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The Economics of Policy Instruments to Stimulate Wind Power in Brazil

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Abstract

Large-scale deployment of renewable energy technologies, such as wind power and solar energy, has been taking place in industrialized and developing economics mainly because of various fiscal and regulatory policies. An understanding of the economy-wide impacts of those policies is an important part of an overall analysis of them. Using a perfect foresight computable general equilibrium model, this study analyzes the economy-wide costs of achieving a 10 percent share of wind power in Brazil's electricity supply mix by 2030. Brazil is in the midst of an active program of wind capacity expansion. The welfare loss would be small, 0.1 percent of total baseline welfare in the absence of the 10 percent wind power expansion. The study also finds that, in the case of Brazil, production subsidies financed through increased value-added tax would have superior impacts on welfare and greenhouse gas mitigation, compared with a consumption mandate where electricity utilities are allowed to pass the increased electricity supply costs directly to consumers. These two policies would impact various production sectors differently to achieve the wind power expansion targets: the burden of the mandate falls mostly on electricity-intensive production and consumption, whereas the burden of the subsidy is distributed toward goods and services with higher value added.

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The Economics of Policy Instruments to Stimulate Wind Power in Brazil[§]

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1 Introduction

In addition to large hydropower potential, Brazil is endowed with good wind power potential, mostly in the northeast and southern parts of the country, especially across the states of Bahia, Rio Grande do Norte and Ceara. A large portion of the economic potential of hydropower has already been exploited in Brazil and further expansion is increasingly constrained by environmental sensitivity and the remoteness of much of the remaining resource (REN21, 2014). On the other hand, emissions of greenhouse gas (GHG) from the power sector is rapidly increasing due to the increasing share of thermal power generation in the power supply mix (IEA, 2014b). Therefore, the government is planning to expand wind power and expects wind power to contribute 9% of total electricity consumption in the country by 2021.[1] Moreover, wind power provides an excellent complementarity to hydropower in Brazil, as the high wind seasons coincide with low rainfall seasons.

Currently, Brazil is the leader in Latin America in developing wind power; total installed capacity for wind power generation increased by more than -fold in just four years since 2010 (GWEC, 2014).[2] Brazil has introduced a number of policies and programs to promote large-scale deployment of wind energy. Existing policies aimed at wind power development include market (or purchase) guarantee, where the government procures wind power through competitive bidding or auctions (Franca, 2011). In addition, the government has launched specific programs to facilitate a large-scale deployment of renewable energy, including wind power (REN21, 2014).

Although Brazil and many other countries have introduced policies to promote renewable energy, including wind energy, the implications of such policies from a broader economic perspective are often not addressed. This clouds an already complex debate over whether or not a large-scale deployment of energy technologies that are yet to gain economic competitiveness should be promoted through government support policies rather than being left to markets.

[1] The Brazilian government's Decennial Energy Plan (PDE 2021) sets a goal of 16 GW of installed wind capacity by 2021, accounting for 9 % of national electricity consumption (GWEC, 2014).
[2] By the end of 2010, total wind power capacity was 927 MW, it increased to more than 5000 MW by the end of 2014 (GWEC, 2014).

Economy-wide macroeconomic models, particularly computable general equilibrium (CGE) models, are used to assess the economy-wide impacts of a policy. However, only a limited number of studies are available in the literature that assess renewable energy policies using a CGE framework (Timilsina and Landis, 2014; Böhringer and Löschel, 2006; Rana, 2003). The main obstacle to the use of CGE modeling approach to assess renewable energy is that the share of renewable energy in the total energy mix is very small. Therefore, renewable energy technologies are not treated as a separate economic activity or sector in input-output tables or social accounting matrix, the main database for a CGE modeling exercise. Moreover, most CGE models represent electricity generation technologies as a single technology thereby ignoring the heterogeneity among various technologies to generate electricity.[3]

The existing literature also diverges on techniques for representing renewable energy policy instruments in a CGE framework, particularly modeling renewable energy mandates. Some studies represent a renewable energy mandate, such as a biofuel blending mandate (a regulatory policy), through an equivalent fiscal policy, such as a subsidy to biofuels to the level that increases its consumption to satisfy a mandate or target (see. Hertel et al. 2010; Sorda and Banse, 2011 and Timilsina et al. 2012b). This approach is easier to incorporate in a CGE model. However, the general equilibrium effects derived through this approach might be different from the actual effects of a mandate because a mandate has a significant, direct effect on energy prices and thus the behavior of consumers, whereas consumer behavior is more indirectly affected by the energy price impacts of a renewable subsidy financed by the government through increases in other taxes.

The remainder of the paper is structured as follows. In section 2, a brief description of the CGE model is given. In section 3, the results of our simulations are presented. Finally, section 4 contains a summary and the conclusions of this study.

2 Model Description

We model Brazil's efforts to promote wind power generation in a perfect foresight intertemporal computable general equilibrium model. Base year data about the economy are

[3]However, recognizing the role of power sector on climate change mitigation policies, CGE models developed for climate change mitigation polices started to represent different electricity generation technologies separately instead of lumping them in a single technology (see e.g., Rana 2003; Paltsev et al. 2005; Timilsina and Shrestha, 2006).

