Abstract

Many developing countries are highly dependent on fossil fuels and are net importers of oil, which makes them particularly vulnerable to large oil price fluctuations. Oil shocks affect economies through the deterioration of both its trade balance account as well as its fiscal position. The higher oil prices lead to higher oil imports and a worsening of the balance of trade account. The problem is compounded by the fact that this lead to higher subsidies and transfers and hence a deteriorating fiscal position of the economy. International organizations such as the World Bank, the regional banks (Inter-American Bank, Asian Bank and African Bank) are promoting the expansion of renewable electricity generation in developing countries to try to reduce the dependency on fossil fuel of developing economies and make them less vulnerable to oil price shocks. Moreover, renewable energy sources are non-pollutant and non-contributors to greenhouse effects and global warming.

Understanding the economy wide effects from oil price shocks and the expansion of renewable technologies is important particularly for developing countries that are net importers of oil. The developing country that we have chosen is Nicaragua. It was chosen for several reasons; one of them is that the country is highly dependent on foreign oil. Secondly, the country has been rapidly making the transition from oil sources to a range of renewable energy sources. And finally, the country has great potential for solar, wind, and geothermal power expansion due to its yet untapped resources. However, the effect on the economy or its different sectors has not been analyzed. If Nicaragua reaches its goal of 90% of its generation from renewable sources by 2020 without having to sacrifice its economic growth or suffer from marked increases in electricity prices; it may provide a path forward for other small and fossil fuel importing countries.

To analyze the implications of changes in the electricity matrix on prices and the economy at large, we need to use a top-down model that allow us to know the effects on the economy at large. In our case we have chosen the Mitigation, Adaptation and New Technologies Applied General Equilibrium (MANAGE) model- a dynamic recursive model for a single country model that is very flexible with regards to productivity assumptions, a detailed energy specification, and intra-fuel energy substitution and multi-input and multi-output production structure. Since we also want to know the effect of changes in oil prices or levelized cost of energy (LCOE) on the electricity matrix, a bottom-up model was also used- OSeMOSYS- is an open source modelling system for long-run integrated and energy planning.

The main contribution of this paper is the analysis of the differences of a top-down and bottom-up approaches, and the implications for the results of each method, helping the current void in the literature since there are very few papers that analyze how important the drawbacks of each methods may be.

1 Introduction

Electricity is a vital component for progress, linked to almost every conceivable aspect of development such as education, sanitation, water, and income per capita, etc. Hence, governments around the
world put a lot of emphasis on the investment planning for electricity generation expansion and the national electricity matrix, since without electricity there cannot be production and household welfare improvements and damper development. Choosing in what and when to invest, and the type of electricity generating technologies has consequences for the development of the country, environmental goals, energy security and independence. The choice of the when and what requires knowledge of the benefits and cost of different decisions. If governments decide to develop renewable technologies, there are tradeoffs that need to be taken into account; the price of electricity for consumers may increase, job losses may happen, alongside positive benefits of reduction in greenhouse gas (GHG) emissions and pollution, less dependence on foreign imports for the production of electricity (i.e. oil, natural gas). Moreover, the decision of when and in what to invest also will depend on external factors, such as the price of oil, the levelized cost of electricity (LCOE) of the different electricity generating technologies, among other factors.

To analyze the implications of changes in the electricity matrix on prices and its effect at the sectoral level we need to use a model that describes the entire economy and allow the substitution between the different factors of production in the economy, to maximize social welfare [Helgesen, 2013]. This type of model is a top-down model that allow us to know the effects on the economy at large. If we want to know the effect of changes in oil prices or LCOE on the electricity matrix, a bottom-up model must be used. Bottom-up models include detailed descriptions of the technological aspects of the energy system and how it can develop in the future; take the demand as exogenous and give us the most cost efficient way to produce electricity [Helgesen, 2013]. To be able to understand the effects on the electricity matrix and the economy at large, we need to use both approaches. A top-down model relies on smooth aggregate production functions to describe the technology choice in the electricity sector [Lanz and Rausch, 2011a] that cannot take into account the constraints that are present in this sector. The bottom-up models have a rich technological underpinning [Helgesen, 2013] but are partial equilibrium models, that only convey information about the specific sector, i.e. electricity sector. By linking both models [1] we can take into account the particularities present in the electricity sector, and understand the general equilibrium effects that will arise from changes in prices and in the production mix of electricity, and the implications for the rest of the sectors. However, before combining the two sectors, in this essay we will test both the top-down and bottom-up approaches and analyze the the pitfalls of each method.

