittently produced renewable sources.

In the article by Khastieva et al. (2020), strategic transmission investment decisions are combined with the inherent uncertainty of renewable energies such as onshore and offshore wind and solar. This model is particularly useful in electricity systems that face the challenge of incorporating renewable sources efficiently and reliably. The research demonstrates that it is possible to design mechanisms that promote investments that are both efficient and resilient in the face of the uncertainty inherent in the energy transition.

4. The integration of Renewable Energies in Electricity Systems

A fundamental topic in the literature on energy economics is the efficient integration of renewable generation sources into power systems. Technological and climate change, and their adverse effects on the environment, have given rise to new models of energy generation. The technological disruption represented by renewables, their grid parity, and the goal of reducing (CO_2) emissions explain the changes in the technological mix of generation.

At present, this topic is at the center of academic debate in the fields of energy and environmental economics. The energy transition toward clean sources entails the creation of new industries and the generation of green jobs, carrying significant macroeconomic and redistributive implications. In particular, the integration of renewables has substantial consequences in terms of economic and productive development for any region with these generation sources. Indeed, these regions become attractive for encouraging private investment and generating employment. Likewise, cheaper renewable energy can enhance the competitiveness of various productive sectors. Some households also benefit from the transition when they gain access to these renewable sources.

However, the energy transition can also negatively affect certain sectors of the economy if optimal and efficient regulatory mechanisms are not designed. Vulnerable economic sectors, in particular, may be notably harmed if the transition results in disproportionate increases in energy prices or in regressive subsidies. Furthermore, governments that receive substantial revenues from the commercialization of traditional energy sources, such as oil or gas, may suffer a significant reduction in fiscal income. Therefore, the energy transition requires the design of public policies that stimulate private investment while simultaneously maximizing the welfare of society as a whole.

On the other hand, the integration of renewable energies entails significant technical and economic challenges. One of the main concerns of the energy transition relates to the need to ensure a stable system of energy production and supply when it depends on the climate. The inherent uncertainty that characterizes clean energy sources also affects other aspects of the transition, such as the design of electricity markets, investment in smart grids, and the development of backup technologies like storage or interconnections.

Moreover, the inclusion of renewable energy sources in the power system changes the dynamics of market prices because the marginal operating costs of these technologies tend to zero. As a result, it becomes necessary to design new mechanisms to promote investment in a way that accounts for the interests of the various actors in the electricity system: generators, transmission network operators, distribution network operators, marketers, and ultimately consumers.

In this context of challenges and opportunities, Rosellón's research is especially relevant. This section analyzes his contributions on the integration of renewable energies in power systems. Rosellón studies how to effectively incorporate renewable resources, reduce costs, and promote social benefits. He also examines how the large-scale incorporation of renewable sources affects the operation and reliability of power systems, as well as its environmental and economic implications.

4.1. Impact of Renewable Energy on Electricity System Costs and Social Welfare.

As is well known, renewable energy sources have characteristics that differentiate them from conventional sources. First, the marginal cost of producing clean energy tends to zero. Second, renewable generation is intermittent because it depends on natural resources such as 16 the sun or wind, which creates a high degree of uncertainty regarding energy supply. Finally, there is an unequal geographic distribution of clean energy plants, since the potential for generating energy varies across territories. As a result, some areas have a competitive advantage over others, being able to access renewable energy more efficiently and at lower cost.

The properties mentioned above affect the design and operation of electricity systems, which must include backup from other energy sources—such as gas, hydropower, or storage—to guarantee supply during periods of low or no renewable production. Their viability requires investments not only in generation but also—and especially—in storage, with optimal solutions such as hybrid renewable–storage models, smart grids, and demand management. All of these add costs to the system, beyond the initial investment, operations, and technical adaptation of processes.

In addition, large-scale integration of renewable energy demands extra costs, particularly in the case of high-capacity turbines. Transmission and distribution costs also increase due to the need for new investments to evacuate energy and supply consumers.

