Energy transition policies in France and their impact on electricity generation

– DRAFT VERSION –

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Abstract:
France experienced recently the important transformation of its energy and environmental policy through the entry into force of the Energy Transition for Green Growth Act and the recent Paris agreement between the parties to the United Nations Framework Convention on Climate Change. In this paper, we study the economic implications of this transformation on electricity generation. In particular, we focus on the economic rationale of conducting France energy transition with an extraordinary portfolio of market-based policies including feed-in tariffs, auctions, carbon pricing and the European Union cap and trade scheme. We find that such approach can produce more economic inefficiencies than the sole application of a carbon pricing policy. We emphasized, however, that the uncertainties in the ability of the current wholesale and the newly created capacity markets to address both economical and physical requirements of security of supply, favored the continuation of conservative (and risk adverse) policies. Finally, we discuss the structure of the future electricity mix expected to emerge from the current policies and question its social optimality.

Introduction

In December of 2015, the parties to the United Nations Framework Convention on Climate Change agreed during the 21st session held in Paris (the COP21) to "hold the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change."[1] This agreement was not only an international diplomatic success for France, but also the pinnacle of a three years domestic process, that saw the important transformation of French energy and environmental policy through the entry into force of the Energy Transition for Green Growth Act (ETGG Act),[2] a few months before the COP21.

[1] United Nations, "Adoption of the Paris Agreement," Framework Convention on Climate Change, Conference of the Parties, Twenty-first session, FCCC/CP/2015/L.9, 12 December 2015.
[2] Loi relative à la transition énergétique pour la croissance verte, n° 2015-992, 17 août 2015. (Energy Transition for Green Growth Act, 17 August 2015).

The political value of the Paris agreement will certainly help to consolidate the public acceptance of the Act and its long-term objectives to accelerate France's energy transition and reduction of green house gas (GHG) emissions.

The objectives are to reduce France GHG emissions by 40% in 2030 compared to 1990,[3] increase the share of renewable energy sources to 32% of the final energy consumption and 40% of the electricity consumption in 2030, reduce the fossil fuels consumption by 30% in 2030 as well as the final energy consumption by 50% in 2050 compared to 2012. The Act also pushes for the diversification of electricity production by reducing the share of nuclear power to 50% by 2025 and by capping the nuclear power capacity to the current level of 62.3 gigawatt electrical (GWe).

Furthermore, what was not advertised much by the government, but may be the most important economic measure of the Act, is the decision to increase significantly the French carbon tax also referred as the "Climate and Energy Contribution" (CCE). The CCE, created by the same government in 2014, is a component of a domestic tax on the consumption of energy products (TICPE),[4,5] and is applied through all sectors of the economy including electricity generation and transportation.[6] At the time of its creation, it introduced carbon pricing at a relatively low (and politically benign) level of €7/tCO_2 which was to be slowly raised to €14.5/tCO_2 in 2015 and €22/tCO_2 in 2016. But in July 2015, through an amendment of the ETGG Act supported by the socialists, ecologists and centrists, the decision was taken to increase the CCE even further to €56/tCO_2 in 2020 and €100/tCO_2 in 2030.

Together these decisions have the potential to reshape greatly the supply of electricity in France. It will not be the first time that the country faces such important transformation, as can be seen by the evolution of gross electric production from 1973 to 1990 and the massive development of nuclear power

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[3] Note that in 2012, GHG emissions were already 12% less than their 1990 level. See: Ministère de l'écologie, du development durable et de l'énergie, "Inventaire des émissions de gaz à effet de serre de la France: les résultats 1990-2012." 17 avril 2014, http://www.developpement-durable.gouv.fr/Inventaire-des-emissions-de-gaz-a.html

[4] Ministère de l'économie et des finances, "Présentation des dispositions législatives adoptées dans le cadre des lois de finances pour 2014 et de finances rectificative pour 2013 concernant la fiscalité énergétique et environnementale," 12 mars 2014. http://circulaire.legifrance.gouv.fr/pdf/2014/03/cir_38051.pdf

[5] The TICPE, Tax Interieur sur la consommation des produits energetiques, was formally a fuel tax.

[6] There are some exemptions, however, within the transportation sector. Ministère de l'écologie, du development durable et de l'énergie, "La fiscalité des produits pétroliers dans les lois de finances rectificative pour 2014 (LFR) et loi de finances pour 2015 (LFI)," January 13, 2015.

during that time (Figure 1). But today's context is certainly very different. The main reason being that electricity production and distribution is not a state monopoly anymore. The sector was slowly transformed over the last twenty years into a regulated market that continues today its liberalization and integration with European partners under the directives of the European Union.[7] Hence, to pursue its energy transition, France will need to implement sound and efficient market based economic policies.

By making the choice of a strong carbon pricing policy, the French government has chosen what is recognized as the most efficient and first best policy, but at the same time, it has not yet gave up on existing Feed-In Tariffs and auction policies inherited from its predecessors. The effects of such an extraordinary portfolio of economic measures is therefore of particular interest and is the focus of this study.