In this paper we will be using the Open Source Energy Modeling System (OSeMOSYS) as the bottom-up model that has been adapted to the Nicaraguan electricity system. The Mitigation, Adaptation and New Technologies Applied General Equilibrium (MANAGE) has been chosen as the top-down model that has been modified with the Nicaraguan macro data and tailored to the idiosyncrasy of the Nicaraguan economy[2]. We chose MANAGE and OSeMOSYS, since both are available to users worldwide[3] and could therefore be adapted to any country for which there is appropriate data.

The main contribution of this paper is to provide an in-depth analysis of the differences in both approaches, describing how the role of key structural assumptions of each method will alter results. To achieve this, we will calibrate and adjust both models for Nicaragua, based on the information from the Central Bank as well as detailed information from the Ministry of Energy of Nicaragua.

2 Literature Review

The top-down approach is one of the most common methods used to understand the energy sector and the sectoral changes and implications on welfare. The top-down models come from the first models developed by [Koopman, 1951], [Arrow and Debreu, 1954] and [Forrester, 1961, 1968]. These top-down approaches or macroeconomic models take four different forms [Herbst et al, 2012, Helgesen, 2013]: a) Input-Output

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[1] We will be linking both models through a hard linkage. Hard linkage is not the only possible way of linking different models. Soft linkage is another possible way to do it; the difference between hard and soft linkage lies in whether the user controls the transfer of information or not (as defined by [Wene, 1996]). A third approach is through integration, in which one models influence the other, but they are not run independently.

[2] MANAGE is an annual recursive dynamics model where each solution of the model represents the changes between one year and the next.

[3] The fact that the code lines are available to users allows to check the assumptions in which the model is based.
models, b) Econometric models; c) Computable General Equilibrium (CGE) models, and d) System Dynamic models. In the case of the Input-Output models, they follow the monetary flows between different sectors between intermediate and final sector user. Hence, they estimate the impacts in monetary terms, but they do not let us analyze prices, since the prices are exogenous. (A CGE model uses a Social Accounting Matrix (SAM) which is an Input-Output model, while at the same time allowing endogenous prices.) The econometric models allow us to estimate statistical relations between variables of interest, however, they suffer from the Lucas critique in the sense that we should not use predicted effects of a change in policy based on past historical data and relations to forecast future estimates. In the case of System Dynamic model, they establish rules about the behavior of the different agents (or actors) in the economy, producing simulations based on the assumptions. Finally, the CGE models are based on micro theory, with consumers maximizing utility and producers maximizing profits; and prices and outputs for the different activities of the economy change in order to reach a general equilibrium in the economy. For this reason and the limitations of the other models, a CGE model will be the focus of our top-down approach.

CGE models have been used to analyze the energy sector, normally relying on disaggregating the energy sector as an additional sector, with substitution between capital, labor and energy . This approach relies on a smooth substitution where a small change in energy requirements leads to a small change in the output or mix of inputs may not be realistic. A small change in energy may lead to big changes in the input mix, since to produce an additional unit of electricity may require building an additional plant.

