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Economics of Transiting to Renewable Energy in Morocco

A General Equilibrium Analysis

Govinda R. Timilsina
Florian Landis

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Abstract

Morocco has set an ambitious target of supplying 42 percent of electricity through renewable sources, 14 percent each through hydro, wind, and solar, by 2020. To analyze the economic and environmental implications of implementing this target, this study uses a dynamic computable general equilibrium model with foresight that includes explicit representation of various electricity generation technologies. Two types of policy instruments, a production subsidy financed through fossil fuel taxation and a renewable energy mandate financed through increased electricity prices, have been considered to attract investment in renewable energy. The study shows that meeting the renewable target would achieve up to 15 percent reduction of national greenhouse gas emissions in 2020 compared with a situation in the absence of the target, or the baseline. However, meeting the target would decrease household consumption of goods and services, thereby worsening household welfare. The study also shows that the renewable production subsidy financed through fossil fuel taxation is superior to the mandate policy to meet the renewable energy target in Morocco, as the former would cause a lower loss in economic welfare and a larger reduction of greenhouse gas emissions than the latter.

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Economics of Transiting to Renewable Energy in Morocco: A General Equilibrium Analysis

Govinda R. Timilsina§ and Florian Landis§

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§ Govinda R. Timilsina is Senior Economist at World Bank, Washington, DC (gtimilsina@worldbank.org). Florian Landis was a research assistant to the World Bank while working on this study, currently he is affiliated with ZEW Germany (landis@zew.de).

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1. Introduction

Morocco, a country situated in the northwestern corner of the African continent, is well known for its renewable energy potential, particularly solar energy. Despite having enormous potential for solar energy, Morocco at present depends almost entirely (97%) on imports to meet its energy demand (IEA, 2012). All fossil energy resources, coal, oil and natural gas, are imported, thereby making Morocco the largest energy importer in North Africa. Its energy demand is rapidly growing; for example, Morocco needs to double its power generation capacity by 2020 to meet the growing demand. To secure energy supply in a sustainable and environmentally friendly manner, Morocco has been exploring ways to harness hydro, solar and wind resources for power generation. The government has planned to meet 42% of its total power generation by commissioning an additional 6 GW of total generating capacity from solar, wind and hydro power plants by 2020 (Falconer and Frisari, 2012). To realize this plan the government launched an ambitious solar power plan in 2009 aiming to install 2 GW of solar power-–generating capacity by 2020. The development of one of the solar power complexes, with total planned capacity of about 500 MW, has been started at Ouarzazate valley in the south-central region of Morocco with the total estimated cost of US$1.3 billion. This concentrated solar power (CSP) complex will be completed by 2015.

How does the development of renewable energy, which is often expensive compared to conventional technologies to generate electricity, affect economic development in Morocco? To answer this question all direct and indirect impacts throughout the economy of the country due to the expansion of solar power should be evaluated. Computable general equilibrium (CGE) models are the most common tools used to assess the economic efficiencies of policy instruments or development activities. This is because a CGE model can capture economy-wide impacts of a policy instrument, or a development activity.

Since renewable energy technologies are relatively expensive compared to conventional technologies to generate electricity, a private investor would not be interested to invest in them unless sufficient expected returns on investment are guaranteed by some other means. The current costs of renewable energy technologies require that the Moroccan government needs to arrange for additional financing to renewable energy technologies to make them attractive to investors. For example, in the case of the Ouarzazate CSP project, the Government of Morocco will provide financial contribution to the operators, while obtaining grants and concessional loans from bilateral and multi-lateral development agencies, such as the African Development Bank and the World Bank.[1]

Often governments use two types of policy instruments for supporting renewable energy investment: (i) a production subsidy, and (ii) a regulatory mandate. Under the first instrument governments finance the subsidies; however, the costs would ultimately, though indirectly, be passed on to consumers as governments would have to increase taxes to finance the subsidies. In this study, this occurs through increased taxes on fossil fuels to finance the subsidy. Under the second case, the extra cost of exploiting renewable power sources is directly passed to consumers by increasing the price of electricity. Since electricity price hikes are often sensitive politically in most developing countries, the first approach would be more convenient to the governments. An interesting question is, "which of these two policy instruments would be economically efficient?" This study investigates this question by modeling the two policy instruments within a CGE model that focuses on the investment choices made in the electricity sector.

One of the main obstacles to apply a 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 separate economic activities or sectors in input-output tables or social accounting matrices, the main database for a CGE modeling exercise. Most CGE models represent electricity generation technologies as a single technology thereby ignoring the heterogeneity among various technologies to generate electricity[2]. Moreover, the literature diverges on technique of representing renewable energy policy instruments in a CGE framework, particularly modeling renewable energy mandates. Many existing 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

[1] The 160 MW Ouarzazate Phase I project will yield a net financial deficit over the entire 25-year operational period despite grants and concessional loans it obtained. This deficit stems from the difference between the price of solar power that the Moroccan Agency for Solar Energy (MASEN), a government entity, agreed with the private developers and the price that the electric grid pays to MASEN (AfDB, 2012).

[2] 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).

et al., 2010; Sorda and Banse, 2011; Timilsina et al., 2012a). Most of these studies use this approach because it is straightforward to incorporate in a CGE model. However, the general equilibrium effects derived through this type of policy might be different from the actual effects of a mandate because a mandate, in reality, affects the behavior of consumers, whereas a consumer's behavior would be neutral to a subsidy financed by the government.[3]

In this study we developed a CGE model to analyze both the regulatory and the fiscal policy in order to assess the economy wide costs of renewable energy policy instruments. According to the policy targeting literature (see e.g. Bhagwati, 1969), for the achievement of a minimum market share or output of a good or input factor, a subsidy on that good/factor is the most efficient instrument. Other more indirect policies, such as taxation of a substitute—an example in case of solar power would be a carbon tax on fossil fuels—are more distorting and thus reach the policy objective only at higher costs. However, it is not a priori clear if a subsidy is the optimal policy to promote renewable energy technologies. Depending on how the government collects revenue to compensate for the cost of the subsidy, the subsidy can have relevant distorting effects. On the other hand, a mandate may not cause the government additional costs, but it will raise the average cost of electricity and thus reduce welfare by making consumers shift their consumption away from electricity. In this paper we compare these two policy instruments in terms of their economic efficiency.

In addition to setting up a systematic modeling framework for ex-ante evaluation of renewable energy development programs, the paper develops an innovative methodology to compare policy instruments. Notably, we use a perfect foresight intertemporal CGE model. This represents a considerable advance over the recursive dynamic models often used for energy policy analysis.

The remainder of the paper is structured as follows. In section 2 presents a brief description of the CGE model and data used. Section 3 outlines the scenarios simulated. The results of our simulations and the sensitivity analysis are presented in Section 4. Finally, Section 5 concludes the paper.

[3] A biofuel mandate, for example, would increase price of the blend. Consumers must be expected to buy less of the blend as a consequence, which will affect the welfare they draw from consumption. A subsidy on the other hand (e.g. on biofuel) will not affect the price of the blend negatively, thus leaving demand at business as usual levels. However, consumers invariably will have to bear some of the cost of the subsidy through increases in taxation or through reductions in government services (Timilsina et al. 2011).

2. Model and Data

In this section we present the CGE model developed for the study and the necessary data. Instead of presenting the detailed description of the CGE model, we focus on the aspects where the paper attempts to make a methodological contribution, such as representing renewable energy technologies in the model, incorporating the subsidy and mandate policies.