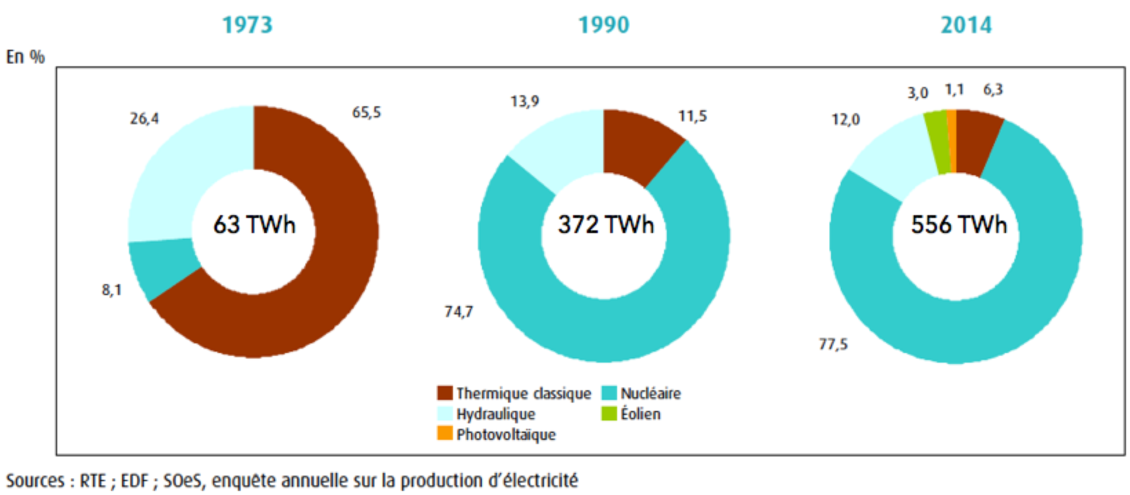

Figure 1: Structure of gross electricity production in France in 1973, 1990 and 2014. The country gross production reached 556 TWh in 2014 of which 77.5% was supplied by nuclear power. (Thermique classique translates in fossil fuel fired plants, Eolien in Wind Power, Nucléaire in Nuclear, Hydraulique in Hydro-electric power, Photovoltaïque in PV).

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[7] Ministère de l'écologie, du development durable et de l'énergie, "Les étapes de l'ouverture à la concurrence du marché de l'électricité" (Steps in the opening to competition of the French electricity market), 2007. http://www.developpement-durable.gouv.fr/Les-etapes-de-l-ouverture-a-la.html

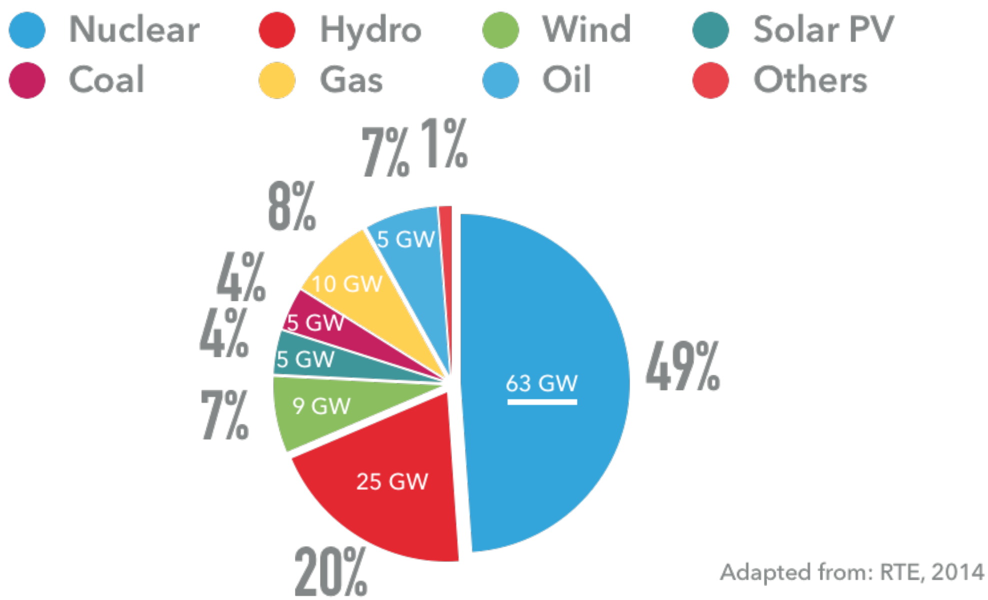

Figure 2: Structure of installed electricity generation capacity as of 12/31/2014

In this paper, we develop an understanding of the economic rationale and degree of efficiency of conducting the energy transition with a portfolio of policies, rather than simply achieve the multiple objectives of emission abatement and diversification of electricity production (including the large deployment of renewables) through a carbon pricing policy alone. Next, we point out that the current structure of the electricity market, may not be adequate to sustain the energy transition once the penetration of renewables has achieved a high level and electricity is mostly supplied with technology that have a zero (renewable) or near zero (nuclear) marginal cost of producing one megawatt-hour (MWh). Finally, we discuss the likely future composition of the French electricity mix in the year 2030, the time horizon of the ETGG Act, and whether or not this outcome will be socially optimal.

Economic policies for the promotion of renewables in France

The development of policies to actively promote renewable energies in France started a decade ago, and as since been evolving rapidly. The first step in this development was the POPE Act.[8] It had for objectives to increase France energy independence and security of supply by encouraging energy savings and diversifying electricity production with priorities given to renewable and low carbon emission technologies to address climate change. The act established, for the first time, renewables energy capacity targets. These targets, set in the 2006 *Programmation pluriannuelle des investissements de production d'électricité* (Pluriannual Programation of investments in electricity production, PPI hereafter),

[8] Loi de programme fixant les orientations de la politique énergétique, n° 2005-781, 13 juillet 2005. (Planning law setting the orientations of the energy policy).