Some of the criticism to top-down models is the lack of "flexibility beyond current production and consumption patterns" . This is a fair criticism that it is difficult to correct, since it is not easy to represent new pathways or structural changes that may happen due to a change in the energy matrix. Another criticism that is made to top-down approach, especially CGE models is that the "fuel substitutions patterns are inconsistent with bottom-up data." Bottom-up approaches are detailed models of the energy system that account for the restrictions present in the electricity system and try to model as realistically as possible the energy sector. These models tend to be partial equilibrium models focusing on the energy markets and flows and the competition between energy technologies for supply and demand, technological constraints and production capacities. Bottom-up models assume exogenous macroeconomic scenarios, and focus on computing the effects of the shocks (i.e. capacity constraints, carbon tax) and how the shocks alter the mix between production technologies and the demand for energy and investment. They take into account constraints that are not modelled in the CGE. These constraints are investment restrictions, peak and base load, contracted investment plans, transmission and losses restrictions, among others. However, with bottom-up approaches we cannot answer questions about sectoral and regional impacts, or effects on other sectors of the economy besides the electricity sector.

Most of the bottom-up models for the energy sector follow the tradition of Markal family or the Edmonds-Reilly family. These type of models take the economic growth projections as exogenous coming from other models and used them to derive the demand for energy services, which is one of the key inputs of the energy models. Unlike top down approaches, it is not possible to assess the impact on the whole economy, though it is possible to assess the changes in the energy matrix derived from changes in prices or changes in the expansion plans for the energy matrix.

As mentioned in , one of the main drawbacks of bottom-up approach are some of the assumptions of "micro-economic behaviors of economic agents in choosing and adopting technologies". Some papers like score that "traditional bottom-up models" underestimate behavioral and market failures, transaction cost; with the main shortcoming being the absence of linkages between energy sector and the rest of the economy, specifically they cite, "the impact of energy prices and technical change on energy service demand (rebound effect)", the impact on general economic growth, and the "impact on the energy trade”, and finally but not less important, the impact of "energy investment” which will affect and may have a crowding out effect on the other sectors of the economy. The lack of linkages of the energy sector with the rest of the economy comes from the fact that top-down models do not replicate the technical constraints and specific technological policies that may be present in the energy sector, which cannot be
fully represented by the usual "stylized substitution" present in the top-down models between labor, capital, other intermediate inputs and energy [Grubb et al., 2002].

Just like the top-down approach, the bottom up approach can also be of four different types ([Fleiter et al., 2011]; [Helgesen, 2013]; [Herbst et al., 2012]): a) Optimization models, b) Simulation models, c) Accounting models and d) Multi-agent models. Optimization models follow the tradition of Markal (Fishbone et al., 1980; Fishbone and Abilock, 1981; Helgesen, 2013) where the goal is to minimize the cost given an exogenous energy service demands that must be met. Simulation models are different from optimization models in that they can include econometric estimations, which can include partial optimization [Helgesen, 2013], in creating a prototype of an energy system that helps to understand how an energy system performs in the real world [Howells et al., 2011]. Accounting models are based on exogenous assumptions that do not have the capacity to consider the effects of electricity prices [Helgesen, 2013]. Multi-agent models are a broader kind of optimization models that include simultaneous optimization by more agents [Helgesen, 2013]. For our bottom-up approach we have decided for an optimization model since it allows for a detailed description of inputs, outputs and parameters and in the specific case of OSeMOSYS, easily accessible code that is compact and relatively straightforward.

There are several papers attempting to reconcile the two approaches, but rather than jumping straight into the integration, we focus on understanding the differences and magnitude of the differences that arise when we use either approach, which will serve as guide when performing an integrated approach.

3 Analytical Framework

3.1 MANAGE

MANAGE is a recursive dynamic single country CGE model designed to focus on energy, emissions and climate change. The model is a single country CGE model that allows us to have a detailed specification for the energy sector that allows for capital/labor/energy substitution in production, as well as intra-fuel energy substitution across all demand agents with multi-output and multi-production structure. In the short-run, energy is assumed to be a near complement with capital, but a substitute in the long-run. Therefore, when the price of electricity goes up, e.g. due to an increase in the price of oil, then this increase leads to greater production cost in the short run, but not in the long run since there is time to adjust, and technology is developed to counteract the increase in price.

