Nicaragua’s Climate Mitigation Policy: Sectoral and Inter-Household Effects

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Abstract

The objective of this paper is to assess the economic and distributional impacts of Nicaragua’s commitments to limit future greenhouse gas emissions in the context of the Paris Agreement, known as the Nationally Determined Contributions (NDCs). The analysis relies on a single-country computable general equilibrium (CGE) model, known as the Mitigation, Adaptation and New Technologies Applied General Equilibrium (MANAGE) Model and Open-Source energy Modeling System (OSeMOSYS). A key feature of the MANAGE model is that it is geared toward energy and environmental applications, similar to the prominent global Integrated Assessment Models (IAMs). A soft-linkage between MANAGE and OSeMOSYS links the energy sector, economic sectors, and households, which helps illustrate the scenarios of climate change mitigation. This linkage maintains the detailed specification of the energy model as well as those from general equilibrium models.

The model is calibrated to an updated social accounting matrix for Nicaragua, which disaggregates households into 20 representative types: 10 rural and 10 urban households. For the household disaggregation we have used the information from the 2014 Living Standards Measurement Study (LSMS) for Nicaragua. Our analysis focuses on the distributional impacts of meeting the NDCs—in a dynamic framework as the MANAGE model is a (recursive) dynamic model. The results show that the change in the electricity matrix affects richer rural households slightly harder. Moreover, we find that a carbon tax in Nicaragua is necessary for the country to achieve reduction in emissions consistent with keeping global warming below 2°C.

Keywords: CGE Modeling, Household Survey, Government Policy, Distributional Effects, Nationally Determined Contributions, Nicaragua

JEL classification: C61, C68, D5, Q48, Q52.

1. Introduction

The Paris Agreement reflects an international consensus that climate change is a significant threat to human life and action is needed to prevent continued global warming. A report by the United Nations Framework Convention on Climate Change (UNFCC, 2016) highlights that Intended Nationally Determined Contributions (INDC) will bring the average emissions per capita down by as much as 8 percent by 2020. Nicaragua is a late signatory to the Paris Agreement, having argued that the agreement did not have stringent enough commitments by developed countries (GoN, 2018). The country deposited its instrument of ratification to the Paris Agreement though it has not yet formally signed the Agreement.[1] According to a World Bank study (WB, 2013), Nicaragua is a “renewable energy paradise” with extensive solar, wind, geothermal and wave energy resources. Therefore, it has the potential to substantially increase its electricity generation from ‘clean’ energy sources and to provide quality services to Nicaraguans that lack access to the national grid and reliable electricity supply.[2] Also, a substantial share of its economy is heavily reliant on natural resources with its most important sectors being agriculture, manufacturing (especially apparel and textiles), and services (tourism industry—hotels and restaurants).

The greenhouse gas (GHG) emissions for Nicaragua in 2010 were just over 15 $MtCO_2eq$[3], (around 2 tCO_2eq per capita), or 0.01 percent of the global GHG emissions. The main contributors to GHG emissions are land-use change and forestry (67.9 percent) and the energy sector (29.4 percent). Oil is the only source of CO_2 emissions from fossil fuels combustion, while transportation sector accounts for half of fossil fuels combustion emissions (IEA, 2020). Though Nicaragua is a low emitter of greenhouse gases, it is ranked as the “world’s fourth-most-affected country by extreme weather” according the 2017 Germanwatch Climate Risk Index (Kreft et al., 2017).

Nicaragua’s vulnerability to climate change comes mainly from the fact that rural Nicaraguans, which make up 41 percent of the population, have at least half of their income coming from rain-fed agriculture (with less than 2 percent of the households using irrigation according to Food and Agricultural Organization of the United Nations (FAO, 2020). With such phenomena as El Niño and La Niña bringing droughts and floods, “25 percent of farming households experience chronic or temporary food insecurity” (FAO, 2020). Moreover, Nicaragua’s mean annual temperature has increased by 0.9˚C since 1960 and is expected to increase by 3.5˚C by 2100 (FAO, 2020). Frequency of hot days and hot nights have also been increasing every season. Furthermore, decreases in precipitation are already affecting the country—precipitation has decreased by 8.4 percent in 2010 relative to the mid-century levels and it is expected to decrease by 36.6 percent by 2100 (WB, 2009)[4].