are not only objectives for investments but also ceilings beyond which no further capacity can be installed. It was decided that investments in renewables capacity would be encouraged through a Feed-In Tariffs (FITs) policy. FITs were introduced in 2006 for wind energy and in 2009 for solar PV. Prices are guaranteed for a certain period of time, usually ten to twenty years, depending on the technology. During that time, EDF (*Electricité de France*, the historical producer of electricity and former state monopole in France, now a private company owned at 85% by the state), has the obligation to buy the electricity produced by renewables at a fixed price set by the government (usually well above the market spot price). EDF is then reimbursed through a so-called "contribution", the CSPE (*contribution au service public de l'électricité*), which is charged directly to the consumer electricity bill. In 2016, the CSPE, set at €22.5/MWh, represents about 16% of an average electricity bill.[9] Until 2015, the CSPE couldn't exceed €550,000 per year for the largest consumers, thus placing the cost of the development of renewables almost entirely on small consumers. This unequal treatment will be addressed in 2016, with the CSPE being integrated in an existing tax, the TICFE (Interior Tax on Final Electricity consumption, historically only applicable to large electricity consumers), liberalizing this contribution to the development of renewables to all consumers independently of their total consumption.[10]

It is important to note that until the government introduced carbon pricing in 2014, only electricity consumers supported the development of renewables, even if electricity production, largely dominated by nuclear power, was not a large emitter of carbon (less than 12% of all emissions in 2012).[11] The recent political decision to significantly increase the carbon tax will shift some of the costs burden on the industries as well as other sectors of the economy.

From the economic standpoint, the choice of a FIT policy coupled with a capacity cap not only reduces uncertainties in the decisions to invest, but also prevents the development of over capacity and places a limit on the costs to consumers if the FIT were set too high. The effects of the policy and the difficulty to set the correct FIT

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[9] Two third of the CSPE finance the deployment of renewable energy, the rest contributes to tariff equalization across the country (same tariff for all independent of were people live) and social costs (subsidy to low income households). See: http://www.lesechos.fr/industrie-services/energie-environnement/021481006103-le-gaz-et-les-carburants-vont-payer-pour-le-solaire-1175546.php?O86AhwcoBDJu9aWt.99

[10] Electricity intensive industries and some transport industries (train, metro, tramway…) will have access to a lower tax level, however. See: Douanes, "Réforme de la taxe intérieure sur la consommation finale d'électricité (TICFE)", December 31, 2015, http://www.douane.gouv.fr/articles/a12667-reforme-de-la-taxe-interieure-sur-la-consommation-finale-d-electricite-ticfe

[11] See page 21: http://www.developpement-durable.gouv.fr/IMG/pdf/Chiffres_cles_du_climat_en_France_et_dans_le_monde_2015.pdf

price corresponding to the desired renewable capacity can be studied by looking at the deployment of wind and photovoltaic (PV) electricity production in France since 2008 (Figure 3).

For wind power, two different objectives were set in 2009: the installation of 19000 MW and 6000 MW of onshore and offshore projects by 2020.[12] FIT for onshore wind power guarantees a revenue of €82/MWh for the first 10 years of production followed by a price between €28/MWh and €82/MWh for the next 5 years, depending on the performance (hours of production per year) in the first 10 years. This FIT mechanism, readjusted after 10 years, encourages the industry to pick the best sites to install their wind turbines and maximize their production.[13] However, as we can see on Figure 3, the current installed capacity is well below the expected target and as of January 2016, no offshore wind capacity was installed. The original FIT price of ~€130/MWh for offshore wind power did not trigger any investment and the policy was replaced in 2012 by an auction mechanism. Consequently, 3000 MW of offshore projects were launched at a price of ~€200/MWh.[14] This shift from FIT to auction confirms the heterogeneity of wind power generation and the profound difference in onshore and offshore technologies, which could have been predicted by the government.

In the case of PV, the opposite happened. A high FIT resulted in the installation of a larger than expected capacity and the objectives set in the 2009 PPI for 2020 (5400 MW) were already reached in 2015 forcing the government to increase the cap to 8000 MW by 2020.

In both cases (wind and PV), mismatch between renewable capacity installation and FIT is inefficient from the economic standpoint, and result in dead weight losses supported by consumers.[15] Moreover, it shows that FITs need dynamic adjustment mechanisms to prevent important pricing mistakes, which may be the results of a

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[12] Ministère de l'Ecologie, de l'Energie, du Dévelopement Durable et de l'Aménagement du Territoire, "Programmation pluriannuelle des investissements de production d'électricité. Période 2009 – 2020," 2009. (Pluriannual Plan of Electricity Production Investments). http://www.developpement-durable.gouv.fr/IMG/pdf/ppi_elec_2009.pdf

[13] Lucy Butler and Karsten Neuhoff, "Comparison of feed-in tariff, quota and auction mechanisms to support wind power development," Renewable Energy, Volume 33, Issue 8, August 2008, Pages 1854-1867, http://dx.doi.org/10.1016/j.renene.2007.10.008.

[14] Le Figaro Economie, "Énergie: l'éolien en mer défend son potentiel," 01/12/2014, http://www.lefigaro.fr/societes/2014/12/01/20005-20141201ARTFIG00195-energie-l-eolien-en-mer-defend-son-potentiel.php

[15] Richard Schmalensee, "Evaluating policies to increase electricity generation from renewable energy," Review of Environmental Economics and Policy 6.1 (2012): 45-64.

lake of information about technology development and deployment costs as well as performance in the long run.