Another reason why MANAGE was chosen is the fact that it allows for both multi-input and multi-output production. Moreover, the model has a vintage structure for capital that allows for putty/semi-putty assumptions with sluggish mobility of installed capital. The assumption of sluggish capital enters the model through two channels. The first one, is the fact that old capital, or the capital at the beginning of period t, has lower substitution elasticity than new capital, or the capital that was invested after the beginning of period t. Therefore, if we have higher savings rates, then by our assumption about sluggish capital, we will have a higher share of new capital and thus greater "overall flexibility" [van der Mensbrugge, 2018]. The second channel is through the allocation of capital across sectors. The assumption in MANAGE is that new

[4]Optimization models such as OSeMOSYS [Howells et al., 2011], TIMES/MARKAL [Loulou et al., 2004], ENERGYPLAN, IKARUS, Model for Energy Supply System Alternatives and their General Environmental Impacts (MESSAGE), Price-Induced Market Equilibrium System (PRIMES)


[6]Optimization models such as OSeMOSYS [Howells et al., 2011], TIMES/MARKAL [Loulou et al., 2004], ENERGYPLAN, IKARUS, Model for Energy Supply System Alternatives and their General Environmental Impacts (MESSAGE), Price-Induced Market Equilibrium System (PRIMES)

[7]Accounting models such as Model for Analysis of Energy Demand (MAED), Mediterranean Prospects (MEDPRO), Mesures d'Utilisation Rationnelle de l'Énergie (MURE).

[8]Accounting models such as Liberalization Model (LIBEMOD), MULTIMOD.

[9]When we say compact we mean a model with around 100 equations, so it is compact and simple in terms of other optimization models.
capital is perfectly mobile across sectors. Therefore, if we have a sector with a declining demand, then the
return to capital needs to be less than the economy-wide average.

In MANAGE most of the equations in the production structure are indexed by v, which symbolizes
vintage capital. The only exemption are those production equations that are not vintage specific, i.e. non
energy intermediate demand for inputs. Furthermore, each production activity is indexed by a, and is
different from the index of produced commodities, i (allowing for the combination of outputs from different
activities into a single produced good, for example electricity). This is very important since the country
electricity supply comes from multiple activities: thermal, hydro, wind, solar and biomass, and the change
towards renewable is a central question in this paper.

There are different closures that are available, depending on the nature of the simulation. The standard
closure in MANAGE is that the capital behaves like labor markets with upward sloping supply schedule
for aggregate capital supply and inter-sectoral capital mobility that depends on a Constant Elasticity of
Transformation (CET). In the dynamic scenario, then new capital is allocated across sectors. The standard
closure or default closure implies that the government expenditures and government savings are fixed in real
terms. The household tax shifter is endogenous, though the household savings shifter is fixed, investment
is savings driven and public and foreign savings are fixed. Finally, in the case of the standard closure, the
trade balance is fixed and GDP is endogenous.

MANAGE was tailored to reflect the Nicaraguan economy using the Nicaraguan social accounting ma-
trix (SAM) . The 2010 SAM of Nicaragua was provided by the Central Bank of Nicaragua . Since the
SAM provided by the Central Bank provided an ample disaggregation, we use the richness of the data and
disaggregated MANAGE as well into 115 activities (ranging from agriculture to public sector, including as
well a disaggregated sector for electricity generation). 118 commodities and factors such as capital, labor
(self-employed and employed), land, and natural resources. The elasticities of substitution used in the model
are based on the best estimates found in the literature and expert advice (Arrow et al. [1961],van der Werf
2008).

As observed in Figure 2, MANAGE assumes there is decomposition between the different electricity
generating technologies. However, the model does not take into account the fact that there might be
constraints, i.e., capacity factors, operational life, residual capacity, total maximum capacity and storage
capacity that make the smooth substitution infeasible the among different electricity generating technologies.