Following common practice in CGE modeling, we aggregate individual households to a single representative household. This representative consumer is assumed to live infinitely and has perfect foresight, which is a standard assumption in a perfect foresight dynamic CGE models (see Goulder 1996). The representative agent is endowed with an initial capital stock K_0, and streams of effective hours of labor L_t, which measured in efficiency units, grow at the same exogenous rate.

Factors are used by 17 sectors to produce a range of 19 different goods and services (Table 1). The set of goods and services in the economy can be partitioned into three subsets: fuels (coal, gasoline, diesel, LPG, other petroleum products, natural gas), electricity and other goods and services.

Table 1: Sectors and Commodities in the Moroccan CGE model

Production Sectors		Commodities	
j1	Agriculture	i1	Agricultural output
j2	Forestry	i2	Forest products
		i3	Petroleum
		f1	Coal
		f2	Natural gas
j3	Other Mining	i4	Other mining products
j4	Food and Tobacco	i5	Food and tobacco
j5	Textile and Leather	i6	Textiles and leather
j6	Chemical industry	i7	Chemicals
j7	Mechanical engineering, metallurgical and electrical industry	i8	Mechanical and electric products, processed metals
j8	Other manufacturing	i9	Other manufacturing
j9	Petroleum Refinery	**f3**	Gasoline
		f4	Diesel
		f5	Butane and propane
		f6	Other petroleum products
ele	Electricity generation	**ele**	Electricity
j10	Construction and public work	i10	Construction and public work
j11	Transport	i11	Transport services
j12	Service sector	i12	Other Services
j13	General government	i13	Public service and social security

All goods but electricity are produced from intermediate goods, labor, capital, and energy according to the nesting structure depicted in Figure 1. The nested structure for electricity production is presented in Figures 3 and 4. Goods and services can either be exported or sold on the domestic market. Shifting sales between the two markets is possible according to a constant elasticity of transformation CET function with elasticity of transformation $\tau = 2$ ($\tau = 0.5$ in the case of electricity). On the domestic market, the domestically produced good is aggregated with its imported version to build an Armington aggregate (Figure 2).

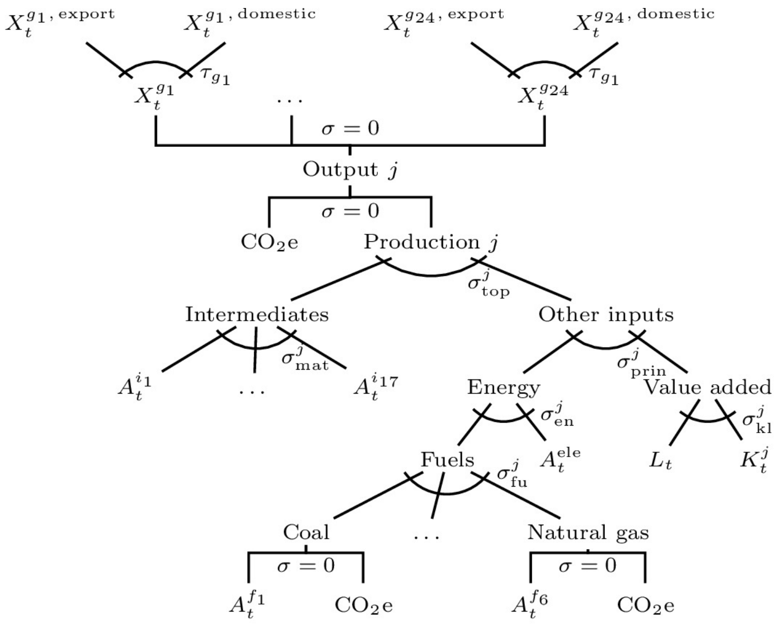


Figure 1: Nesting structure of non-electricity production sectors

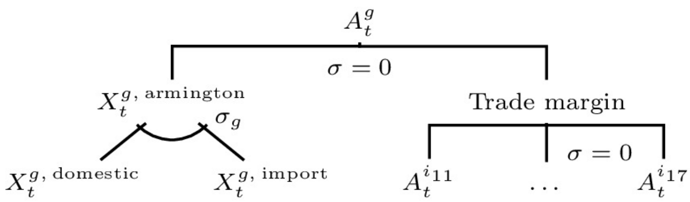


Figure 2: Armington aggregates of tradable goods

The electricity good itself is produced using four different generation technologies $e \in$ {thermal, solar, wind, hydro} each of which is modeled as a nested CES production function according to Figure 3.

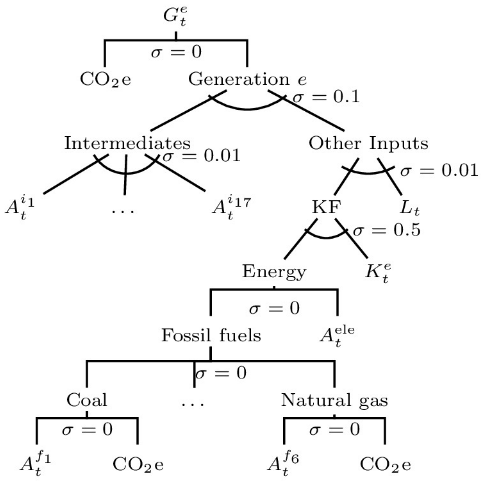


Figure 3: Nesting structure for electricity generation sectors

The sum of electricity generation levels G^e sums up to the total produced electricity good ($X_t^{ele} = \sum_e G_t^e$, where e refers to type of generation, hydro, solar, wind and thermal).

Capital stocks for production and capacities for power generation are endogenously modeled as depreciating stocks that need to be invested into according to

$$K_t^j = (1 - \delta^j)K_{t-1}^j + I_{t-1}^j, \tag{1}$$

$$K_t^e = (1 - \delta^e)K_{t-1}^e + I_{t-1}^e, \tag{2}$$

where I_t^j and I_t^e are net investment into capital of production sectors *j* or power generation technologies *e*, respectively. The annual depreciation rate for non-electricity capital is assumed to be 7 percent. For the different power generation technologies, we infer discount rates from expected lifespans of power plants according to the OECD/Nuclear Energy Agency (2010). We assumed that after the lifespan of a power plant, its scrap value is 10% of initial construction cost and we apply the declining-balance method to infer the depreciation rate.[4] Net investments in production specific capital K_t^j and overall power generation investment I_t^G sum up to overall investment I_t,

$$I_t \geq \sum_{j=j1,\dots,j17} I_t^j + I_t^G, \tag{3}$$

while investment in generation capacity I_t^G is distributed among generation technologies according to a nested multinomial logit choice model. The multinomial logit model assumes that investments 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 Section 2.1 and Figure 4).

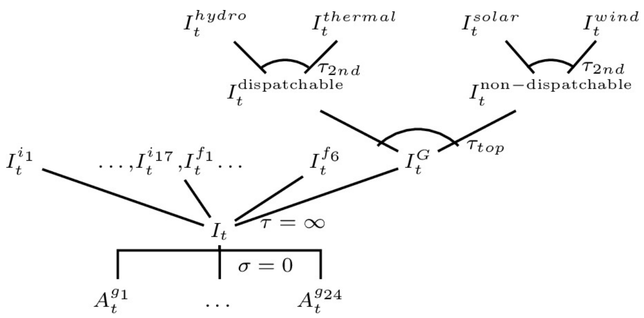


Figure 4: Nesting structure of investment. While aggregate investment is allocated freely between non-electricity capital, investment in power generation I_t^G is allocated between technologies with finite elasticity of transformation.