In 2016, the FIT policy will be replaced by a feed-in premium (FIP) scheme so that producers with installed capacity above 500kW will be required to directly sell their electricity on the wholesale market. Under this new FIP policy, producers will receive a premium covering the difference between the market spot price and former FIT price. This transition from FIT to FIP was encouraged by the European commission to facilitate the integration of renewables in the wholesale electricity market, which is the major benefits of FIP,[16] and accelerate the development of electricity aggregators.[17]

The French government in line with the objectives of the ETGG Act is expected to set new targets for renewable capacity. Current discussions envisioned 24,000 MW of onshore wind and PV in 2018, and between 36,000 to 43,000 MW in 2023.[18] The continuation of this FIT/FIP policy seems at odd, however, with the pursuit of a more aggressive carbon pricing policy. Thus, we will try to understand now, if both policies can complement each other, and if so, how. On the contrary, if they are to be simply redundant and economically inefficient, we want to understand what would be the best alternative policy.

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[16] Julieta Schallenberg-Rodriguez and Reinhard Haas, "Fixed feed-in tariff versus premium: A review of the current Spanish system," Renewable and Sustainable Energy Reviews, Volume 16, Issue 1, 2012, Pages 293-305.

[17] European Commission, Guidance for renewables support schemes, 2013. https://ec.europa.eu/energy/en/topics/renewable-energy/support-schemes

[18] Sciences et Avenir, "Climat: le gouvernement fixe de nouveaux objectifs pour les énergies renouvelables," 11/13/2015. http://www.sciencesetavenir.fr/nature-environnement/20151113.AFP6468/climat-le-gouvernement-fixe-de-nouveaux-objectifs-pour-les-energies-renouvelables.html

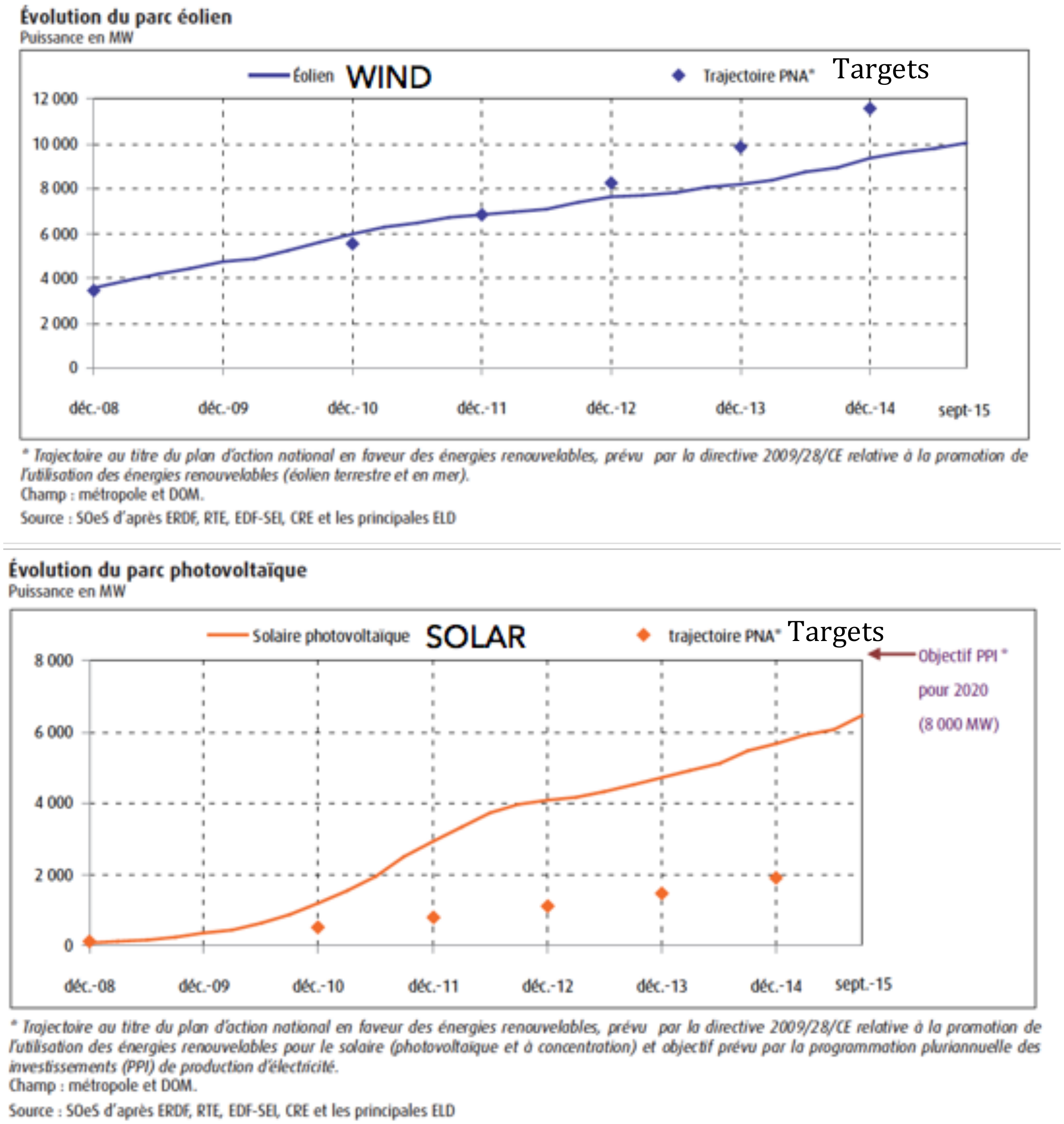

Figure 3: Evolution of installed capacity for wind and PV electricity production. Solid lines are trajectories of installed capacities, diamonds represent the government's original targets.[19]

[19] Graph and data from: Commissariat Général au Dévelopment Durable, "Tableau de bord: éolien," Observations et Statistiques, 702, November 2015; and Commissariat Général au Dévelopment Durable, "Tableau de bord: solaire photovoltaïque," Observations et Statistiques, 701, November 2015,