Rosellón, together with Davi-Arderius et al. (2024), proposes a partial equilibrium model of the electricity system that considers intermittency in renewable generation and the need for conventional backup energy during periods of low renewable production (Davi-Arderius et al., 2024). The model allows simulation of different realistic scenarios on renewable integration and its impact on the electricity system in terms of costs, carbon dioxide emissions, and social welfare. This important contribution warns that intermittency in renewable generation increases dependence on conventional generators, raising gas consumption in combined cycles and reducing part of the expected environmental benefits. The study analyzes the impact of renewable integration on social welfare through a welfare function that considers consumer and producer surpluses and the external costs of carbon dioxide emissions. In this sense, the article contributes to the design of public policies that maximize overall welfare by promoting long-term sustainability, ensuring access to affordable and reliable energy, protecting public health, and generating positive economic effects such as higher levels of employment and competitiveness and a reduction in energy poverty.

Wiegner et al. (2024) build on Rosellón's proposal to study renewable integration in the North Sea. In the same vein as Davi-Arderius et al. (2024), Wiegner examines intermittency in renewable generation and proposes expanding the North Sea grid to integrate renewables and meet the European Union's emission reduction targets.

Rosellón also proposes a "green growth" model, which prioritizes renewable energy production and seeks to maximize social welfare. This approach also fosters the reduction of greenhouse gas emissions. Unlike other researchers who focus solely on promoting policies aimed at mitigating emissions, Rosellón adopts a comprehensive vision that encompasses environmental, social, and economic impacts. Along with Hancevic et al. (2022a), he provides a complete view of how renewable integration transforms the economic and energy system. The researchers do not isolate the effects of the energy transition on a particular sector but consider impacts on the economy as a whole, including electricity generation, employment, 17 consumption, and overall welfare. They compare two energy policy scenarios: on the one hand, the "Fourth Transformation or 4T" system promoted by the Mexican administration during 2021 and 2022, based on fossil fuels such as oil and natural gas; and on the other, the so-called "green scenario" proposed by the authors, which prioritizes the use of renewable energy sources and seeks to maximize social welfare. The authors show that the scenario prioritizing renewable production yields better results in terms of economic growth, employment, and emission reductions. Equally relevant is Rosellón, Hancevic, and Nuñez's observation that the transition toward renewable energy may require compensatory redistributions (Hancevic et al., 2022a)—a wholly realistic point often avoided by energy policy actors. This does not imply an eclectic approach by Rosellón toward promoting renewables; on the contrary, as noted above, a green growth approach does not exempt policymakers and regulators from the responsibility of implementing support instruments that provide alternatives for activities that have no place in the green scenario.

In Davi-Arderius et al. (2025), Rosellón incorporates empirical methods to analyze how a generation mix with a high share of renewable production affects network costs and operational issues. In many cases, the system operator must activate large volumes of conventional gas generation to ensure network stability and security. The detailed empirical study represents an important contribution to the operational and technical debate on renewable integration.

Rosellón's contributions have been decisive in studies on renewable integration and the maximization of social welfare. In this regard, Hancevic and Sandoval (2023) highlight Rosellón's role in the deployment of renewables, the role of self-consumption, and its impact on maximizing total welfare.

These contributions provide highly detailed insights into the difficulties that may arise in integrating renewable energy into electricity transmission networks. His articles argue that energy storage mechanisms must be designed to ensure system operation and supply to all users in situations where intermittent generation plants cannot meet demand. Likewise, his contributions demonstrate that greater consumption of electricity from clean sources can mitigate negative impacts on social welfare.

4.2. Environmental Externalities in Electricity Markets

Rosellón's work also encompasses the study of efficient and sustainable electricity markets, with particular emphasis on renewables as an essential technology in the energy transition. The author proposes pricing systems that regulate market power, taking into account environmental externalities, ensuring supervision and regulation of proper market functioning to prevent price manipulation and, consequently, to foster competition and cost efficiency.

As is well known, environmental externalities are costs not incorporated into the market price but borne by all consumers and society as a whole. In the energy sector, when electricity is 18 generated through fossil fuels such as oil or natural gas, a negative externality is produced, namely pollution and carbon dioxide emissions. This contributes to climate change, negatively affecting the environment and public health. However, the economic value of this impact is not reflected in the price of electricity, as Nordhaus (1972) pointed out.