The utility that the representative agent draws from enjoying leisure time and consumption is denoted U_t. It is a nested CES aggregate of leisure L_t, final goods consumption A_t^i and energy, which itself is a nested aggregate of electricity A_t^{ele} and use of fossil fuels A_t^f (see Figure 5).

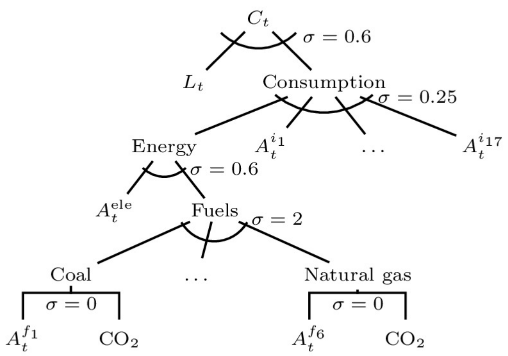


Figure 5: Aggregate consumption as a nested CES function of leisure, goods & services, and energy consumption.

The representative consumer maximizes discounted sum of inter-period utility, which is derived from consumption of goods/services and leisure. This welfare function is expressed as

$$W(C_t) = \sum_{t=0}^{T} \frac{1}{(1+\rho_t)^t} \left(\frac{C_t^{1-\varpi}}{1-\varpi}\right) \tag{4}$$

and the representative household is constrained by the budget constraint

$$\sum_i K_0^i P_0^{k,i} + \sum_e K_0^e P_0^{k,e} - \sum_i K_T^i P_T^{k,i} + \sum_e K_T^e P_T^{k,e} +$$

$$\sum_{t=0}^{T}(L_t w_t + P_t^{FX}\tau_{f,hh} - P_t(\tau_{f,gov} + C_t)) \geq 0 \quad (5)$$

We parameterize the welfare function with an elasticity of intertemporal substitution of $1/\omega = 0.5$ and the rate of pure time preference is $\rho_t = 0.0923$.

The government on the other hand has to pay for an exogenously given stream of government consumption G_t as well as for the potential subsidies in the policy scenarios. To this end, it raises taxes on labor and capital revenues and levies direct transfers $\tau_{hh,gov}$ on households. The budget constraint for year t is:

$$P_t^{FX}\left(\tau_{f,gov} - \tau_{gov,f}\right) + P_t\tau_{hh,gov} + indirect\ tax \geq P_t^G G_t + subsidy \quad (6)$$

Our implementation of the model takes the form of a mixed complementarity problem (MCP) which corresponds to the set of first order conditions arising from the maximization of welfare (4) under the constraints imposed by production possibilities according to the above outlined nested CES production functions.

2.1 Logit model of investment decisions

In our model, investment is distributed among generating technologies according to a nested multinomial logit choice model. Figure 4 provides a schematic of this nested investment decision. The multinomial logit model assumes that besides capacity investments, additional costs have to be incurred when investing in a certain type of capacity. Those additional costs and their random nature determine what technologies are most profitable to invest in and how costly the overall investment is.

In our multinomial logit framework for investment decisions which borrows from Clarke and Edmonds (1993) and is described in more detail in (Landis 2012), we distinguish between investments into generating capacity and investment that are needed to supply the electricity generated from this capacity. We assume that at each point in time a certain number of building sites for power plants become available. In order to invest into capacity of technology i at a specific site, a technology specific investment into transmission capacity a^i

and an additional site specific investment $-\mu\varepsilon^i$ has to be made. The random variables ε^i that determine the site specific investments are assumed to be independently standard Gumbel distributed. Thus, per unit of capacity investment of technology *i* and additional investments are $a^i - \mu\boldsymbol{\varepsilon^i}$ and total investment cost is: $P_I(1 + a^i - \mu\boldsymbol{\varepsilon^i})$. If the investment good is priced at P_I and if the purchasing price of capacity of technology *i* is P_K^i, the net cost of investing in capacity *i* of a specific technology therefore is:

$$v^i(P_I, P_K^i) = P_K^i - P_I(1 + a^i - \mu\varepsilon^i) \tag{7}$$

The energy supplier therefore decides to choose option *i* if

$v^i(P_I, P_K^i) = max_{j=1,..n} v^i(P_I, P_K^i)$, which happens with probability

$$\pi^i(P_I, P_K^i, .., P_K^n) = prob\left[v^i = max_{j=1,..n} v^j\right] = \frac{e^{(P_K^i/P_I - 1 - a^i)/\mu}}{\sum_j e^{(P_K^i/P_I - 1 - a^i)/\mu}} \tag{8}$$

The expected profits of having the choice of investing in either of these options can be shown as in Landis (2012):

$$v^i(P_I, P_K^i .. P_K^n) = \mu[log\left(\sum_{i=1..n} e^{(P_K^i/P_I} - 1 - a^i)/\mu\right) + \xi) \tag{9}$$

The expectation value of overall investment cost then must be

$$C(P_I, P_K^1, .., P_K^n) = \sum_{\boldsymbol{i}} P_K^i \, \pi^i(P_I, P_K^1, .., P_K^n) - V(P_I, P_K^1, .., P_K^n) \tag{10}$$

The per unit overall investment for capacity *i* is then,

$$q^i(P_I, P_K^1, .., P_K^n) = \frac{\pi^i(P_I, P_K^1, .., P_K^n)}{C(P_I, P_K^1, .., P_K^n)} = \frac{\pi^i(P_I, P_K^1, .., P_K^n)}{\sum_i P_K^i \pi^i(P_I, P_K^1, .., P_K^n) - V(P_I, P_K^1, .., P_K^n)} \tag{11}$$

At the top nesting level where overall electricity investment I_t^E (valued at $P_{Y,t}$) is distributed between dispatchable generation capacity (hydro and thermal) I_t^{dsp} (valued at $P_{K,t+1}{}^{dsp}$) and investment in non-dispatchable generation (solar and wind) I_t^{ndsp} (valued at $P_{I,t}{}^{ndsp}$), the multinomial logit choice model implies

$$I_t^{dsp} = I_t^E q^{dsp}\left(P_{Y,t}; P_{k,t+1}^{dsp}, P_{i.t}^{ndsp}\right) \; and \; I_t^{ndsp} = I_t^E q^{ndsp}\left(P_{Y,t}; P_{k,t+1}^{dsp}, P_{i.t}^{ndsp}\right) \tag{12}$$

where the overall investment level I_t^E is determined by the zero profit condition

$$V\left(P_{Y,t}; P_{k,t+1}^{dsp}, P_{i.t}^{ndsp}\right) \leq 0 \; with \; V\left(P_{Y,t}; P_{k,t+1}^{dsp}, P_{i.t}^{ndsp}\right) < 0 \; if \; I_t^E = 0 \tag{13}$$

At the second nesting level, dispatchable and non-dispatchable generation investment I_t^{dsp} and I_t^{ndsp} (valued at $P_{I,t}^{dsp}$ and $P_{I,t}^{ndsp}$) are distributed between investment into the respective generation technologies I_t^i (valued at $P_{K,t+1}^i$) according to

$$I_{i,t}^{dsp} = I_t^{dsp} q_i^{dsp} \left(P_{I.t}^{dsp}; P_{k,t+1}^{hydro}, P_{k.t+1}^{thermal}\right) \, and \, I_{i,t}^{ndsp} = I_t^{ndsp} q_i^{ndsp} \left(P_{I.t}^{ndsp}; P_{k,t+1}^{solar}, P_{k.t+1}^{wind}\right) \tag{14}$$