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[1] Source: UNFCCC NCD Registry. The unconditional target for Nicaragua is to continue to increase the share of renewables to 60 percent by 2030 as well as to maintain the country’s carbon sink at current levels compared to the Business as Usual Scenario (BAU) by 2030. A commitment that it will very likely meet since the generation of electricity from renewable sources is already over 50 percent. The conditional target is to increase the national carbon sink by 20 percent as compared to the BAU scenario.

[2] 13.2 percent of the population still lack access to electricity according to the World Bank (2019a).

[3] Nicaragua’s NDC: “Contribución Nacionalmente Determinada a la Mitigación del Cambio Climático (NDC) de la República de Nicaragua ante la Convención Marco de Naciones Unidas sobre Cambio Climático (CMNUCC)”.

[4] We have taken this into consideration, and we have included in the different scenarios a reduction of the hydro power, though the other forms of renewable power will increase.

This paper explores the effect of climate change policies, including the sectoral as well as interhousehold effects of climate change policies, including INDC commitments. There was a gap in the literature because the other studies that have been based on Nicaragua have not covered the effect of climate change policies.

In de Leon Barido (2015) the authors evaluate fuel-switching strategies and their resulting cost of different power scenarios (2014-2030). The authors study the theoretical potential of solar, geothermal and hydropower energy of the country. It is a bottom up approach that allows the quantification of the cost of energy but does not allow sectoral nor household effects. In the Business as Usual (BAU) scenario, the authors find that 39 percent of the electricity generated comes from oil, and the cost of power averages $129 /MWh. Under a scenario of large hydropower moratorium, the cost of power would be $144/MWh. In the case of risky geothermal investment, the projected cost is $157/MWh. If there was a solar mandate, the projected cost of power rises to $157/MWh.

Kammen and Casillas (2010) describe interventions in a rural Nicaraguan community to show that energy services can be provided in cost-effective manners, offering the potential to address aspects of rural poverty while also transitioning away from fossil fuel dependence. The energy efficiency measures were installation of meters and compact fluorescent lights (CFLs) that were actually implemented in two rural communities in the Atlantic. Moreover, 2 more energy measures were studied, biogas and wind turbine, but these were estimated rather than implemented. The measures can be efficient low-carbon energy systems in rural areas has the potential to produce greater human development, savings, and carbon mitigation returns than in more industrialized areas.

Rivera and Wamsler (2014) study climate change adaption and disaster risk reduction in Nicaragua. The paper analyzes the perceptions of policy makers with regard to climate change adaption (CCA) practices in the urban areas of Nicaragua. Mainly, the paper discovers that the policy makers are at an “early stage” of integrating CCA practices, hence there is limited implementation into urban planning.

Unlike previous papers based on Nicaragua, the purpose of this paper is to assess the economy-wide and distributional impacts (in terms of households’ income) of Nicaragua’s Nationally Determined Contribution (NDC), as well as more stringent policies to reduce GHG emissions. These scenarios would be considered under various modalities for implementing carbon policies, for example stand-alone country-based policies compared with entering an international carbon trading scheme. Nicaragua’s NDC commitment to increase the share of electricity from renewable sources could be very regressive, “due to low-income households spending higher shares of their income on electricity and because of inelastic demand” (Claeys et al., 2018). Therefore, the analysis of distributional impacts of carbon reduction policies in Nicaragua is of a major importance.

Government policies designed to fulfill the NDC commitment to combat climate change are praiseworthy but they have the potential to harm the poorest households, hence the importance of using a model for a developing country that provides a mechanism to study these effects.

The model that we use for the analysis of climate mitigation policy of Nicaragua is the Mitigation, Adaptation and New Technologies Applied General Equilibrium (MANAGE). MANAGE is a single country recursive dynamic model developed specifically to assess the economy-wide energy system and related greenhouse gas emissions (van der Mensbrugghe, 2018).