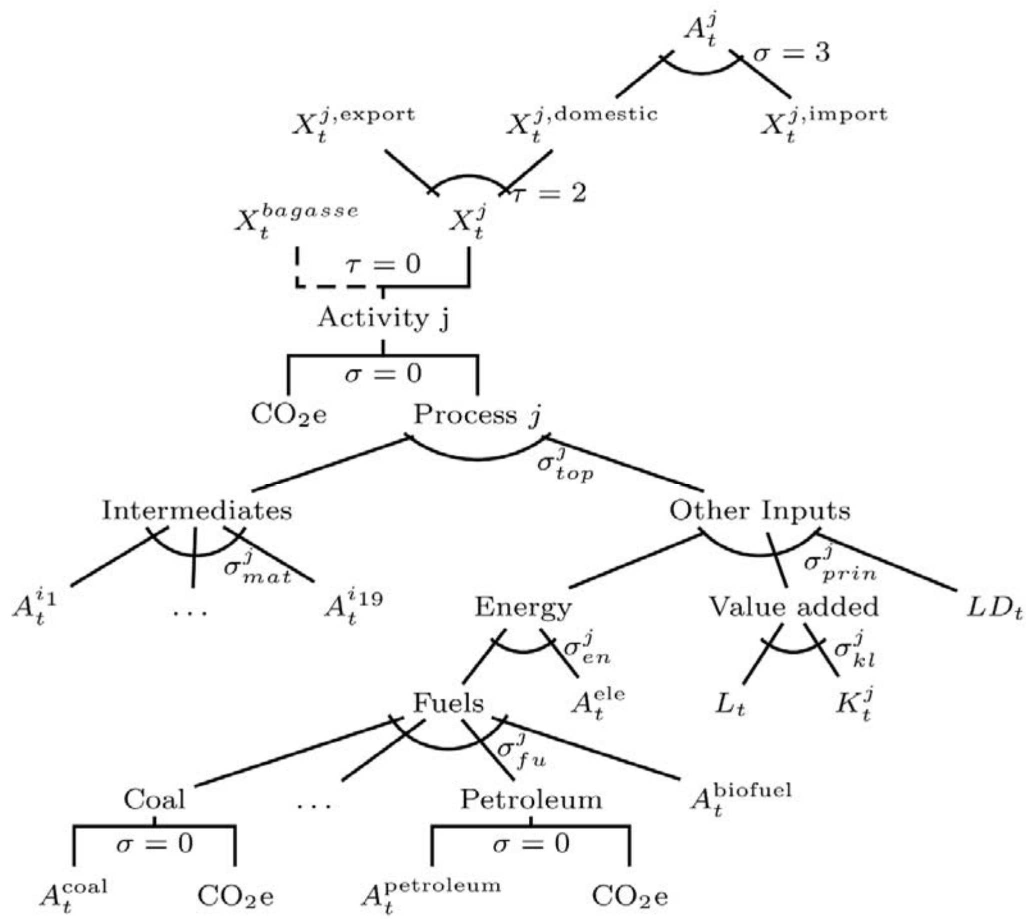
according to a social accounting matrix (SAM) by Chen and Timilsina (2012). We have considered 31 production sectors and 27 goods and services. While the oil refinery industry produces three commodities, gasoline, diesel and other petroleum products, electricity is produced from seven different types of technologies (i.e., hydro, wind, biomass, coal, oil, natural gas and nuclear). The disaggregation of the electricity sector to various power generation technologies is crucial, as without this disaggregation, simulations of policies to promote renewable energy-based electricity generation is not feasible.

Table 1. Production sectors and consumption goods considered in the model

Industry/sectors for production	Goods and services for consumption
1. Sugarcane industry	1. Sugarcane
2. Soybeans industry	2. Soybeans
3. Other agriculture industry	3. Other agricultural products
4. Livestock	4. Livestock
5. Forestry	5. Forest products
6. Crude oil & natural gas	6. Crude oil & natural gas
7. Coal mining	7. Coal
8. Metals and mineral mining	8. Metals and minerals
9. Food & beverages	9. Food & beverages
10. Textile & leather	10. Textile & leather
11. Wood industry	11. Wood
12. Pulp, paper & furniture	12. Pulp, paper & furniture
13. Oil refining	13. Gasoline 14. Diesel 15. Other petroleum products
14. Biofuels	16. Biofuels
15. Chemicals	17. Chemicals
16. Metal industry	18. Metals
17. Non-metallic minerals industry	19. Non- metals (e.g., cement, lime, glass)
18. Machinery & equipment	20. Machinery & equipment
19. Other manufacturing	21. Other manufacturing goods
20. Hydropower 21. Coal fired electricity generation 22. Natural gas fired electricity generation 23. Oil fired electricity generation 24. Windpower 25. Biomass fired electricity generation 26. Nuclear power generation	22. Electricity
27. Gas processing industry	23. Process gas
28. Construction sector	24. Construction goods/services
29. Commercial sector	25. Commercial services
30. Transport sector	26. Transport services
31. Service sector	27. Other services