The levels of dispatchable and non-dispatchable investment I_t^{dsp} and I_t^{dsp} are determined by the zero profit conditions

$$V\left(P_{i,t}^{dsp}; P_{k,t+1}^{hydro}, P_{i.t+1}^{thermal}\right) \leq 0 \, and \, V\left(P_{i,t}^{ndsp}; P_{k,t+1}^{solar}, P_{i.t+1}^{wind}\right) \leq 0 \tag{15}$$

2.2 Policy: Mandate or Subsidy?

In the case of a subsidy, the government subsidizes renewable energy. In this case the electricity utilities or independent power producers (IPPs) will install renewable power plants and generate electricity as long as their post subsidy levelized costs, p^{ren} (including capital cost, operational and maintenance costs and their expected return on investment) does not exceed the market price of electricity (p^{ele})[4]

$$p_t^{ele} = \frac{p_t^{ren}}{1+s^{ren}} \tag{16}$$

Where s^{ren} is subsidy rate to renewables; it is expressed as a fraction of the total unit cost of electricity generation from renewable energy resources. For example, a 0.7 value of s for a renewable source implies that the levelized cost of that renewable energy should be reduced by 70 percent to make it competitive in the market. Therefore, the amount of subsidy is the difference between the pre-subsidy production costs of renewable power and the marginal cost of electricity of the grid where the renewable power is connected.

Government has to finance this subsidy. We assume that the government will increase taxes on fossil fuels to finance the subsidies to renewable energy. The government could finance the subsidy with other measures, such as diverting public expenditure from social sectors

[4] We assumed a competitive electricity market and this price reflects marginal cost of electricity generation. This price is different from retail electricity price which accounts for transmission and distribution charges as well as system' administration charges.

(health, education) or public services (defense, internal security). However, such diversion would tend to directly cut government's contributions to public welfare.

In the case of a renewable energy mandate, a fixed share of total electricity generation should come from renewable energy sources. This implies that the cost of electricity supply would increase as long as $p_t^{ele} < p_t^{ren}$.

Unlike in the case of a subsidy, however, this cost difference is borne directly by electricity consumers. Thus, compared to the case of a subsidy where electricity price does not change due to renewable power sources, electricity grids have to increase their price to recoup these costs. If we designate the cost at which the all electricity is supplied in the absence of renewable energy (i.e., baseline case) as $p_t^{nren}$and the cost of renewable energy as p_t^{ren}, the incremental electricity supply costs incurred due to the mandate is estimated from the following relationship:

$$X_t^{ele}.\left(p_t^{ele} - p_t^{nren}\right) = mandate.X_t^{ele}.(p_t^{ren} - p_t^{nren}) \tag{17}$$

Whenever the government income drops due to policy changes, it raises a tax on fossil fuels in order to keep real government purchases at BAU levels.

2.3. Data

The model is based on three types of data: 1) Moroccan input-output and national accounting data, which are summarized in a SAM; 2) the sectoral energy consumption and CO_2 emissions data; and 3) the elasticities of substitution and transformation. The SAM is for year 2007. The sectors and commodities used in the SAM presented in Table 1. In order to discuss policies that promote renewable power generation, the SAM disaggregates the electricity sector into the four power generation technologies hydro, thermal, wind, and solar. CO_2 emissions coefficients were calibrated using the fuel combustion data the SAM. Non-combustion emissions are assumed to be proportional to the output levels. Our assumptions about elasticities are based on existing studies by Paltsev et al. (2005) and Timilsina and Shrestha (2007) and are presented in the Appendix and in Figures 3, 4, and 5.

3. Renewable Energy Scenarios Simulated

As reflected in Figure 6, we simulated four scenarios (including baseline scenario):

(i) No deployment of renewable energy keeping it at the present level

(ii) Increased deployment of hydropower to share 14% of the total electricity generation by 2020, and

(iii) Increased deployment of hydro and wind power to share 28% (14% each) of the total electricity generation by 2020

(iv) Increased deployment of hydro, wind and solar power to share 42% (14% each) of the total electricity generation by 2020

Under the first scenario, Morocco will continue to use fossil fuel for power generation in the future. In 2010, Morocco's power supply mix consists of 6.8% hydro, 91.5% thermal and remaining 1.5% wind. The share is not expected to change much by 2020 unless policy or programs are launched to deploy renewable energy. The second scenario introduces a target for hydropower to share 14% of the total electricity generation, the third scenario assumes hydro and wind together contribute 28% (14% by each) share of total electricity generation in the country in 2020. Finally, the fourth scenario represents the actual target that Moroccan government aims to meet by 2020 where renewable energy contributes 42% of the total electricity generation (14% each from hydro, wind and solar). Figure 6 portrays these scenarios.

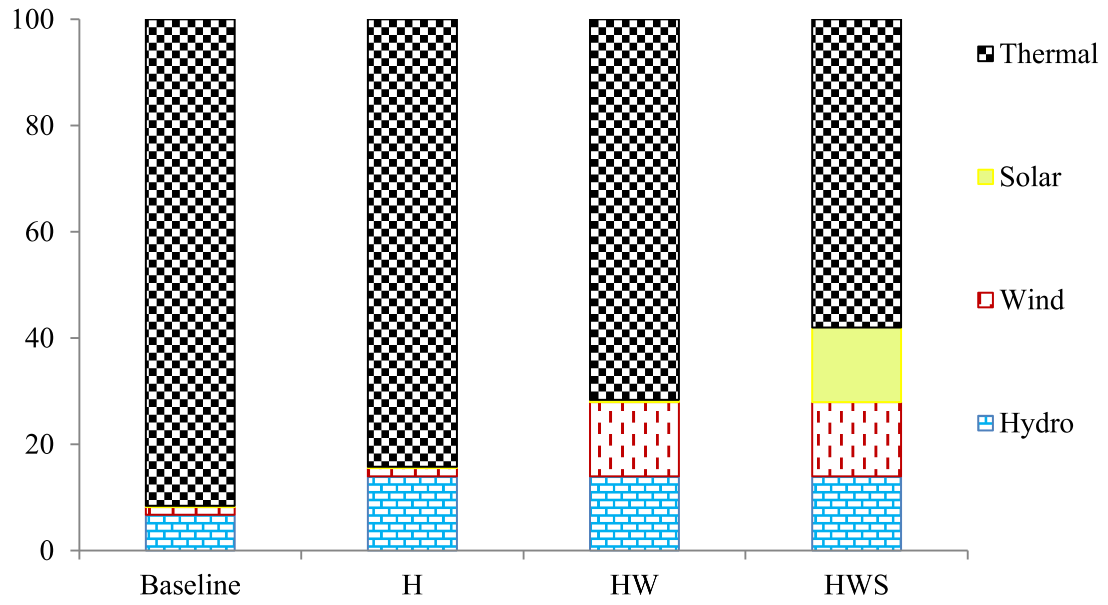
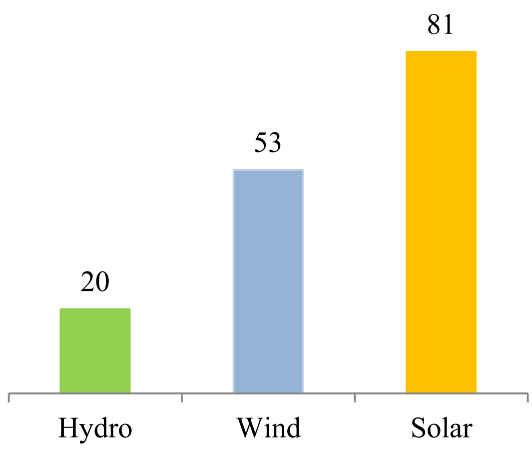
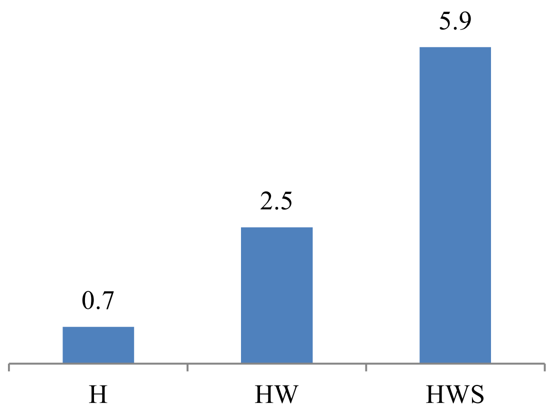