The effects of concurrent FIT/FIP and carbon pricing policies

The introduction of relatively high carbon pricing in the French fiscal legislation, beyond what already existed at the European Union (EU) level, should have a significant impact on electricity production and on CO_2 emissions.[20] Carbon pricing (or carbon tax) leads to the optimal amount of abatement if it is applied to all sectors of the economy and is equal to the social cost of carbon. For electricity production it has the effect of changing the merit order curve of electricity supply. By increasing the carbon price from €14.5/tCO_2 in 2015 to €100/tCO_2 in 2030,[21] and assuming average emissions level of 0.96t/MWh for coal, 0.67t/MWh for oil, and 0.46t/MWh for gas fired plant,[22] the marginal cost of supplying one MWh of electricity will increase for coal, oil and gas power plants respectively by €82, €57 and €39 by 2030. Demand for electricity being rather inelastic, the price for electricity should rise significantly.[23]

So what will be the effects of this new policy on the merit order and consequently on the electricity spot price in France? As shown in figures 1 and 2, fossil fuels power plants represent 19% of the installed capacity but only 6% of the total gross production. These plants are usually turned on to address winter shoulder and peak demand. High carbon pricing will certainly make coal and oil plants less economical and move CCGT plants to become the marginal supplier. The price difference

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[20] Note that a carbon price already existed in France under the EU Emissions Trading System. The scheme failed however to produce a significant price for carbon (well under €10/tCO_2) and has led to further inefficacy in the EU ability to reduce its carbon emissions, see: Richard Schmalensee, "Evaluating policies to increase electricity generation from renewable energy." The outcome of the COP21 could put further pressure on the EU to reform the ETS cap and trade system, see: Carbon Pulse, "EU should revisit its climate policies, say Swedish lawmakers," January 7, 2016. http://carbon-pulse.com/13967/

[21] These figures are significantly higher than what are currently used by the US Environmental Protection Agency. See: Interagency Working Group on Social Cost of Carbon, "Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis - Under Executive Order 12866," 2015. https://www.whitehouse.gov/sites/default/files/omb/inforeg/scc-tsd-final-july-2015.pdf. But less than what is in place in Sweden, \$125/tCO_2, on half of its CO_2 emissions, see: Gernot Wagner et al., "Energy policy: Push renewables to spur carbon pricing," *Nature,* 525, 3 September 2015, p.27.

[22] Real time emissions are available online: RTE, "Émissions de CO2 par kWh produit en France", http://www.rte-france.com/fr/eco2mix/eco2mix-co2

[23] As a comparison, the yearly average Day-Ahead base price (EPEX SPOT) in France in 2015 was €38.48/MWh. See: Mondovisione, "EPEX SPOT Reaches In 2015 The Highest Spot Power Exchange Volume," 01/08/2016. http://www.mondovisione.com/media-and-resources/news/epex-spot-reaches-in-2015-the-highest-spot-power-exchange-volume-ever/

between off peak and peak demand should grow of the order of the carbon price effect on the first gas plant to be dispatched to meet demand. This price increase should drive further installation of renewables as long as their minimum long run average cost is lower than the market price and the plants can be profitable. If the carbon pricing is set correctly to the social cost of carbon, then the share of technologies that do not emit CO_2 in the electricity mix should reach an optimal social equilibrium. This also means that renewables and nuclear plants which emits virtually no CO_2 will be directly competing with each other (and eventually with fossil fuel technologies together with carbon capture and storage).

Concurrently to the effects introduced by carbon pricing, the government FIP policy will also continue to have an impact on the merit order curve. The introduction of subsidized renewables that have zero marginal cost is shifting the supply curve by an amount equal to the renewable generation (Figure 4). This effect reduces the spot market price by pushing technologies with the highest marginal cost out of the supply stack. Thus if the FIP is incorrectly evaluated, gas fired plants could for example close before the carbon pricing starts having an effect on the merit order (because they would never be called).[24] Maintaining the FIP policy under a carbon pricing policy could lead to additional inefficiencies and increases costs for consumers (for example, if the FIP capacity target is capped at a level that is too low compared to the optimal renewable level under the carbon pricing policy). Thus it seems, at first, that the best strategy is to slowly phase out the FIT/FIP policy as the carbon price increases and reaches the social cost of carbon. However, we shall stress why it may be risky to remove as well the cap on the total installed renewables capacity. The reason being two folds: 1) Renewables are mainly intermittent sources of electricity, thus dispatchable sources must be kept at all time to ensure security of supply and stability of the grid in tension and frequency. Unless of course, renewables aggregators become eventually able to guarantee security of supply (hopefully not at the cost of over capacity). 2) When FIT/FIP policies come to an end, the profitability of renewables will depend on relatively high spot market prices, which can only be supplied by high marginal cost technologies such as gas-fired plant. If too much renewables were to be installed and supply electricity at zero marginal cost, they could displaced permanently the high MC plant out of the supply stack, not only undermining their profitability under marginal cost pricing but potentially driving the market to collapse since it requires such plant to exist in the first place (Figure 4).