At times, the market price does not internalize these costs and diverges from the social optimum, which justifies regulatory developments aimed at addressing environmental externalities. Governments may establish taxes on electricity generators so that prices reflect the real cost of energy by including the value of these externalities. In other cases, governments may also subsidize energy generation from clean sources that do not produce emissions.

In this regard, Rosellón suggests a model in which electricity generators bear their environmental costs, instead of society. It is a pricing mechanism with incentives for electricity generators that rewards companies using renewable sources and polluting less. Moreover, it incorporates the value of externalities into the costs of electricity, minimizing the use of polluting fuels and promoting a transition toward cleaner energy sources. The model also reduces the market power of incumbent conventional technology generators.

This academic contribution by Rosellón appears in Varawala et al. (2023), where the authors present the pricing mechanism that addresses environmental externalities and limits the market power of electricity generation companies that rely on polluting sources. The study focuses on the design of regulatory mechanisms for electricity markets where renewables generate instability and uncertainty. The mechanism incorporates incentives for renewable generation, which results in greater competition and a reduction in anticompetitive practices. By integrating economic and environmental variables, the mechanism contributes to maximizing social welfare, balancing economic efficiency with environmental sustainability.

Roy and Pearce (2024) highlight Rosellón's research on environmental externalities in electricity markets and how the incorporation of renewables can reduce such adverse effects. In their study, they show that self-consumption solutions based on solar panels are more efficient than the conventional supply system.

4.3. Microeconomic Perspective

Rosellón also analyzes the integration of renewable energies from a microeconomic perspective, focusing on the decisions of households and users that shape their electricity consumption levels. Households typically make decisions that affect their energy use, such as upgrading appliances or investing in solar panels. Likewise, users respond differently to the tariff system, subsidies, and electricity prices depending on their income levels, financing possibilities, education, and concern for social issues.

All these factors influence household decisions regarding the adoption of clean technologies. In this regard, Rosellón's studies show that households generally do not adopt solar panels because subsidies fail to incentivize investment in this type of renewable energy. Instead, 19 such subsidies discourage energy efficiency and hinder an equitable and sustainable transition.

Rosellón proposes tariff reforms to encourage residential solar energy installation. He suggests redistributing subsidies toward renewable technologies such as solar panels, but targeted at low-income households. In this way, he shows that household decisions are essential for the energy transition to achieve its objectives. Hancevic et al. (2017) propose restructuring the subsidy system in Mexico, evolving from a household consumption-based scheme toward an alternative of subsidies that promote the adoption of a distributed photovoltaic generation system. The article analyzes the program's feasibility at the national level and evaluates its impacts on household expenditures, emissions, and energy savings. The results of the research indicate that the adoption of domestic solar panels is more than compensated for by the reduction in spending on traditional electricity.

In more recent contributions, Hancevic et al. (2022b) propose a two-part tariff model with targeted subsidies to improve the efficiency and equity of the Mexican electricity system. This study uses data from Mexican households and conducts simulations to observe the effects of adopting the proposed system. The authors show that the total amount of subsidies can be reduced, thereby improving efficiency and equity. Moreover, the tariff schemes they suggest can reduce polluting emissions, with clear environmental benefits for the population.

Xin-gang and Yi-min (2019) evaluate the economic performance of photovoltaic systems installed by industrial and commercial enterprises in China. The authors highlight Rosellón's findings regarding the integration of renewable sources in Mexico. They also suggest that the Chinese system should consider Rosellón's proposed reforms regarding subsidy reduction to ensure the economic viability of the system.

The contributions analyzed in this section reveal Rosellón's concern with integrating renewable energies into the electricity system from the perspective of users. These studies provide a complementary view of the transition toward clean sources, highlighting the importance of household behavior in ensuring that the transition works properly and that inefficiencies and inequalities are avoided during the process.

5. Conclusions

Rosellón's work contains important contributions to the design of efficient regulatory models that enable network expansion under conditions of efficiency and flexibility. Indeed, hybrid merchant–regulatory mechanisms combine market incentives with government control, and their validity is demonstrated both theoretically and in empirical applications.

Rosellón's research reflects his growing concern with encouraging private investment while prioritizing the maximization of social welfare. He understands that regulation has a key role in addressing market failures and that negative externalities must always be considered in the definition of regulatory policies.