Figure 6: Renewable energy scenarios simulated in the study (% share of electricity generation in 2020)

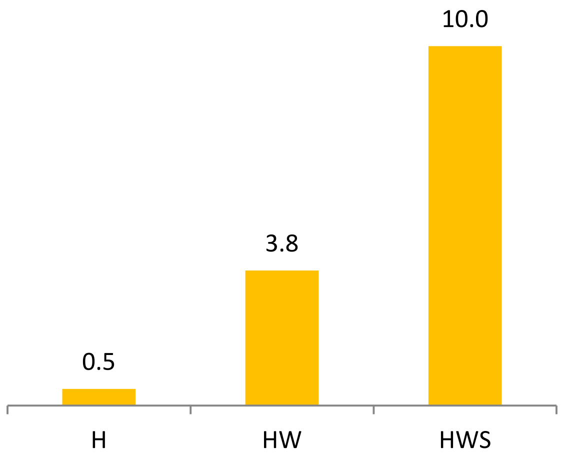
As discussed in Section 2.2 above, two policy instruments were considered to meet the renewables energy targets because the renewable energy resources are expensive compared to their fossil fuel counterparts and thus will not be deployed automatically in the absence of the incentives. The policy instruments are subsidies on renewable energy generation on the one and mandates for minimum power generation shares from renewable sources on the other hand. The subsidies are financed by government through additional taxes introduced to fossil fuels. The mandates are financed directly by consumers through increased electricity prices. Figures 7 (a) – 7 (c) present subsidy rates required to deploy the renewable energy technologies, additional fuel tax rates to finance the subsidies and increased electricity prices if the renewable energy targets were to be met through the mandates. Figure 7(a) implies that hydro, wind and solar power would require, respectively, 20%, 53% and 81% subsidies to make them economically attractive to their fossil fuel counterparts. An additional tax of 0.7% would be required to finance the subsidy to meet the hydro power target alone (Figure 7b), the tax rate increases to 6% to finance all subsidies required to meet the renewable energy targets (42% by 2020). If the renewable energy targets were to be met through mandates instead of subsidies, consumers will be required to pay 10% more for electricity as compared to a situation in the absence of these renewable energy targets (Figure 7c).



(a) Percentage subsidies required



(b) Percentage fuel tax to finance subsidies



(c) Percentage rise in electricity price under the mandate case

Figure 7: Subsidy rate for renewable energy, tax rates on fossil fuels to finance subsidies and electricity price rise under the mandate

4. Results

In this section we discuss the key results from the simulations of various scenarios defined above. Besides the impacts on the aggregated indicators (e.g., welfare and GDP), impacts at disaggregated (or sectoral and commodity) levels are also discussed for a number of variables (e.g., sectoral outputs, commodity prices, international trade of goods and services).

4.1 Impacts on economic welfare

In the CGE framework, the most representative indicator to assess impacts of a policy is the change in welfare or utility. Figure 8 presents change in utility due to the increased deployment of renewable energy in Morocco. Since renewable technologies are expensive to generate electricity compared to existing fossil fuel technologies, it would increase electricity price. In response, households consume lower electricity (discussed later) thereby sacrificing the welfare they derive from electricity as well as other goods. The study finds that an increased share of renewable energy by 42% (14% each through hydro, wind and solar), would cause 0.27% to 0.32% welfare loss, depending on whether the targets are met through subsidies or mandates.[5] Note that both policies reduces welfare, however, the welfare losses due to subsidy policy are smaller than those caused by the mandate policy.

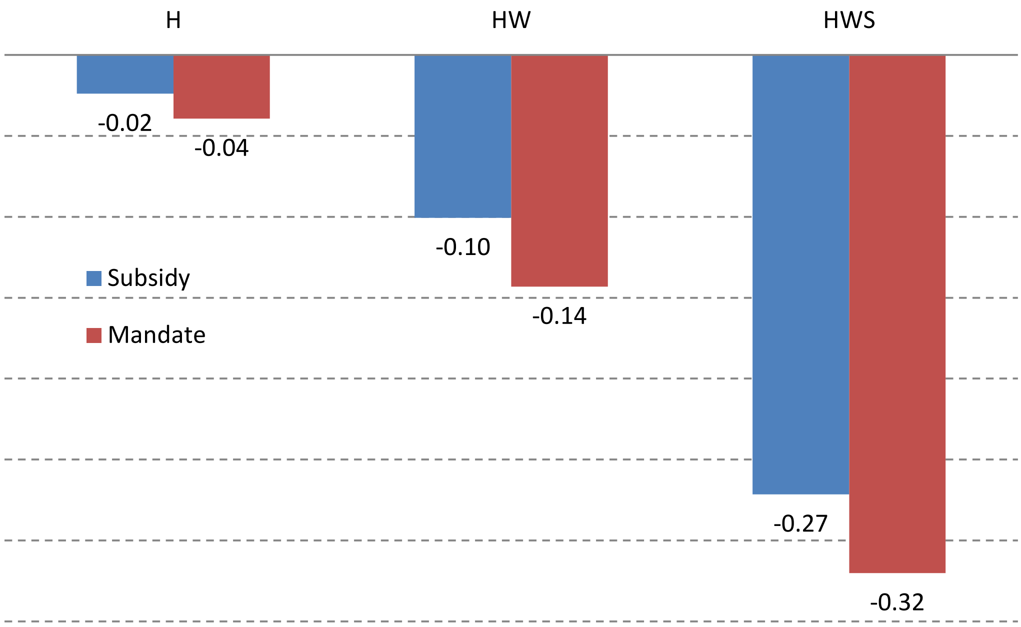


Figure 8: Percentage change in welfare in 2020 compared to baseline

Wind causes higher welfare losses than hydro, and solar causes higher welfare losses than wind for the meeting the same share (14%) irrespective of whether subsidies or mandates are used to meet the targets. This reflects the fact that wind is more expensive than hydro and solar is even more expensive to produce electricity. The higher electricity costs for solar and wind are caused by two factors: (i) their capital costs (investment), US$/kW, are higher and (ii) they are less available thereby requiring more capacity to produce the same amount of electricity.