[24] E-Cube Strategy Consultants, "Evolution du mix électrique français : les actifs gaz au centre de la transition énergétique ?," June 2012. http://e-cube.com/fr/wp-content/uploads/2013/12/1206_E3-ENR_Gaz.pdf

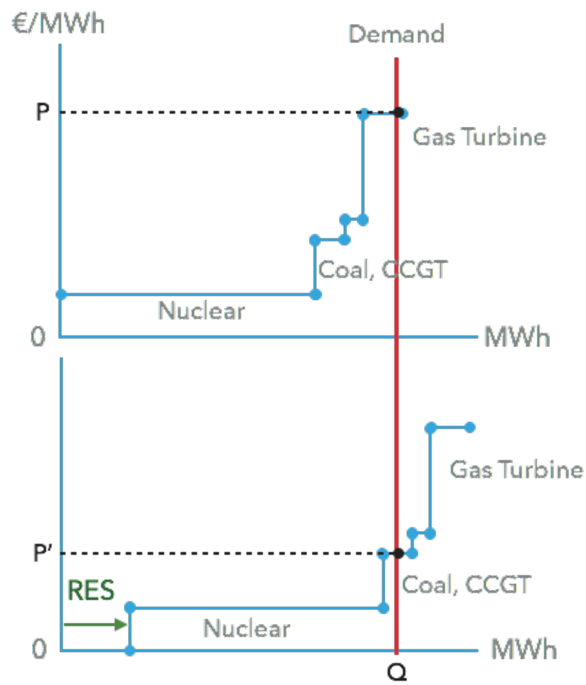

Figure 4: Illustration of the "merit order effect" following the introduction of renewable energy sources (RES) through Feed-In Tariffs (FIT) or Renewable Portfolio Standards (RPS). Assuming inelastic demand, the market price goes down from P to P'.

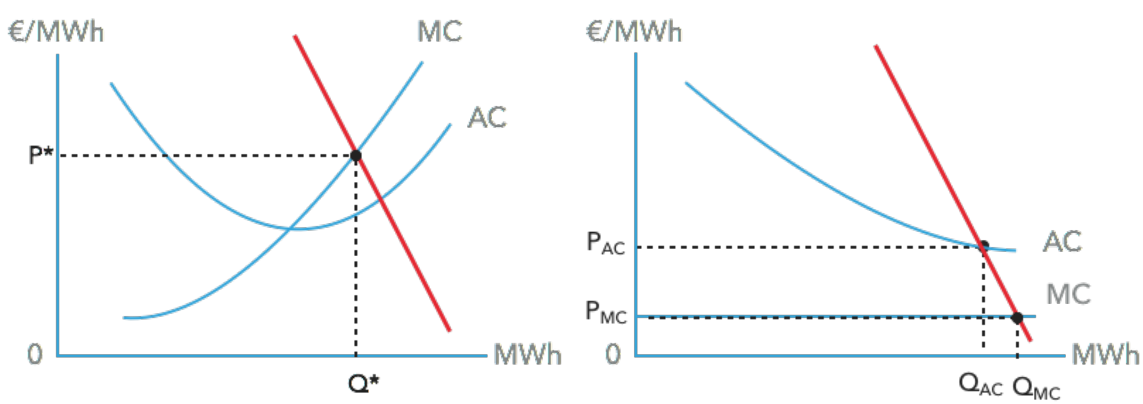

Figure 5: Illustration of Marginal Cost Pricing. Right: current market structure where at least some means of electricity production have high marginal cost greater than their average cost. Left: Once the last unit of high marginal cost power plant is displaced out of the supply curve, only low marginal cost plants (such as nuclear and renewables) remain. Here, marginal cost pricing can no longer be applied; this is a natural monopoly situation.

Intermittency and security of supply – will the new capacity market be sufficient?

As the volume of electricity generated by renewables increases, there are growing concerns with regards to the ability of suppliers to meet demand. As we mentioned earlier, the introduction of subsidized renewables lowers the profitability of flexible plants such as CCGTs by effectively reducing the market spot price (through the merit order effect). If too many such plants were to permanently shut down, the security of supply and stability of the grid would be threaten. These concerns will be partially addressed by the introduction of a capacity market in France starting in 2016.[25] This new market, introduced by the 2010 NOME Act,[26] is the first economic measure design to cope with both the growing capacity of intermittent sources and a rising peak demand in France. The introduction of the capacity market is necessary because the wholesale electricity market alone is unable to provide capacity payment to guarantee security of supply at all time.[27] This new market will rely on three pillars:[28] 1) Obligation for all capacity owners in France to commit on their forecasted availability during "peak periods" (3 years in advance for existing capacities). 2) Obligation for suppliers to own capacity certificates corresponding to the consumption of their own clients located in France during "peak periods", taking into account an extreme reference temperature and the contribution of interconnections. 3) Trading of "capacity certificates", beginning 4 years ahead of delivery year.

This capacity market, targeted at peak demand, should increase revenues of CCGT type plants, which will be likely the most economical fossil fuel plants in 2030 under a €100/tCO_2 carbon price. The market works essentially as an insurance policy for RTE (the electricity transmission system operator in France, a private company and a monopole) that will seek the guarantee that some capacity will be present at all time to meet demand. It does not guarantee, however, that flexible and dispatchable plants will supply any electricity. Thus we can imagine a situation were such plants are never dispatched and the spot market price could again collapse. We can then ask if CCGT type plants are then a requirement for the long-term integration of renewables in the electricity market – or if the current market structure is just not unable to allow a safe and reliable energy transition away from fossil fuels. It seems that unless a new market addressing the economical and physical requirement of security of supply emerges, more regulations will be needed to address this

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[25] Etienne Hubert, "Capacity mechanism implementation in France and future steps," Ministry of Ecology, Sustainable Development and Energy, 9th of March, 2015. http://www.ceem-dauphine.org/assets/dropbox/DGEC-_Etienne_Hubert.pdf
[26] Loi portant nouvelle organisation du marché de l'électricité, n° 2010-1488, 7 décembre 2010. (New organization of the electricity market Act).
[27] Paul L. Joskow, "Capacity Payments in Imperfect Electricity Markets: Need and Design." Utilities Policy, 16(3): 159-170, 2008.
[28] Etienne Hubert, "Capacity mechanism implementation in France and future steps."

fundamental problem.[29] It is important to note that the carbon pricing policy alone seems unable to address this issue. Meanwhile, a significant share of carbon emitting plants should remain in the electricity mix, unless other flexible alternatives such as storage technologies or carbon neutral biomass and biogas plants can be deployed.