3.2 OSeMOSYS

OSeMOSYS is a full-fledged energy model that allow us to take into account constraints of capacity, storage,
operational life. It is an open source code, with no proprietary software. However, it is up to the researcher
to include all the information and parameters that matches a country or region and calibrate it , in order to
fit the model to a country. Being a linear optimization model, the objective as described in equation (1) is
to minimize the cost subject to a given demand, while also taking into account constraint factors.

\[
\text{Objective} \quad \text{Minimize} \sum_{y,t,r} \text{TotalDiscountedCost}_{y,t,r} \tag{1}
\]

Where:

\[
\forall y,t,r \text{TotalDiscountedCost}_{y,t,r} = \text{DiscountedOperatingCost}_{y,t,r} + \text{DiscountedCapitalInvestment}_{y,t,r} + \text{DiscountedTechnologyEmissionPenalty}_{y,t,r} - \text{DiscountedSalvageValue}_{y,t,r} \tag{2}
\]

10The disaggregation included: thermal public generation, hydroelectric public generation, thermal private generation,
geothermal private generation, hydroelectric private generation, biomass private generation, wind private generation, trans-
mission services, distribution services, refined oil.
OSEMOSYS is organized in blocks, with the objective as block (1). The other important blocks are the (2) cost, (3) storage, (4) capacity adequacy, (5) energy balance, (6) constraints and (7) emissions, all of which must be adapted to the country or region in question. The cost includes all costs associated with each technology; hence it includes operation cost, investment cost, net emission production penalties. The cost takes into account capacity constraints, and the fact that for each technology there must be enough capacity to meet its energy use or production requirements (Howells, et al. 2011). It is important to note that the rate of activity, electricity production use and emissions are calculated for time slices during the year. Constraints relate to maximum or minimum: a) total capacity, b) new capacity investment limit, c) annual limit on activity for each technology, d) limit on the model period activity. Moreover, there should be enough capacity to allow a reserve margin as well. The emissions are calculated per unit of activity for each technology. The model also allows for annual limits on the emissions.
By adapting the model, we mean that all of the parameters need to be included into the model (electricity generating technologies, cost structures, storage capacity, energy balances, electricity constraints faced by system, etc) are included. To adapt OSeMOSYS to Nicaragua electricity system, we have used information from the MEM as well as the National Center of Energy Dispatch (CNDC for its acronym in Spanish). For the demand generation we have used the hourly historical national electricity demand as well as the generation profile. The wind turbine output comes from historical values as well as projections from the MEM. The average solar irradiation in Nicaragua is 5.21kWh m\(^{-2}\) d\(^{-1}\) with different irradiation depending on the area of the country. We have also taken into account the seasonality present in Nicaragua, where February to May are the sunniest months. The geothermal and biomass estimates used the information provided from the MEM about the historical information on generation and production (utilization factor, effective capacity and installed capacity). The costs in the objective function and for each electricity generating technology

**Figure 2: Energy Bundle MANAGE**
also come from information provided by the MEM. The model uses a discount rate of 5 percent and two modes of operation\textsuperscript{11} The projections made for MANAGE and OSeMOSYS are from 2011-2040.

4 Results

Three main questions are answered in this paper. The first question relates to what happens to the country if it maintains its current path and suffers from temporal oil shocks (mimicking oil shocks of the last 40 years\textsuperscript{12}) The second question deals with whether Nicaragua is on the path to meets its 80% of electricity generated from renewable sources by 2030? If not what would it take to reach its goal? And finally, but not less important, how much do the results vary between a pure CGE model and and an energy model?