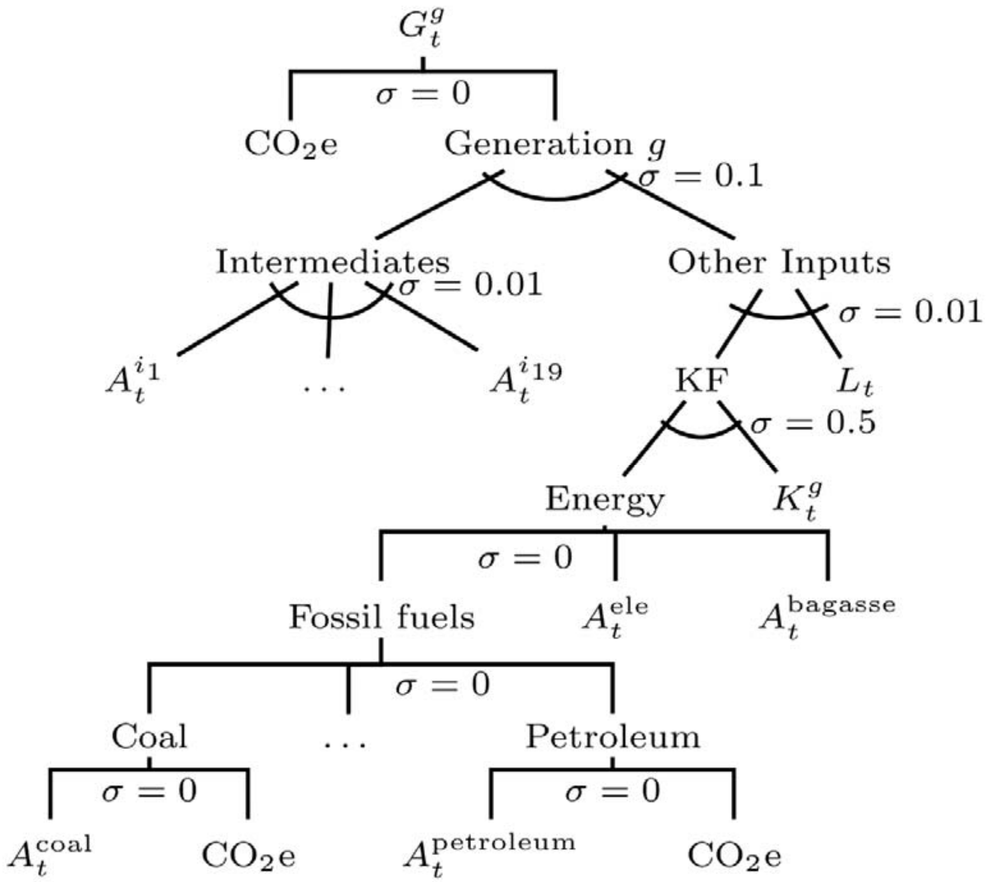
All production sectors, except the sub-sectors with various electricity generation technologies, are assumed to follow the 4-tier nested production structure as illustrated in Figure 1.

Figure 1. Production Structure of industries except electricity



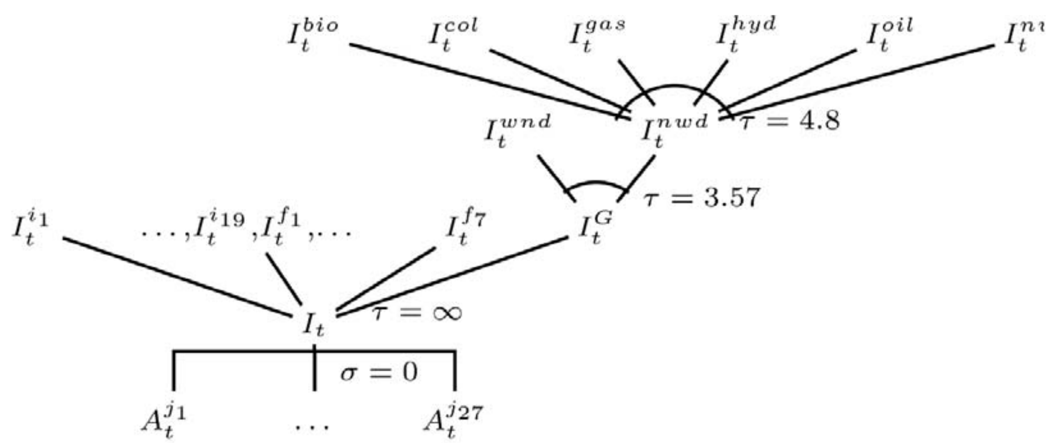
At the bottom tier, a CES function combines coal and petroleum products to have a fuel aggregate. The fuel aggregate is then combined with electricity to have an energy aggregate. Energy is combined with land and value added (capital and labor) inputs, and this energy-value added & land composite is then combined through a CES function with intermediate goods and services to produce outputs. The output is distributed to domestic and foreign consumption (i.e., exports) through a constant elasticity of transformation (CET) functional form. On the domestic market, a domestically produced good is aggregated with its imported counterpart using a CES functional form; all internationally tradable goods and services follow this assumption. For the electricity-generating industries, the production structure is different from that in other sectors (see Figure 2). The main difference is that the electricity production structure allows direct substitution between capital and fuel. This is necessary to portray the substitution potential between fossil fuel-based carbon-intensive electricity generation technologies with carbon free but capital intensive renewable energy technologies.