4.2 Impacts on GDP

Another key macroeconomic variable often used to assess impacts of policy change in CGE framework is the change in GDP. Figure 9 presents impacts of increased penetration of renewable energy on GDP in year 2020. An increased penetration of renewable energy would increase GDP. Although the GDP impacts in terms of percentage look fairly small, they are not that small in absolute term. The 0.09% increase in GDP due to expanded hydropower

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5 Note that the percentage change in economic welfare look like small, but in terms of absolute term they corresponds millions of dollar.

under the mandate case represents US$75 million of GDP gain in 2020; similarly the 0.43% increase in GDP due to 42% share of renewable energy (14% each of hydro, wind and solar) under the subsidy case represents US$359 million of GDP gain in 2020. The positive GDP impacts could be attributed to two factors. First, Morocco avoids significant imports of fossil fuels for power generation and secondly the investment on renewable energy would spillover throughout the economy.

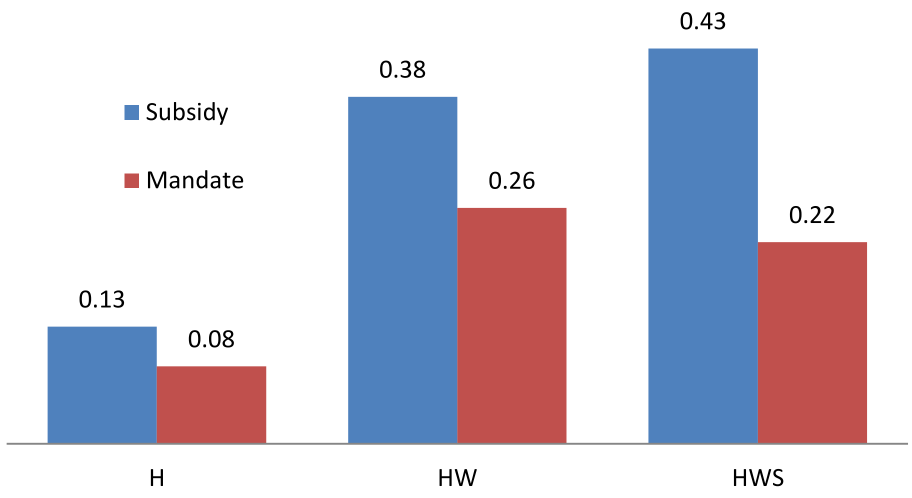

Figure 9: Percentage change in GDP in 2020 compared to baseline

The increased welfare and decreased GDP impacts might need further explanation to avoid potential confusion to readers. It is well recognized that GDP does not indicate any non-monetary transactions in the economy for example value of leisure, value of services that do not produce monetary transaction such as time spent for own cooking or cleaning own house. On the other hand, a measure of welfare used in the study accounts for leisure time at the value of wage rate. Thus, economists often use welfare indicators to assess or compare policy instruments. On the other hand, GDP is more popular and easy to understand indicator for policy makers. The study does not intend to discuss on the merits of these two indicators instead it discusses both results.

The subsidy policy causes more increase in GDP than the mandate policy. This is mainly due to the differing interaction of subsidy policy to the electricity sector output than that of the mandate policy (to be discussed in the next section). Under the mandate case, the electricity price rises, thereby reducing its demand and its total production. This would lead to reduction of sectoral value added of the electricity sector. In the case of subsidy, electricity price decreases due to higher penetration of renewable energy with no fuel costs, leading to higher sectoral value added.

The economic impacts of meeting the renewable energy targets are different across sectors. Table 2 presents the impacts of meeting renewable energy targets on gross outputs under different scenarios and under different policy instruments to meet the targets. This is because various sectors have differing interactions, directly and indirectly, with the renewable electricity generating industries. The sectoral impacts also are different for the same sector depending on what policy instrument (subsidy or mandate) is used to promote the renewable energy. With exception of few sectors, subsidy would cause larger impacts than mandate irrespective of the sign of the impacts. In some sectors (electricity, textile and leather) however, the impacts change sign between subsidy and mandate. In the power sector for example, a subsidy, in fact would reduce electricity price. This is because in the case of subsidy, government finances subsidies to renewable energy technologies by taxing fossil fuels therefore not directly passing the incremental capital costs of renewable energy to the consumers. This would cause electricity price to fall as renewable energy technologies do not have a fuel costs. In the case of subsidy, industries with higher petroleum intensity, such as chemicals, transport, oil refinery, mining experience relatively higher negative impacts on gross output. This is caused by fuel tax introduced to finance the renewable energy subsidies. On the other hand, the electricity sector suffers the most in the case of mandate because electricity prices goes up due to the mandate thereby causing electricity demand to fall. The reduction in demand causes a reduction in the supply to clear the electricity market.

Table 2: Impacts of renewable energy targets on sectoral outputs in 2020

(% change from the baseline)

Sector	Subsidy			Mandate		
	H	HW	HWS	H	HW	HWS
Agriculture	-0.2	-0.5	-1.0	-0.1	-0.2	-0.2
Forestry	-0.2	-0.2	-0.3	-0.1	0.0	0.2
Other mining	-0.8	-2.4	-4.9	-0.7	-1.6	-2.9
Food & tobacco	-0.2	-0.4	-0.8	-0.1	-0.2	-0.4
Textile & leather	1.2	3.8	6.7	-0.1	-0.9	-3.1
Chemicals	-0.9	-2.5	-5.1	-0.5	-0.8	-1.3
Machinery	0.1	0.4	0.3	0.1	0.4	0.4
Other manufacturing	0.2	0.4	0.1	0.1	0.3	0.1
Petroleum Refining	-1.0	-3.1	-6.3	-0.4	-0.9	-1.4
Electricity	1.0	2.6	4.3	-0.6	-2.7	-6.3

Construction	0.4	1.3	1.9	0.4	1.1	1.6
Transport	-0.1	-0.5	-1.1	-0.1	-0.2	-0.4
Service	0.0	0.1	-0.1	0.0	0.1	0.0

4.3 Impacts on Commodity Prices

In a CGE modeling exercise, the impacts on prices of a policy instrument (or any model shock) help to explain its impacts on other variables, such as household consumption, international trade and so on. Table 3 presents impacts on commodity prices of meeting renewable energy targets in Morocco in 2020. The alternative policy instruments considered (subsidies and mandates) have different impacts on commodity prices. While the subsidy policy decreases price of electricity, a mandate would raise it. This is because, under the case of subsidy, government bears the incremental electricity supply costs caused by increased share of renewable energy in the grid and the incremental costs do not directly pass on to consumers. This makes the cost of renewable energy in the market seem low, especially as there are no fuel costs. As the added supply of seemingly low-cost renewable energy replaces the most expensive conventional power plants, the equilibrium retail price for electricity decreases compared to the situation in the absence of renewable energy. In the case of mandate, in contrast, the incremental cost of electricity supply due to renewable energy is financed through increased price of electricity which is directly borne by electricity consumers.