The model has been calibrated to a 2014 Social Accounting Matrix (SAM) of Nicaragua. The source table contains 118 commodities as well as factors of production such as capital, labor, land, and natural resources. It also includes a disaggregation of households by deciles for both urban and rural groups. Nicaragua remains one of the poorest countries in Central America with very uneven income distribution within and across rural and urban regions[5], hence economy-wide policies such as carbon taxes are likely to have highly differential impacts across households.

OSeMOSYS is a long-run integrated assessment energy model used at the national level for Nicaragua; covering the energy sector, including among other sectors, the electricity as well as the transportation sector for the year from 2014-2030[6]. Though the results are per year, the information that feeds the model includes daily splits about energy usage. Moreover, the constraints on the energy model are per technology. The electricity sector does not use storage; hence we have not modelled storage.

The proposed scenarios for this paper are the following:

i) A business-as-usual (BaU) scenario where the country achieves 50 percent share of renewables in total primary energy supply (TPES)[7] or more by 2030[8];
ii) In scenario 2 Nicaragua meets its unconditional target of reaching 60 percent share of renewables in TPES, or more by 2030, as well as maintains the country's carbon sink at current levels;[9]
iii) Scenario 3 includes an additional reduction in emissions consistent with keeping global warming below 2°C[10];
iv) Scenario 4 projects an increase in the share of renewables by 85 percent by 2030 (in line with the original NDC commitment from Nicaragua).

2. Methods

2.1 Computable General Equilibrium (CGE)

CGE models combine economic theory with data, representing the market choices of different agents while maintaining resource allocation constrains. One of the features that make CGE so appealing is the fact that CGE captures industry to industry linkages highlighting effects that are not usually intuitive, since they bring greater level of detail and complexity than other models.

MANAGE is a recursive dynamic single country computable general equilibrium (CGE) model designed to focus on energy, emissions and climate change. MANAGE allows evaluation of the distributional effects of policies for the different economic sectors and agents. Like other

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[5] In 2018, an average per capita income was 5,157 \$2011 PPP, with a 2014 Gini index of 46.2, the 29th highest in the world (World Bank, 2019b).

[6] Though we have done other scenarios that go over until 2040.

[7] 50 percent share of renewable in TPES is around 2110.45 GWh of electricity generated from renewable sources for the year 2014, the base year.

[8] Though it is unusual to see the INDC commitment in terms of electricity generation from renewable energy, studies like Mani et.al. 2018, indicates how China has a renewable energy target of 15 percent in primary energy (100 GW of solar PV and 200 GW of wind by 2020, and 20 percent in primary energy. For Japan, the goal is 22-24 percent in power generation. In the case of the EU the goal is to have at least 27 percent in power generation by 2030.

[9] In the current assessment we do not explicitly model carbon sink.

[10] Nicaragua's INDC would imply a -8 percent decrease in emissions (Mani et.al.2018). Hence to be consistent with keeping global warming below 2℃ the reduction the reduction should be around -15 percent reduction in emissions.

models the economic agents maximize the utility of households and profit of the firm. Prices adjust so that there is a global equilibrium across all sectors. The model enables a detailed specification for the energy sector, 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.[11]

The final demand comprises of public and private expenditure on goods and services. The economic agents are represented by households, firms, government. The factors of production are labor (skilled and unskilled), capital (mobile and fixed), energy, and land.

The household income comes from the after-tax remuneration from production factors: land, labor, natural resources, capital and transfers. The household expenditure is allocated into consumption, taxes and savings. The household is based on an aggregation of commodities, using a nested structure. The aggregated commodities include agriculture and food, natural resources, energy, textile and wearing apparel, manufacturing, construction, private services, and public services.

The production of the firms is modelled using a nested constant-elasticity-of-substitution (CES) with a little twist, given that MANAGE deviates from the standard CES where the intermediate and value added bundle are a fixed share of output, but in MANAGE there is capital/energy substitution as well as complementarity. The model is solved as a static equilibrium with dynamic equations linking exogenous factors driven by the accumulation of capital and employment growth. Population and labor stock growth are exogenous.