Electricity production in 2030 and beyond

The ETGG Act objectives have the potential to greatly reshape the electricity production landscape in France. Figure 6 shows the evolution of net production between 2014 and 2030 as it is forecasted by RTE.[30] Increase in energy efficiency, including in households that highly rely on electrical heating in winter (and result in great thermal sensitivity of the demand in France), together with the development of peak shaving strategies are expected to stabilize electricity demand around 500 TWh per year (Figure 7). The government objective of 40% of the electricity consumption supplied by renewables in 2030 relies on the important deployment of wind and solar power and the upkeep of existing hydroelectric capacity. The development of wind and solar capacity and the reduction of the share of nuclear power require, however, the development of additional thermal capacity, probably in the form of CCGT and biomass/biogas plants.[31] This leads to the counter intuitive results of increasing the share of carbon emitting power plants in the total net electricity production. Looking at this 2030 picture, we ask the following question: Is this 40% renewables, 50% nuclear and 10% gas electricity mix socially optimal?

To answer this question, we recall that for this outcome to be socially optimal, the cost of electricity must reflect the negative externalities induced by its generation. The introduction of carbon pricing at the social cost of carbon will certainly address the externalities induced by electricity generation from fossil fuels technologies. It should impact the structure of the electricity mix so that carbon emissions are reduced to their socially optimal amount, which might not be null. Thus we would expect the share of carbon emitting power plants to either shrink to the benefits of zero carbon emitting plants, or be replaced by more efficient, less emitting plants. We see here that coal and fuel plants are replaced by CCGTs in the 2030 40/50/10 mix. It is hard, however, to understand why their share could increase so significantly. We can think of two reasons: 1) This outcome will be technically

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[29] Joskow, P. and Tirole, J. (2007), Reliability and competitive electricity markets. The RAND Journal of Economics, 38: 60–84. doi: 10.1111/j.1756-2171.2007.tb00044.x

[30] RTE, "Bilan prévisionel de l'équilibre offre-demande d'électricité en France: Edition 2015," 2016.

[31] Coal and oil-fired plants are expected to disappear by 2020 (when the price of carbon will reach €56/tCO_2).

required to deal with the intermittency of renewable resources. 2) It is the likely consequence of capping both renewables and nuclear capacities.

The second point raises further questions, particularly about the future of nuclear electricity generation in France. The legacy of the 1970's to 1990's development of nuclear power remains a strong source of pride in French institutions, [32] and it is a difficult topic to deal with politically when discussing the future of the energy mix.

As the oldest series of reactors in service are reaching the end of their designed lifetime, a public debate on the future of nuclear energy in France has yet to happen. What is certain is that the ETGG Act has capped the total installed capacity putting an end to further expansion. If nuclear energy was to remain important in France in the second part of the 21st century, EDF will have to make large investments: first, to increase the lifetime of current plants from 40 to 60 years, an operation that should raise the true historical cost of nuclear electricity generation, ~€60/MWh in 2014,[33] by ~€13/MWh;[34] second, by eventually starting to build new plants. The current costs of construction of the European Pressurized Reactor (EPR) are not a good sign for future investments, however. Costs were initially estimated at €3 billions for the 1650 MW power plant and are now expected to reach €10.5 billions. [35] Two similar reactors were sold to the UK in 2013 €for 31.2 billions and the British government had to guarantee a price of €109/MWh for 35 years.[36] This price is certainly too high to compete, for example, with onshore wind energy in France and maybe, even with CCGT plants under a high carbon price. EDF's CEO realized that, and recently announced that the company was seeking to develop a new version of the EPR able to compete on the whole sale market with a production cost of €70/MWh. He also expressed the wish to replace all the existing nuclear capacity by 30 or 40 new EPR

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[32] Gabrielle Hecht, "The Radiance of France: Nuclear Power and National Identity after World War II," MIT Press, 2nd Edition, 2009.

[33] Cours des Comptes, "Le coût de production de l'électricité nucléaire: Actualisation 2014," May 2014. https://www.ccomptes.fr/Publications/Publications/Le-cout-de-production-de-l-electricite-nucleaire-actualisation-2014

[34] Assuming 416 TWh of electricity produced by the EDF reactors (current level) and an investment of €110 billions, from 2011 to 2030, to increase all plants life time by 20 years.

[35] Le Monde, "Nouveau report de la mise en service de l'EPR de Flamanville," September 3, 2015. http://www.lemonde.fr/economie/article/2015/09/03/nouveau-report-et-reevaluation-du-cout-pour-le-reacteur-epr-de-flamanville_4744155_3234.html

[36] Les Echos, "Comment EDF espère baisser le coût du nouveau nucléaire," October 21, 2015. http://www.lesechos.fr/industrie-services/energie-environnement/021420800156-comment-edf-espere-baisser-le-cout-du-nouveau-nucleaire-1167896.php

plants in 2050.[37] We remain skeptical of this possibility that seems rather unrealistic in light of the massive and risky capital investments that such endeavor would require. Furthermore, it would only be fair to other sources of electricity that externalities from nuclear power generation finally be taken into account in the evaluation of its costs, including the ability to cover major damages resulting from large accidental releases.

Thus, we can conclude with high certainty that the 2030 energy mix envisioned as the outcome of the ETGG Act is probably not socially optimal, even if it seems to be a necessary step in the right direction.