Table 3: Impacts of Renewable Energy Targets on Commodity Prices in 2020
(% change from the baseline)

Sector	Subsidy			Mandate		
	H	HW	HWS	H	HW	HWS
Agriculture	0.05	0.06	-0.02	0.01	-0.06	-0.23
Forestry	0.06	0.02	-0.26	0.04	-0.04	-0.28
Other mining	0.04	0.13	0.29	0.02	0.07	0.12
Food & tobacco	0.03	0.04	-0.02	0.01	-0.04	-0.16
Textile & leather	-0.07	-0.24	-0.50	-0.03	-0.08	-0.13
Chemicals	0.00	-0.04	-0.13	-0.01	-0.07	-0.16
Machinery	-0.04	-0.14	-0.32	-0.02	-0.08	-0.16
Other manufacturing	-0.02	-0.04	-0.06	-0.01	-0.01	0.00
Electricity	-2.18	-5.26	-8.31	0.47	3.76	10.01
Construction	0.02	0.04	0.04	-0.01	-0.07	-0.18
Transport	0.20	0.66	1.39	-0.01	-0.09	-0.25
Service	0.00	-0.06	-0.26	-0.02	-0.12	-0.32
Gasoline	0.78	2.88	6.66	-0.12	-0.27	-0.40

Diesel	0.74	2.70	6.16	-0.04	-0.14	-0.26
LPG	0.70	2.56	5.86	0.03	0.08	0.12
Other petroleum	0.31	1.31	3.33	0.03	0.07	0.10

The impacts on prices of other commodities are mainly influenced by two factors: (i) the price of electricity and (ii) the price of fossil fuels which will be increased due to the fuel tax imposed to finance the renewable energy subsidy. Under the subsidy case, prices of all commodities except those of fossil fuel intensive sectors (e.g., construction, transportation, chemicals, mining, petroleum products) would decrease.

In the case of mandate, most prices are seen to be decreasing. This is because the renewable electricity mandate increases electricity prices. It causes demand for goods and services to fall (please see Table 4) thereby causing demand curves shifting left and thus resulting in lower prices.

4.4 Impacts on household consumption

The impacts on household consumption of goods and services are presented in Table 4. Household consumption of goods and services decreases due to increased share of renewable energy in the national electricity grid in Morocco no matter whether the policy instrument is a subsidy or a mandate. The exception is electricity consumption under the subsidy case which increases due to reduction in electricity prices. The decrease in household consumption of other goods and services under the subsidy case has to be attributed to the fuel tax imposed to petroleum products to finance the renewable subsidy. In the case of mandate, the same effect comes from the increased electricity price that causes reduction in household demand for goods and services. Note that the percentage reductions in household consumption of goods are smaller under the subsidy case as compared to that under mandate case. This is consistent with other results and also implies that the subsidy is a more efficient policy than the mandate.

Table 4: Impacts of Renewable Energy Targets on Household Consumption in 2020
(% change from the baseline)

Sector	Subsidy			Mandate		
	H	HW	HWS	H	HW	HWS
Agriculture	-0.09	-0.27	-0.54	-0.12	-0.33	-0.59
Forestry	-0.09	-0.25	-0.48	-0.13	-0.33	-0.58
Other mining	-0.09	-0.28	-0.62	-0.12	-0.36	-0.68

Food & tobacco	-0.09	-0.26	-0.54	-0.12	-0.33	-0.61
Textile & leather	-0.06	-0.19	-0.42	-0.11	-0.32	-0.62
Chemicals	-0.08	-0.24	-0.51	-0.11	-0.32	-0.61
Machinery	-0.07	-0.22	-0.47	-0.11	-0.32	-0.61
Other manufacturing	-0.07	-0.24	-0.53	-0.11	-0.34	-0.65
Electricity	1.15	2.98	5.11	-0.33	-2.08	-5.06
Construction	-0.08	-0.26	-0.56	-0.11	-0.32	-0.60
Transport	-0.09	-0.35	-0.87	-0.12	-0.42	-0.86
Service	-0.08	-0.23	-0.48	-0.11	-0.31	-0.57
Gasoline	-0.71	-2.25	-4.67	0.05	0.43	1.10
Diesel	-0.64	-1.92	-3.78	-0.10	-0.01	0.33
LPG	-0.55	-1.64	-3.22	-0.09	0.02	0.37

4.5 Impacts on exports and imports

The impacts on international trade of increased renewable energy penetration in the Moroccan electricity grid are presented in Table 5. The impacts are mixed across the tradable commodities. Both policies reduce imports of fossil fuels, particularly those used for power generation (e.g., coal, natural gas) as electricity generation from these fuels are substituted by solar power. For example, imports of coal decrease by 29% and 33% under the subsidy and mandate policies, respectively, when the share of renewable energy in total electricity generation increases to 42%. Similar trends can be seen for imports of natural gas. The tax on fossil fuels to finance the subsidy further reduces the imports of petroleum products under the subsidy case as compared to that in the mandate case.

The mandate policy causes a decrease in exports of most tradable goods. On the other hand, the subsidy policy is found to increase exports of some commodities, especially electricity and electricity intensive goods/services. The reason is that electricity price decreases under the subsidy case. Note however that government does not need to export the electricity under the decreased price because it is unlikely that a government subsidizes renewable electricity for the purpose of exporting it.

Table 5: Change of imports and exports relative to BAU in the year 2020 (%)

Commodity	Imports						Exports					
	Subsidy			Mandate			Subsidy			Mandate		
	H	HW	HWS	H	HW	HWS	H	HW	HWS	H	HW	HWS
Agriculture	0.2	0.5	0.7	0.1	0.0	-0.4	-0.47	-1.10	-1.83	-0.26	-0.31	-0.12
Forestry	0.4	0.7	0.3	0.2	0.3	-0.3	-0.48	-0.71	-0.65	-0.33	-0.11	0.52
Other Mining	-0.3	-0.8	-1.6	-0.3	-0.7	-1.2	-0.94	-2.78	-5.72	-0.75	-1.87	-3.28
Food and Tobacco	0.2	0.5	0.8	0.1	0.0	-0.3	-0.31	-0.80	-1.48	-0.20	-0.34	-0.42
Textile and Leather	0.7	2.2	3.9	-0.1	-0.6	-1.9	1.24	3.82	6.86	-0.09	-0.92	-3.14
Chemical	0.0	0.1	-0.1	-0.1	-0.2	-0.5	-0.91	-2.58	-5.24	-0.46	-0.85	-1.23
Machinery	0.3	0.8	1.1	0.2	0.7	0.9	0.06	0.24	-0.05	0.04	0.24	0.12
Other manufacturing	0.3	1.1	1.9	0.2	0.8	1.2	0.06	-0.04	-0.94	0.04	-0.01	-0.55
Electricity	-1.2	-2.8	-4.2	0.0	1.2	3.6	2.10	5.31	8.68	-0.80	-4.52	-10.69
Transport	0.2	0.5	1.0	-0.1	-0.2	-0.5	-0.66	-2.11	-4.54	-0.14	-0.21	-0.25
Services	0.1	0.2	0.1	0.0	0.0	-0.2	-0.11	-0.18	-0.35	-0.02	0.14	0.29
Coal	-5.9	-16.5	-28.5	-6.9	-19.3	-32.7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Crude oil	-1.0	-3.1	-6.3	-0.4	-0.9	-1.4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Natural gas	-6.4	-17.7	-30.7	-7.3	-20.3	-34.6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Gasoline	-0.4	-1.1	-2.0	-0.4	-1.0	-1.6	-1.38	-4.42	-9.06	-0.36	-0.76	-1.16
Diesel	-0.2	-0.5	-1.3	0.1	0.6	1.1	-1.41	-4.34	-8.60	-0.64	-1.55	-2.49
LPG	-0.3	-0.8	-1.9	0.2	0.8	1.5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

Note: Morocco does not produce fossil fuels (coal, crude oil and natural gas) and therefore does not export these commodities; hence corresponding cells in the table are designated "n.a."