One of the distinctive features of the model is a vintage structure for capital that allows for putty/semi-putty assumptions with sluggish mobility of installed capital. The vintage structure impacts model results through two channels. First, it is typically assumed that Old capital has lower substitution elasticities than New capital. A higher savings rates will lead to a higher share of new capital and thus greater overall flexibility. The second channel is through the allocation of capital across sectors. New capital is assumed to be perfectly mobile across sectors. Old capital is sluggish and released using an upward sloping supply curve. In sectors where demand is declining, the return to capital will be less than the economy-wide average.

Another important feature of the MANAGE model includes incorporation of the non-price related changes in preferences. This is accomplished via preference ‘twist’ parameters (Dixon and Rimmer, 2002). The twist parameters change the preference for one set of commodities in a demand system relative to other commodities, but without changing the aggregate cost. In the case of electricity generation, such feature allows us to assume a target for renewable electricity as a share of total electricity demand and implement the twist assuming no change in prices (from the base year).

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[11] Just like in the case of GTAP, the household demand is modeled using constant-differences-in elasticity (CDE). Import demand also assumes the familiar Armington assumption, where goods are differentiated based on region of origin. One of the assumptions made in MANAGE is that prices of exports and imports prices are exogenous (small country assumption), therefore the level of production of a small country does not affect the price received by exporters nor the internal demand affect world prices. The production structure is a nested Constant Elasticity of Substitution (CES) with intermediate inputs and value added as a fixed share of output.

MANAGE model solves a Mixed Complementary Problem (MCP) to find equilibrium solutions. MCP is given by a system of equation, where we have sets of non-negative variables: prices, quantities, and income levels, while optimizing behavior of agents.

2.2 Energy System

OSeMOSYS is an engineering optimization model that could be used for both medium and long-term energy planning or energy policy analysis. The model is a representation of the energy system, including the most important energy carriers and conversion technologies, with all the interrelations and dependencies represented. OSeMOSYS computes the energy supply mix (in terms of generation capacity and energy delivery) which meets the energy services demands every year and in every time step, minimizing the total discounted costs. Being a linear optimization model, the objective as described in equation (1) is to minimize the cost subject to a given demand, and while also taking into account constraint factors.

$$\text{Objective} \qquad \text{minimize } \sum\nolimits_{y,t,r} \text{TotalDiscountedCost}_{y,t,r} \qquad (1)$$

where:

$$\begin{aligned}
&\forall_{y,t,r}\text{TotalDiscountedCost}_{y,t,r}\\
&\quad = \text{DiscountedOperatingCost}_{y,t,r} + \text{DiscountedCapitalInvestment}_{y,t,r}\\
&\quad + \text{DiscountedTechnologyEmissionsPenalty}_{y,t,r} - \text{DiscountedSalvageValue}_{y,t,r}
\end{aligned}$$

It can cover all or individual energy sectors, including heat, electricity and transport and has a user-defined spatial and temporal domain and scale. The energy demands can be met through a range of technologies which have certain techno-economic characteristics and draw on a set of resources, defined by certain potentials and costs. On top of this, policy scenarios may impose certain technical constraints, economic realities or environmental targets. As in most long-term optimisation modeling tools, OSeMOSYS in its standard configuration assumes a unique decision-maker, perfect foresight and competitive markets.

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 are 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 and 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 allows for annual limit on the emissions as well, if there are targets to meet.

OSeMOSYS provides the "structure" to find the best cost-efficient matrix of electricity, however, it is up to the researcher to adapt it to the country in question. By adapting the model, we mean that all of the parameters need to be included into the model (electricity generating technologies, cost structures of the country, storage capacity of the country, energy balances for the country, electricity constraints faced by the electricity, etc).