For the different scenarios, both models use the same forecast for the different variables, i.e. gross domestic product (GDP), oil prices, etc. With respect to oil prices, we have assume an increase in prices in the medium and long term, with the price of oil going from $40.72 per barrel in 2015 to $96.59 in 2033. OSeMOSYS includes investment that has already been contracted for the different electricity generating technologies. Both models assume that there is a decrease in the cost of the wind and solar technologies over time, based on studies by the National Renewable Energy Laboratory\textsuperscript{13} OSeMOSYS takes into account the retirement of the plants at the end of their useful life, as well as a reduction in the cost of solar and wind technologies over the time period 2014-2040. In both MANAGE and OSeMOSYS electricity is being supplied by the lowest cost technology.

<table>
<thead>
<tr>
<th>Variables MANAGE in BAU Scenario</th>
<th>2010</th>
<th>2014</th>
<th>2024</th>
<th>2034</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of Return</td>
<td>1</td>
<td>1.03</td>
<td>1.25</td>
<td>145</td>
</tr>
<tr>
<td>Wages:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Formal no secondary edu</td>
<td>1</td>
<td>1.08</td>
<td>1.47</td>
<td>2.25</td>
</tr>
<tr>
<td>Formal secondary edu</td>
<td>1</td>
<td>1.10</td>
<td>1.56</td>
<td>2.51</td>
</tr>
<tr>
<td>Formal tertiary edu</td>
<td>1</td>
<td>1.05</td>
<td>1.41</td>
<td>2.18</td>
</tr>
<tr>
<td>Informal no secondary edu</td>
<td>1</td>
<td>1.04</td>
<td>1.28</td>
<td>1.8</td>
</tr>
<tr>
<td>Informal secondary edu</td>
<td>1</td>
<td>1.07</td>
<td>1.45</td>
<td>2.24</td>
</tr>
<tr>
<td>Informal tertiary edu</td>
<td>1</td>
<td>1.08</td>
<td>1.51</td>
<td>2.40</td>
</tr>
</tbody>
</table>

Table 1: Key Results from MANAGE

The results in Table 1 from MANAGE show that the rate of return increases from 1 in the base year to 1.45 in the year 2034. Where the more profitable sectors attract more investment, and sectors in decline see lower rates of return. Another key variable is wages. Wages are subdivided into the different categories that appear in the Nicaraguan SAM. These categories include formal sector and informal sector. Within each sector, there is a subdivision between workers with no secondary education, workers with secondary education and those with a college degree. One of the biggest winners in our dynamic model are for workers with at least secondary education.

The main sectors of the Nicaraguan economy are as follows: Services (35.2%), Food (15.2%), Agriculture (14.8%), Public Services (10.4%), Construction (6.8%), Apparel and Clothing (4.7%), Manufacturing (4.3%), Refined Oil (3.2%) and Mining (1.8%).

In the Business as Usual (BAU) scenario for MANAGE we see that if we let the model run with no additional restrictions. the thermal generation increases over time, it goes from 79.9% in 2014 to 81.4%.

\textsuperscript{11}Modes of operation are usually defined if a technology can use various input or output fuels and can choose the mix of these input or output/fuels. In OSeMOSYS for example, a CHP plant may vary between producing heat in one mode of operation and electricity in another. The capacity remains constant simply because the same piece of machinery produces both outputs. The modes of operation are indexed by the letter m.

\textsuperscript{12}Looking at the crude oil prices for the last 70 years we have had shocks to the price of oil at least every 10 years.

\textsuperscript{13}In the case of the wind stations we have applied an annualized rate of -0.49% and -0.02% for the periods 2014-2030 and 2030-2040 respectively.
a modest increase, but not in line with the predictions by the Ministry of Energy (See Table 2: BAU: MANAGE vs. OSeMOSYS).