Figure 2: Nesting structure for electricity generation sectors



Following Timilsina and Landis (2014), we used a nested multinomial logit choice model to distribute investment to various types of electricity generation technologies. The multinomial logit model assumes that investment in generation capacity—unlike the more aggregated investment in the other production sectors—implicitly entails additional technology and site specific investments needed to provide the generated power to consumers (see Figure 3). The nature of those additional costs determines what technologies are most profitable to invest in and how costly the overall investment is. We also account for the investments needed for transmission facilities, which is important as wind power resources are often located in remote areas away from load centers and access to national transmission grids needs to be built. We assume that at each point in time a certain number of building sites for power plants become available. In order to invest into electricity generation capacity of a technology at a specific site, a technology specific investment into transmission capacity and an additional site specific investment has to be made. The site specific investment need is calibrated with levelized cost of electricity generation technologies from various sources.

Figure 3: The nested multinomial logit choice model for investment decision in the electricity sector



Our study follows a standard approach used in the literature to model household behavior. Under the perfect foresight framework, a representative household maximizes a Ramsey type welfare function, where the household maximizes the present value of its consumptions over time. The overall household consumption is a nested CES aggregate of leisure and consumption of aggregated final goods and services. The final goods and services are a CES aggregate of energy and non-energy goods and services. The aggregated energy good is, like in the production sector, a CES combination of electricity and fossil fuels (Figure 4).

The model assumes that labor is perfectly mobile between sectors, capital is sector specific, and land can be transformed between its sector specific states according to a nested constant elasticity of transformation CET function as in Figure 5. While land is not an input to production for many sectors, it is an inpub, especially in agricultural and mining sectors.

Figure 4: Representation of household behavior

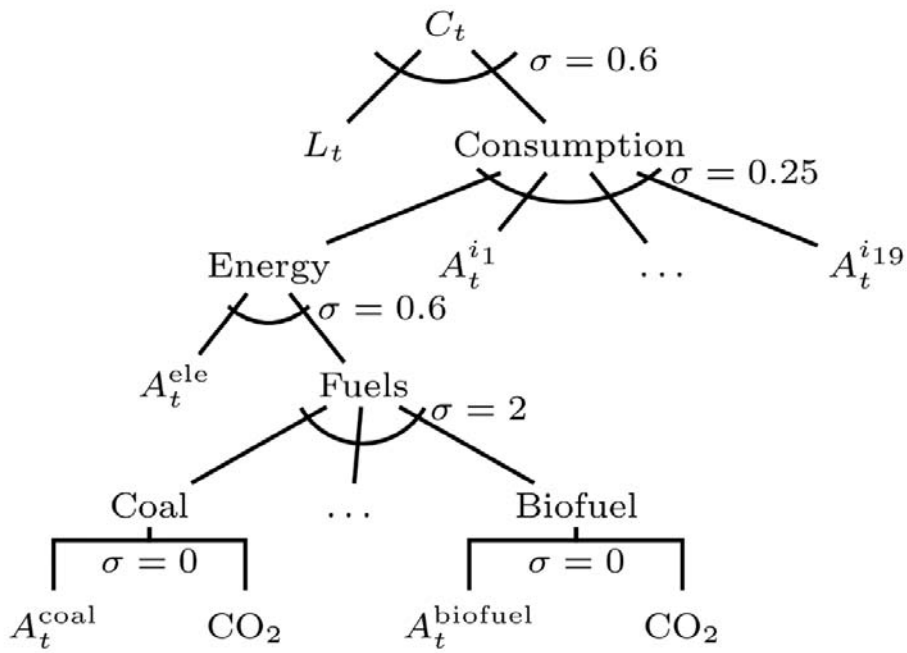
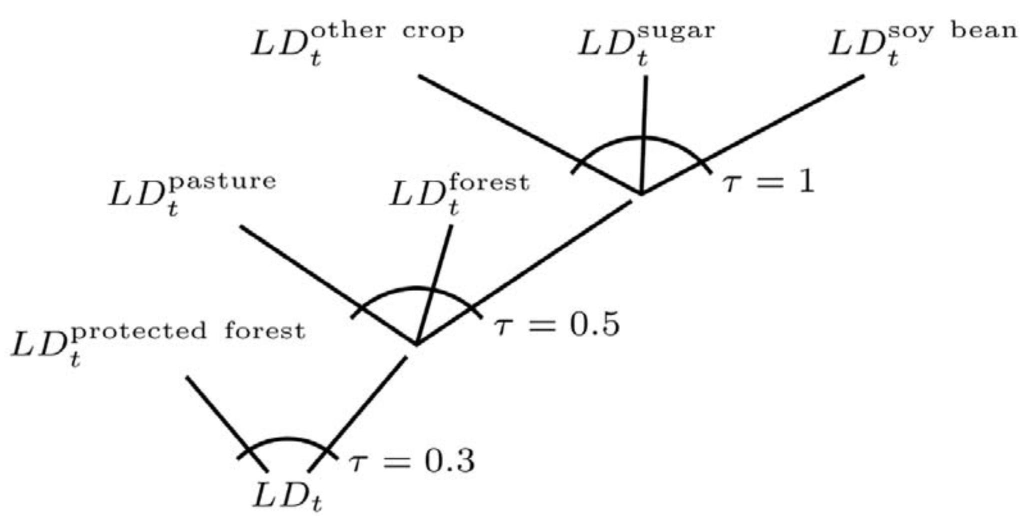