4.6. Impacts on GHG Emissions

One of the key benefits of increased renewable energy penetration in the national electricity supply system in Morocco, where fossil fuel is the predominant source for electricity generation in the baseline, is that it helps reduce GHG emissions and other air pollutants. Figure10 presents percentage reduction of total GHG emissions from the baseline case due to the increased penetration of renewable energy in the national grid. In 2020, a 42% penetration of renewable energy in the national grid would reduce GHG emissions by 14% to 15% from the baseline, depending upon the policy instruments to implement the renewable energy targets. This is because the subsidy policy also includes an offsetting increase in taxes on fossil fuels. Since the GHG reduction by the mandate policy is 1 percent lower than the GHG reduction by the subsidy policy, the latter is superior to the former if GHG reduction is one of the objectives of the substitution of fossil fuels with renewable energy in Morocco.

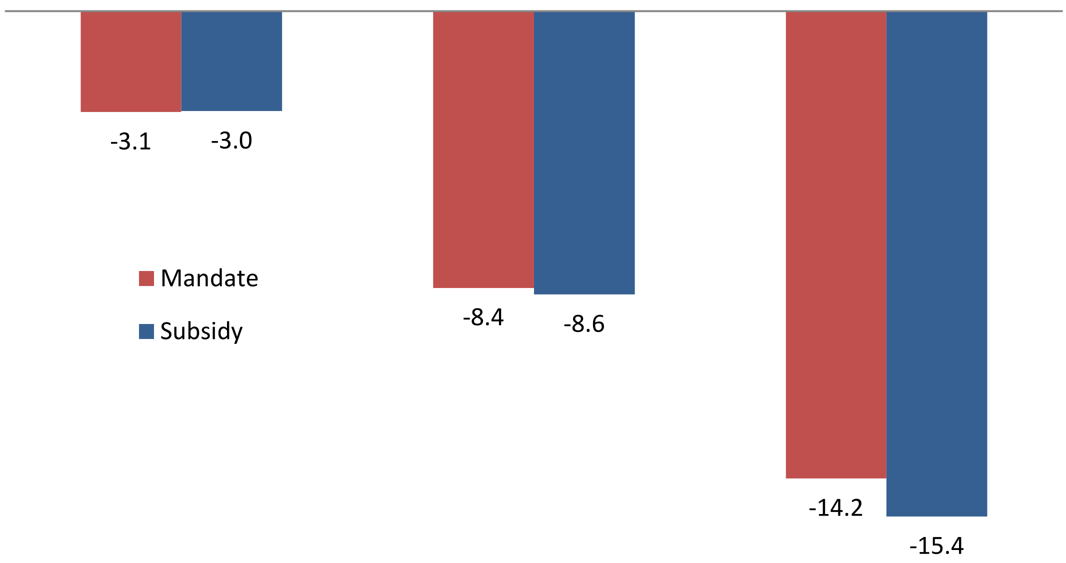

Figure 10: Change in GHG emissions of the economy from the base case (%)

5. Conclusions

Endowed with good potential for renewable energy resources, particularly solar energy, Morocco has introduced a target to supply 42% of its total electricity production through renewable energy (14% each by hydro, wind and solar) by 2020. To realize the target the government has already taken some initiatives, such as ambitious concentrated solar power projects. Using a perfect foresight dynamic computable general equilibrium model, this study analyzes economy-wide impacts of meeting the renewable energy target. Assuming that the government would consider either a production subsidy or a mandate to attract private investors in the renewable electricity generation industry, this study also compares these two policy measures in terms of their general equilibrium effects.

Since renewable energy technologies are expensive compared to conventional fossil fuel technologies to generate electricity, it was anticipated that increased penetration of renewable energy would have significant negative impacts to the economy. Our study shows that meeting the government target on renewable energy—42% national electricity supply by 2020—would cost the households more in terms of their economic welfare as compared to a situation in the absence of the renewable energy target.

At the sectoral level, the two policy measures (i.e., subsidy and mandate) have quite different impacts because they interact differently with various economic sectors, particularly renewable electricity industries. When the subsidy is financed through a fossil fuel tax, fossil fuel intensive industries (e.g., petroleum refinery, mining, transportation) are found to be affected more negatively. On the other hand, when a mandate financed through increased electricity price is introduced, electricity intensive industries (e.g., machinery, other manufacturing and service sectors) are impacted more negatively. Moreover, under the subsidy policy, key economic sectors, such as electric power, textiles, construction, and machinery, enjoy increases in their outputs due to investment on renewable energy, some sectors, such as mining and chemicals, exhibit losses in their outputs due to increased petroleum prices resulted from taxes introduced to finance the renewable energy programs.

In terms of GHG mitigation, the subsidy policy would be more effective than the mandate policy because the fuel tax introduced to finance the renewable energy subsidy would also contribute to reduce GHG emissions.

The economic and environmental implications of meeting renewable energy targets in Morocco depend on how these targets are implemented. The implementation policy that considers production subsidies financed through fossil fuel taxation are found superior to a consumption mandate that increases the price of electricity significantly, because the former causes smaller welfare loss and higher GHG reduction.

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Appendix: Elasticities of substitution

Table A1. Elasticities Used in the Model

Industry/Commodity	$\sigma_{mat,i}$	$\sigma_{prin,i}$	$\sigma_{kl,i}$	$\sigma_{en,i}$	$\sigma_{fu,i}$	σ_g	$\sigma_{top,i}$
Other agriculture	0.3	0.3	0.6	0.6	2.0	3.0	0.1
Sugarcane industry	0.3	0.3	0.6	0.6	2.0	3.0	0.1
Soybean industry	0.3	0.3	0.6	0.6	2.0	3.0	0.1
Forest sector	0.3	0.3	0.6	0.6	2.0	3.0	0.1
Livestock sector	0.3	0.3	0.6	0.6	2.0	3.0	0.1
Food and beverage	0.2	0.2	0.6	0.6	2.0	3.0	0.1
Crude oil & natural gas	0.2	0.2	0.6	0.5	0.8	3.0	0.1
Metal & mineral mining	0.2	0.2	0.6	0.6	0.8	3.0	0.1
Coal mining	0.2	0.2	0.6	0.6	0.8	3.0	0.1
Textile & leather	0.3	0.3	0.6	0.6	0.8	3.0	0.1
Wood production	0.3	0.3	0.5	0.6	0.8	3.0	0.1
Pulp paper & furniture	0.3	0.3	0.6	0.5	0.8	3.0	0.1
Petroleum refinery: Gasoline,diesel, other petrol	0.3	0.3	0.5	0.3	0.8	3.0	0.1
Biofuels sector	0.3	0.3	0.5	0.6	0.8	3.0	0.1
Chemical industry	0.3	0.3	0.6	0.3	0.8	3.0	0.1
Non metallic industry	0.2	0.2	0.5	0.3	0.8	3.0	0.1
Metal industry	0.3	0.3	0.5	0.3	0.8	3.0	0.1
Machinery equipment	0.3	0.3	0.5	0.2	0.8	3.0	0.1
Other manufacturing	0.3	0.3	0.5	0.6	0.8	3.0	0.1
Electricity						1.0	_
Processed gas	0.2	0.2	0.5	0.1	0.1	3.0	0.1
Construction sector	0.3	0.3	0.5	0.3	0.8	3.0	0.1
Commercial sector	0.3	0.3	0.6	0.6	2.0	3.0	0.1
Transportation sector	0.3	0.3	0.6	0.3	0.8	3.0	0.1
Other service sector	0.2	0.2	0.6	0.3	2.0	3.0	0.1

For each commodity g, the Armington elasticity for aggregating the imported and the domestic variety (see Figure 2) is denoted by σ_g. The other elasticities apply to production functions of sectors as illustrated in Figure 1.
Sources: Paltsev et al. (2005); Timilsina and Shrestha (2007).