<table>
<thead>
<tr>
<th>BAU: Electricity Matrix</th>
<th>2014</th>
<th>2014</th>
<th>2024</th>
<th>2024</th>
<th>2034</th>
<th>2034</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>79.9%</td>
<td>56.8%</td>
<td>79.3%</td>
<td>38.3%</td>
<td>81.4%</td>
<td>36.9%</td>
</tr>
<tr>
<td>Hydro</td>
<td>8.7%</td>
<td>9.2%</td>
<td>8.9%</td>
<td>10.8%</td>
<td>8.0%</td>
<td>10.4%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>4%</td>
<td>9.7%</td>
<td>4.1%</td>
<td>11.4%</td>
<td>3.8%</td>
<td>11%</td>
</tr>
<tr>
<td>Biomass</td>
<td>4.5%</td>
<td>11.2%</td>
<td>4.6%</td>
<td>24.2%</td>
<td>4.0%</td>
<td>23.3%</td>
</tr>
<tr>
<td>Wind</td>
<td>2.9%</td>
<td>13%</td>
<td>3.1%</td>
<td>15.2%</td>
<td>2.7%</td>
<td>18.1%</td>
</tr>
<tr>
<td>Solar</td>
<td>0%</td>
<td>0.1%</td>
<td>0%</td>
<td>0.1%</td>
<td>0%</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

Table 2: BAU: MANAGE vs. OSeMOSYS

OSeMOSYS BAU scenario includes projects that are already in the process of being constructed, or that have been already approved for construction. The model also takes into account restrictions due to residual capacity, capacity limits per year, availability factor, constraints that are not modelled in MANAGE. The results for the BAU scenario differ from those of MANAGE, where we see that though thermal sources in 2014 are the most important technology for electricity generation, they will decline to 36.9% by 2034. Biomass is an important electricity generating technology that will increase significantly its share in electricity generation, going from 11.2% in 2014 to 23.3% in 2034.

In neither BAU scenario does the country achieve its target of 80% of electricity generation coming from renewable sources. In both models, to achieve this target, the levels of investment need to be well above the current levels if the country is to achieve its renewable target.

After building BAU scenarios for each model, we proceed to test each model’s reaction to oil price shocks. After all, it is not only a concern over GHG emissions that the country is changing its electricity matrix, but also because of concerns over the disruptive effects of oil price shocks. We apply a 50% increase in oil prices in 2020 and a 25% increase in 2028. We find that using OSeMOSYS, the total discounted cost with no shock is US$60,105 millions. However, with the oil shocks in 2020 and 2028, the total discounted cost with shock is US$61,354 millions. The shocks are big enough that it leads to significant increase in cost, but not to a change in the electricity matrix composition.

In MANAGE, a 50% price shock in 2020 and 25% in 2028 produces momentary changes in the electricity matrix composition, with generation from both thermal public and thermal private, decreasing considerably in 2020 (-44.6% and -9.5%) and going back up in 2021, since the oil price shocks is a one year shock. The behavior is very different in the OSeMOSYS model, since, once a facility has been built it must be used, and electricity substitution does not happen as easily as in a CGE model. A oil shock price leads to reductions in the mining and apparel sector as well as the refined oil sector. These sectors have an intensive usage of electricity compared to the others, and therefore they are hit the hardest in the presence of an oil price shock.

An oil price shocks of 300% is needed in year 2020 and 2028 for us to see changes not only in the total discounted cost but in the electricity matrix composition. The new total discounted cost rise to US$ 67,098 millions, with important changes in the electricity matrix, with thermal decreasing its share significantly after the first shock (year 2020). The thermal electricity generation decreases from 523% in 2019 to 38.4% in 2021. The decrease in electricity generation is compensated with increases in biomass, wind, hydro and geothermal generation.

14 This information was gathered from the report of the MEM called ”Expansion Plan for Electricity Generation from 2015-2022”.