Figure 5. CET nesting structure for allocation of land to different uses



Note: Demand for protected forest is assumed to be exogenous.

We considered two types of policy instruments to promote renewable energy: a production subsidy, and a renewable energy portfolio standard. While the subsidy is designed to pass the financial burden to all consumers indirectly, through increased taxation in other goods and services to finance the subsidy, the mandate passes the burden to electricity consumers directly through increased electricity prices.

3. Results and Discussion

As of year 2012, Brazil has installed 121,000 MW of electricity generation capacity, of which wind power accounts for around 1%, nuclear power accounts for 2%, thermal power (coal, gas and oil) accounts for 27% and hydropower accounts for the remaining 70% (EPE, 2013). In 2012, total electricity generation in Brazil was 552.5 TWh, of which wind power plants generated 5.3TWh or less than 1% (IEA, 2014a). In this study we are analyzing policies to increase the share of wind power in total generation to 10% by 2030. In fact, Brazilian government's Decennial Energy Plan (PDE 2021) aims to increase the share of wind power in the total electricity production to 9% by 2021 (GWEC, 2014). We stayed a bit conservative, considering the growth of total electricity demand in the country and assumed that the country would achieve the wind power target by 2030.

If a production subsidy from the government is used to achieve the target, the subsidy would need to be equivalent to 65% of electricity supply cost of wind power to achieve the 10% target. Since the government needs additional revenue to finance the wind power subsidy, we assumed that it would increase the value added tax (VAT). However, the increase in VAT would be very small. When a consumption mandate is implemented to promote wind power, the electric utility is allowed to increase its tariff so that it can pass the incremental system cost caused by wind power addition to consumers. Meeting the 10% wind power target by 2030 through the consumption mandate would increase the average electricity bill by 6.2%.[4]

The model simulation results under subsidy and mandate scenarios are presented below. We first present impacts of the policies on electricity system followed by the impacts on the national economy and GHG emissions.

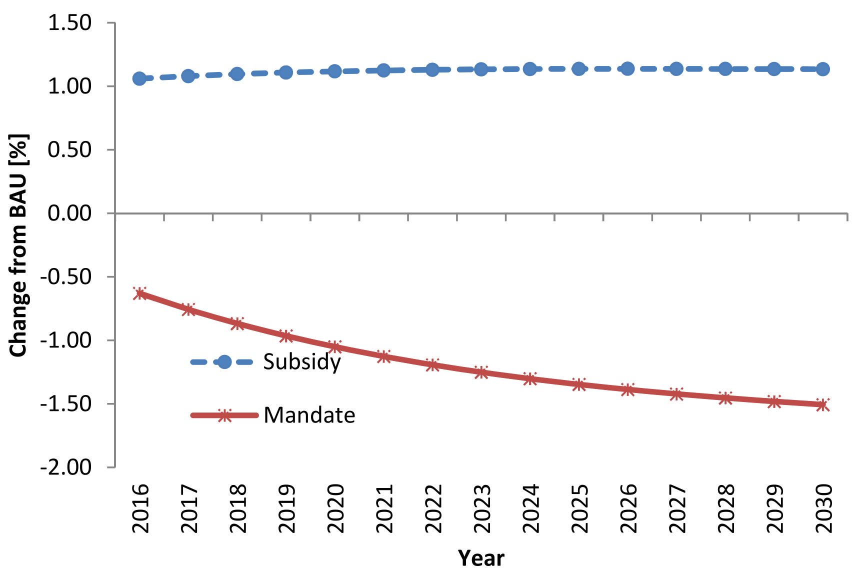
[4] The subsidy policy averages the premium for wind power into a relatively large base of total consumptions of goods and services in the country whereas the mandate policy averages the premium into relatively smaller base of consumption of electricity only.