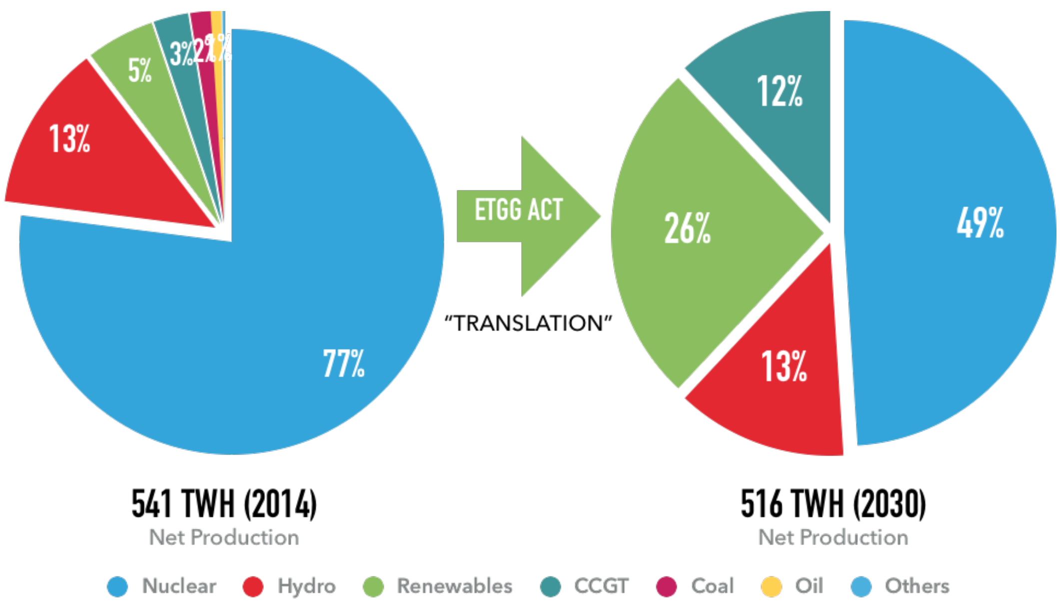

Figure 6: The impact of the Energy Transition for Green Growth Act on the French Electricity mix. Data for the right pie chart are adapted from RTE.

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[37] Le Monde, "EDF n'est pas prêt à sortir du nucléaire en France," October 23, 2015. http://www.lemonde.fr/economie/article/2015/10/23/edf-envisage-de-construire-jusqu-a-40-epr-d-ici-a-2050_4795963_3234.html

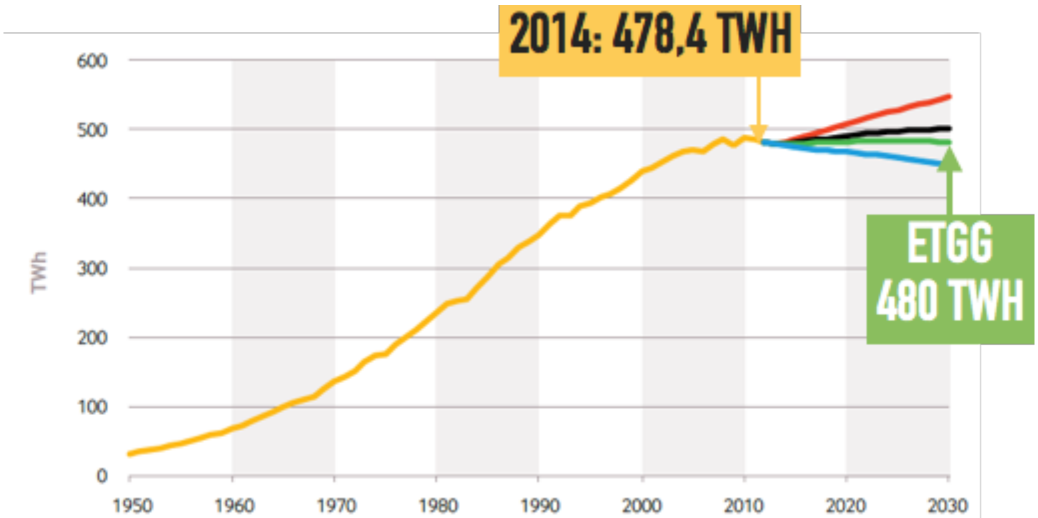

Figure 7: Historical electricity demand in France and 2014 forecasts by RTE. The black line is the reference scenario (status quo) with the red and blue lines representing the upper and lower bounds for demand evolution with strong and weak economic growth. The green line represents the potential outcome of the new ETGG Act.[38]

Conclusion

In this paper, we have studied the economic rationale of conducting France energy transition with an extraordinary portfolio of economic policies impacting electricity generation, and including feed-in tariffs, auctions, carbon pricing and the EU ETS cap and trade scheme. We find that such approach is mostly inefficient. The carbon pricing policy alone should be sufficient to achieve the multiple objectives of emission abatement and diversification of electricity production. We noted however that the uncertainties in the ability of the current wholesale and the newly created capacity markets to address both economical and physical requirements of security of supply, favored the continuation of conservative (and risk adverse) policies such as placing a cap on of the installed renewables capacity. Finally, we have discussed extensively the potential impact of the 2015 Energy Transition for Green Growth Act on the structure of the French electricity mix. We find that the likely outcome is not socially optimal, and that the next round of policies will need to address, not only the current market failures, but also the question of whether or not nuclear energy should continue to play such an important role in the French electricity mix in the second half of the 21st century.

[38] RTE, "Bilan prévisionel de l'équilibre offre-demande d'électricité en France: Edition 2014," 2015.