His work integrates the principles of second-best theory and the Little–Mirrlees rule to address pricing and tariff design problems in markets with lumpy investments and structural constraints. The author shows that it is possible to apply complex theoretical frameworks to real regulatory problems in the natural gas market. Rosellón's studies put forward concrete public policy proposals derived from abstract economic concepts, highlighting the practical value of his work.

In the field of the electricity market, Rosellón offers one of the best contributions in the literature on the application of nodal prices. His research shows that these prices reflect the marginal costs of electricity generation and energy transmission. This subject is especially timely in Europe. In this regard, Rosellón considers this approach an essential tool for improving the operational efficiency of the electricity system. Moreover, it allows the improvement of social welfare for society as a whole. His articles demonstrate that nodal prices optimize the generation and commercialization process of electricity, promote more rational infrastructure investments, and generate clear signals for private investment that enable the expansion of transmission networks.

Rosellón promotes hybrid mechanisms that combine economic regulation and commercial incentives. Among them are LTFTRs and the H-R-G-V mechanism, aimed at the efficient and economically sustainable expansion of transmission networks. The author advocates both the elimination of generalized subsidies for society regardless of income or wealth, and the protection of the most economically vulnerable sectors by guaranteeing access to energy efficiently and at lower cost.

The H-R-G-V mechanism represents one of the most valuable contributions of Rosellón's scientific work. The mechanism features a multilevel structure in which the transmission company at the upper level makes investment and pricing decisions, while the independent system operator at the lower level manages network operations. This results in optimal private investment decisions for network expansion that make it possible to achieve the social welfare objectives pursued by regulators.

Rosellón's focus on renewable energy is also noteworthy. His research combines economic, social, and ecological considerations. He highlights models that maximize total welfare within a "green growth" context. This particular feature of his studies sets him apart from other approaches that focus only on emission mitigation.

One of Rosellón's main contributions regarding the integration of renewable energy sources is the introduction of uncertainty and intermittency of clean sources into electricity planning models. In various articles, he proposes a combination of solutions such as energy storage, the expansion of smart grids, and the use of backup technologies to ensure supply stability while guaranteeing service efficiency. Storage deployment is the keystone of the viability of a renewable energy mix. Rosellón also evaluates the impact of renewable energy integration in terms of costs, pollutant emissions, and welfare surpluses. To carry out this analysis, he employs partial and general equilibrium models that allow the simulation of realistic scenarios and the promotion of public policies that support a sustainable and equitable energy transition for society as a whole.

Rosellón also proposes pricing mechanisms to integrate environmental costs and minimize possible negative externalities. He demonstrates that these mechanisms promote clean energy and, moreover, reduce or eliminate the market power of traditional generators, improving competition. These mechanisms should ultimately lead to the disappearance of polluting technologies.

From a microeconomic perspective, his research focuses on individual decisions regarding self-consumption through household solar panel installation. He considers consumer choice fundamental to the success of a sustainable energy transition. To this end, Rosellón points out that subsidies should be redirected toward clean technologies, especially for low-income households, through progressive tariffs.

The impact of his work extends beyond Mexico: his models have been used by researchers and policymakers in Latin America, Europe, and the United States and have been cited by influential experts such as Joskow and Hogan. This positions him as an academic reference in the regulation of energy networks, with particular emphasis on natural gas and its interrelation with electricity markets. His work has laid the foundation for today's academic debate.

In short, Rosellón's contributions stand out not only for their theoretical rigor and empirical evidence but also for his deep and constant concern with maximizing social welfare. His work meets the highest demands of scientific research while never losing sight of the pursuit of social justice and the common good. All his reform proposals are directed at providing solutions for the most disadvantaged consumers. Rosellón designs regulatory models that seek to minimize the origins of negative externalities, encourage efficient investment to expand transmission networks, and ensure equitable access to energy, particularly for the most vulnerable socioeconomic sectors. The entirety of Rosellón's work demonstrates his comprehensive approach, which combines economic efficiency, environmental sustainability, and distributive justice, and at the same time consolidates him as an indispensable reference for understanding and transforming the energy systems of the present and future.

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