3.1 Impacts on the electricity sector

The impacts of the wind power subsidy and mandate on total electricity generation in Brazil are presented in Figure 6. In the case of the subsidy, the policy basically increases the amount of electricity available at any price (an outward shift of the electricity supply curve). This causes the aggregate price of electricity to drop, thereby increasing electricity demand.[5] To meet the increased demand more electricity would be generated. As can be seen from Figure 6, the subsidy to cause 10% penetration of wind power in Brazilian electricity system would lead to a 1% increase in total electricity generation.

In the case of the mandate, the increased electricity cost, thereby increased electricity price due to expanded wind power is directly transferred to households. The increase in electricity price would decrease its demand. Figure 6 indicates that the expansion of wind power to meet 10% of the total electricity generation, would decrease total electricity demand by 1.5%.

Figure 6: Impacts of wind power subsidy and mandate on total electricity generation



Pushing wind power into the electricity generation mix through policy instruments means replacing electricity that would have been generated from other technologies, such as

[5] There would be real income drop due to increased VAT to finance the subsidy, however this drop is distributed across the savings, and consumption of various goods and services. It could reduce the demand for electricity as well, but the effect of net drop in relative price of electricity is more than offsetting the demand loss due to increased VAT.

hydro, nuclear, coal, oil etc. Table 2 shows how the 10% penetration of wind power replaces other electricity generation from other technologies. The wind replaces 6.6% and 7.2% hydropower respectively under subsidy and mandate policy. The replacement rates are different between these two policy cases because the subsidy policy increases the total electricity generation, whereas the mandate policy decreases the total electricity generation. Similarly, the corresponding replacements of natural gas based generations are 1.8% and 1.4%.

Table 2: Impacts of 10% penetration of wind power on electricity generation mix in 2030

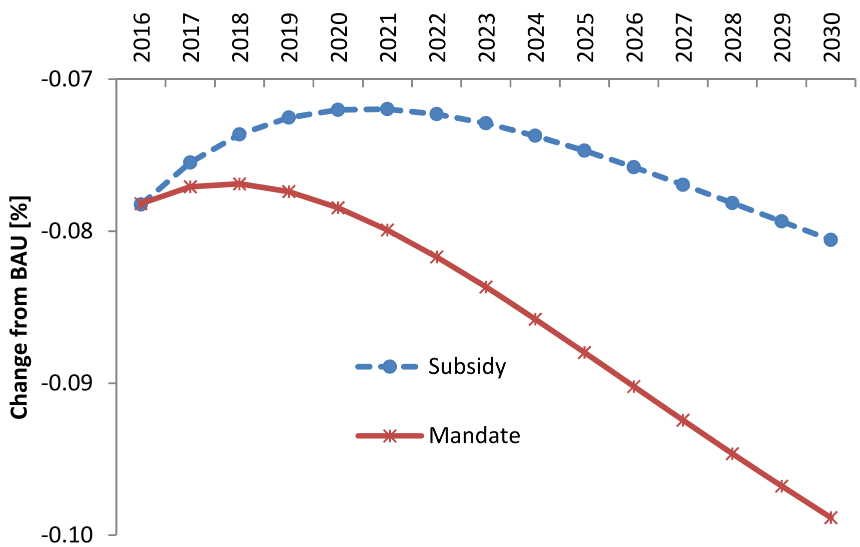
Generation type	Generation mix (% share of technologies on total generation)		
	Baseline	Subsidy Case	Mandate Case
Hydro	80.0	73.4	72.8
Coal	1.8	1.5	1.5
Natural gas	6.9	5.2	5.5
Oil	4.2	3.3	3.4
Wind	0.2	10.0	10.0
Biomass	4.1	4.1	4.2
Nuclear	2.8	2.5	2.5

3.2 Impacts on economic welfare

Figure 7 illustrates the welfare impacts of meeting wind power targets in Brazil. Higher penetration of wind power causes a loss in economic welfare no matter whether a subsidy or mandate is used as policy instrument. This is because to reach the high share of wind power, it is necessary to realize wind projects that would not be economically viable without policy supports, and the policy supports are not cost free. The adverse welfare impacts of wind power expansion increases along with the share of wind power in the total electricity generation over time.

Figure 7 illustrates that the welfare loss would higher in the case of consumption mandate. This is because the mandate directly impacts consumers through a notably increase in the electricity price. Consumers reduce their electricity consumption due to the price increase caused by higher penetration of wind power into the national electricity supply system under the mandate. In the case of production subsidy, in contrast, the adverse welfare impacts are smaller compared to that in the case of consumption mandate because the cost of the policy is covered by very small increases in the prices of goods and services in general through the increase in VAT, rather than through a more significant increase in the price of one commodity (electricity).[6]

Figure 7: Impacts of expansion of wind power on economic welfare (% change from the baseline)