15 The total discounted cost include the discounted operating cost, the discounted capital investment, minus the discounted salvage value, for the years 2014-2035.
<table>
<thead>
<tr>
<th>Oil Shock vs. BAU (MANAGE)</th>
<th>2020</th>
<th>2021</th>
<th>2028</th>
<th>2029</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Public</td>
<td>-44.6%</td>
<td>2.9%</td>
<td>-16%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Hydro Public</td>
<td>16.5%</td>
<td>3.8%</td>
<td>5.9%</td>
<td>-0.4%</td>
</tr>
<tr>
<td>Thermal Private</td>
<td>-9.5%</td>
<td>0.2%</td>
<td>-5.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>14.3%</td>
<td>2.4%</td>
<td>5.3%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Hydro Private</td>
<td>16.5%</td>
<td>3.5%</td>
<td>6.0%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Biomass</td>
<td>15.9%</td>
<td>3.3%</td>
<td>5.8%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Wind</td>
<td>3.5%</td>
<td>4.6%</td>
<td>6.2%</td>
<td>-0.4%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2.0%</td>
<td>-0.8%</td>
<td>0.7%</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Mining</td>
<td>-8.9%</td>
<td>2.4%</td>
<td>-4.0%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Apparel</td>
<td>-8.5%</td>
<td>2.4%</td>
<td>-3.6%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Refined Oil</td>
<td>-32.4%</td>
<td>7.4%</td>
<td>25%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Construction</td>
<td>-4.4%</td>
<td>0.1%</td>
<td>-1.7%</td>
<td>-0.1%</td>
</tr>
</tbody>
</table>

Table 3: Oil Price Shock of 50% in 2020 and 25% in 2028 in MANAGE

<table>
<thead>
<tr>
<th>Changes in Electricity Matrix</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>52.3%</td>
<td>47.5%</td>
<td>38.4%</td>
</tr>
<tr>
<td>Hydro</td>
<td>8.5%</td>
<td>9.2%</td>
<td>10.8%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>9%</td>
<td>9.8%</td>
<td>11.5%</td>
</tr>
<tr>
<td>Biomass</td>
<td>18.3%</td>
<td>20.4%</td>
<td>23.9%</td>
</tr>
<tr>
<td>Wind</td>
<td>11.9%</td>
<td>13%</td>
<td>15.3%</td>
</tr>
</tbody>
</table>

Table 4: Changes in Electricity Matrix: Shock of 300%

5 Conclusions and Future Work

In this paper we provide a framework for the study of energy-related questions in the context of the general economy through the use of open code models. Most models that study energy related questions are for developed countries and are proprietary software that cannot be used by other researchers.

We have seen that even under similar assumptions, top-down and bottom up models differ considerably. In our case, the CGE model tends to rely more on fossil fuels, or thermal sources. Thermal sources are what is used more intensively in the base year of the model and even with oil price shocks we tend to go back to thermal sources for electricity generation, with significant fluctuations in the electricity generation across years in the presence of shocks. The energy model provides results that are more in line with the projections of the MEM. Bottom-up approaches like our energy model does not produce big fluctuations in the generation sources from year to year, even in the presence of oil price shocks. This is also more in line with reality, since once a power plant is installed, it cannot be used to generate a different type of electricity generation technology.

Under the BAU the country will not achieve its renewable target by 2030. If the country desires to achieve this target, it will lead to increases in the electricity generation cost in the short run and medium term. One of the viable ways to achieve this is through the use of geothermal sources especially.

5.1 Future work

We are working on building a hard-linked CGE energy model. A hard-linkage model will allow us to use the linkages present in a CGE model between the different sectors, so that we can take into account first order and second order effects of changes in the electricity matrix as well as prices, while also modelling the constraints present in energy models, to which the electricity sector is subjected to.
Moreover, given the country potential for exporting electricity, we are also exploring the possibility of expanding the model to the entire Central American market - Central America Common Market for electricity. Nicaragua has the potential to become a net exporter, while countries like Guatemala, Honduras, and El Salvador are facing increasing challenges meeting their ever increasing electricity demands, and could potentially benefit from importing electricity.

References


D. van der Mensbrugghe. Mitigation, adaptation and new technologies applied general equilibrium (manage) model version 2.0g, 2018.