3.3 Impacts on GDP and sectoral value added

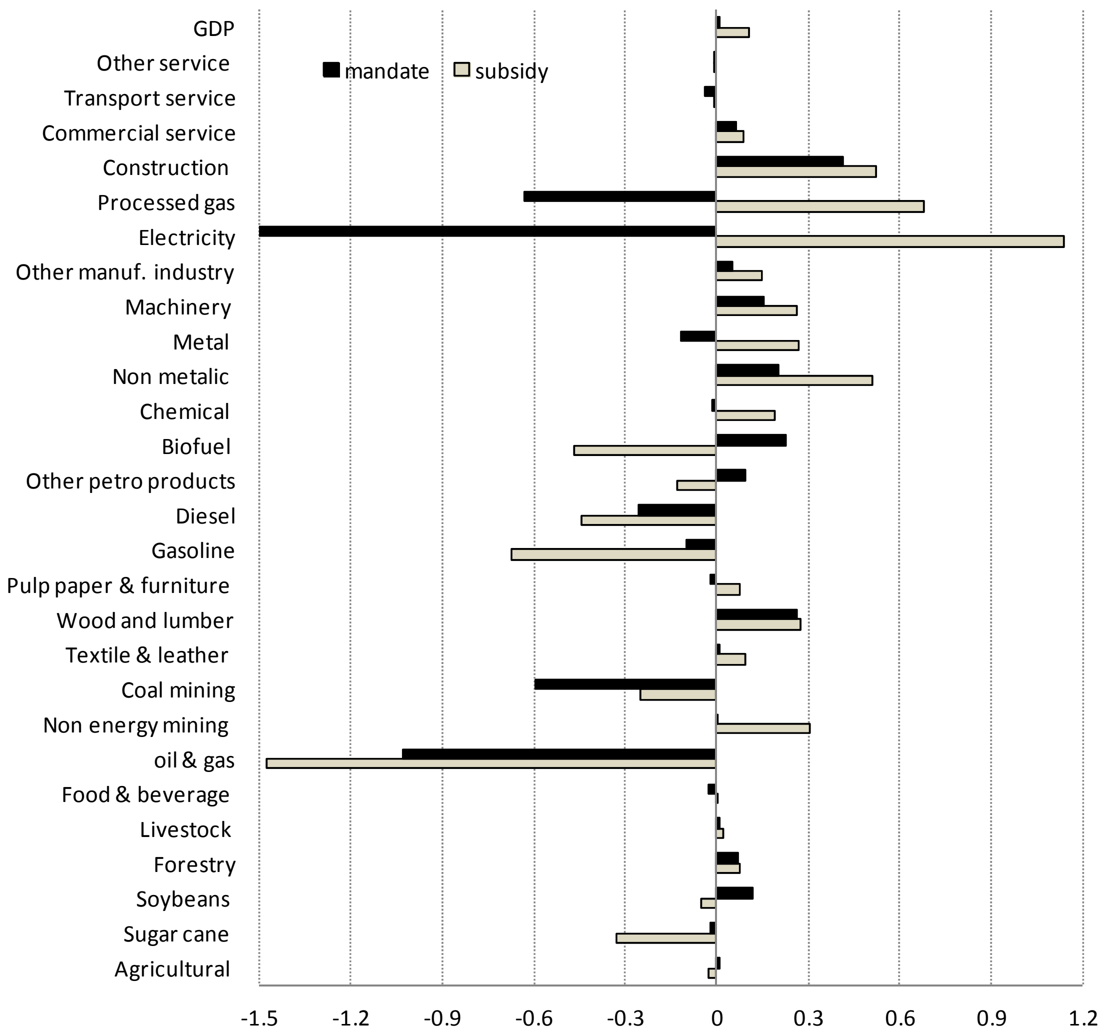
Figure 8 presents impacts of 10% wind penetration to sectoral value added and GDP.[7] The results vary significantly across the sectors. Moreover the sectoral impacts are much different between subsidy and mandate cases. A mandate to promote wind power expansion would reduce sectoral value added of energy sectors, most notably electricity and oil and gas. This is because the mandate makes electricity expensive thereby reducing its demand. In response electricity generation to meet the demand also drops. Fuel demand for electricity also decreases thereby lowering their production and thus value added. Although a production subsidy to wind power does not raise electricity price, it would still have regressive impacts in certain sectors. This is because, the wind power production subsidy is financed through an increase in value added tax in all other sectors. The value added tax would have negative implications in outputs of sectors which produce relatively higher value added per unit of

[6] This finding recalls the general point from public finance theory that for a given level of total expenditure, deadweight loss is higher if the expenditure is financed with significant increases in taxes on a small number of goods versus smaller per-unit taxes on a larger number of goods (taking into account also the relative elasticities of demand of the various goods). See Parry (2003) for a discussion of this in the context of greenhouse gas mitigation instruments.

[7] Like in any CGE study, we have presented the impacts as percentage change from the baseline. However, if any reader is interested to know the actual dollar value of the impacts, they are available upon request to authors.

output (i.e., capital and labor intensive sectors). As expected, sectors which supply goods and services to wind power industry would experience increased value added under both policy scenarios. Examples are construction, machinery industries, commercial services, wood and lumber, forestry.

Figure 8: Change of sectoral activity and GDP relative to BAU in the year 2030 (%)

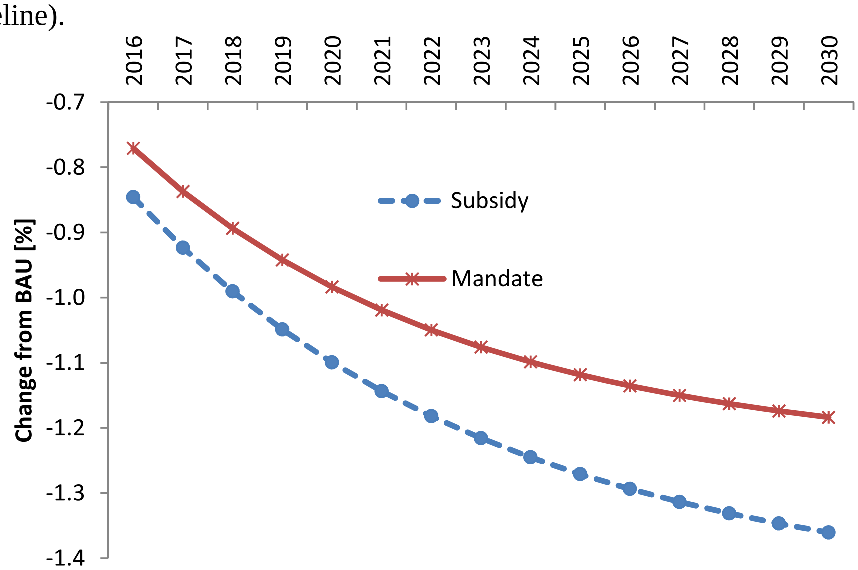


While aggregate consumption in the Brazilian economy goes down due to wind power policy, investment goes up. And policy induced changes in GDP, the sum of values of consumption, investment, government spending, and net exports, turn out to be driven mainly by changes in value of consumption and investment. On the one hand, the increase in the value of investments is bigger than the decrease in the value of consumption, leading to an increase in GDP for both policies in by 2030. On the other hand, we argued above that both the reduction in consumption is smaller and the increase in investment bigger under a subsidy than under a mandate and thus the increase in GDP turns out to be bigger for the subsidy than for the mandate (see Figure 8).

3.4 Impacts on GHG emissions

A 10% penetration of wind power in Brazil's electricity generation mix would reduce 1.2% and 1.4% of total energy sector GHG emissions in the country in 2030 if the penetration was caused by mandate and subsidy policies, respectively. The mandate causes lower mitigation of GHG compared to the subsidy, as the mandate causes more replacement of hydro and less replacement of natural gas based electricity generation compared to the subsidy policy.

Figure 9: Economy wide CO_2 emissions reduction (percentage deviation from the baseline).



4. Conclusions

Fiscal policies (subsidies in particular) and regulatory policies (particularly mandates) are the main instruments introduced in both developing and developed countries to encourage a large-scale deployment of renewable energy, such as wind power. Which policy instrument would be attractive from the broader economic perspective, however, has not been clearly answered yet. This study aims to address this question in the case of wind power in the Brazilian electricity mix.

The study shows that expansion of wind power would reduce economic welfare no matter whether a subsidy or a mandate is used to drive the expansion. This is because the cost of wind power generation is still expensive compared to most traditional sources of electricity generation in Brazil. However, we found that in Brazil, a subsidy causes lower welfare loss compared to the mandate to achieve the same level of wind power penetration. This is because the subsidy did not raise electricity prices but financed wind expansion through very small increases in consumer prices throughout the economy, whereas the mandate did lead to a considerable increase in the price of electricity. Since the subsidy causes less welfare loss compared to the mandate and it also causes higher reduction of GHG emissions than a mandate does, the study concludes that subsidy policy is superior to mandate for Brazil's efforts in promoting renewable energy. Although this finding is consistent with general principles in public finance and with findings in other studies of renewable energy policy (e.g., McCullough et al. 2011; Timilsina and Landis, 2014), it should not be generalized because the results from CGE models are country specific: particular parameters, such as those reflecting electricity supply mix, and elasticity of substitution, can be significantly different across countries.

The sectoral results are different not only between the two policy instruments but across the sectors for a given policy instrument. Sectoral value added of fossil fuel industries decreased under both policy instruments whereas the value added of industries providing goods and services to wind power industry increased. The decrease in value added of fossil fuel industries is higher under subsidies compared to those with the mandate due to tax imposed on fossil fuels to generate a fund to finance the subsidy.

The analysis is carried out based on present (2012) data on electricity supply costs of various technologies to generate electricity. The capital costs of renewable energy technologies, including wind power technologies, have declined over time in the past. However, it is difficult to predict how far the cost reduction will go and when wind power technologies would be economically competitive with traditional sources of electricity generation. Even if they are competitive in terms of the levelized costs of electricity generation, utility planners still discount wind and solar because these are intermittent resources to generate electricity and do not provide a firm power or capacity guarantee, which is essential to have a reliable electricity supply system.

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