2.3 Distinctive Characteristics of the Nicaraguan Electricity Industry

The electricity sector is different from other sectors because of the following: a) the quantity of power generating is fixed at specific times and the generating capacities are limited*;* b) the process to build power plants may take years, even decades; c) electricity needs to be consumed as soon as it is produced because of the cost of storage. Therefore, electricity sector needs to be modelled a little different from the other sectors and these distinctive included.

In the case of Nicaragua, the different electricity generating technologies are composed of: biomass (especially sugar cane produced by the sugar mill), thermal (mostly from oil), geothermal, hydro (consisting mainly of hydro plants that produce less than 10 MW, or mini hydro (100 KW to 1 MW, though with plants with a bigger hydro plants in the investment plants), solar[12] and wind plants (with 25 percent load factor). The thermal sector, is the most important sector, generating 56 percent of the total electricity produced in the country.

Table No. 1:
Electricity generating technologies and their capacities in 2014

Technology	Production (MW)	Share (%)
Biomass	126.72	11.47%
Thermal	617.49	55.91%
Geothermal	109.10	9.88%
Hydro	103.14	9.34%
Solar	0.00	0.00%
Wind	148.00	13.40%

The electricity supply needs year to build its capacity to be able to meet expected and unexpected demand hikes. This feature is encompassed in OSeMOSYS and we will take advantage of that fact and make sure that no electricity is produced above the accumulated capacity. Unlike the other commodities, we assume that there is a fixed endowment of capital whose upper bounds are defined by the available capacity per year for each technology for the different technologies. The sector-specific capital can be thought of as special equipment that has no economic use in another sector , such as a water dam used to produce hydro-electricity cannot be used for solar panels, or much less in another sector.

In MANAGE we have that each consumer good could also have its own energy bundle, which allows different demand shares across the energy sector. The top nest decomposes demand for good k into a non-energy bundle, XKFNNRG, and an energy bundle, XKFNRG, see respectively equations (2) and (3). Equation (4) defines the price of consumed good k for household h, PKF.

$$XKF_{h,k}^{NNRG} = \propto_{h,k}^{NNRG} XKF_{h,k}\left(\frac{PKF_{h,k}}{PKF_{h,k}^{NNRG}}\right)^{\sigma_{h,k}^{a}} \qquad (2)$$

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[12] Since the solar technology represents 0.12% and it is not expected to grow.

$$XKF_{h,k}^{NRG} = \propto_{h,k}^{NRG} XKF_{h,k} (\frac{PKF_{h,k}}{PKF_{h,k}^{NRG}})^{\sigma_{h,k}^{a}} \qquad (3)$$

$$XKF_{h,k} = [\propto_{h,k}^{NNRG} \left(PKF_{h,k}^{NNRG}\right)^{1-\sigma_{h,k}^{a}} + \propto_{h,k}^{NRG} \left(PKF_{h,k}^{NRG}\right)^{1-\sigma_{h,k}^{a}}]^{1/(1-\sigma_{h,k}^{a})} \qquad (4)$$

The energy bundle also allows for energy efficiency through the λ parameter that is specific for each consumer good (k), household (h) and for each energy carrier (e). So it allows us to match better OSeMOSYS and MANAGE, since we could have a larger energy efficiency in household demand destined for energy use than for other sectors, as seen in equation (5). Equation (6) determines the price of the energy bundle for each agent and for each consumed commodity.

$$XA_{e,h} = \sum_{k} \propto_{h,e,k}^{f} \frac{XKF_{h,k}^{NRG}}{\lambda_{h,e,k}^{eh}} (\frac{\lambda_{h,e,k}^{eh} PKF_{h,k}^{NRG}}{\chi_{e}^{PA} PAF_{e,h}})^{\sigma_{h,k}^{ce}} \qquad (5)$$

$$PKF_{h,k}^{NRG} = [\sum_{e} \propto_{h,e,k}^{f} (\frac{\chi_{e}^{PA} PAF_{e,h}}{\lambda_{h,e,k}^{eh}})^{1-\sigma_{h,k}^{ce}}]^{1/(1-\sigma_{h,k}^{ce})} \qquad (6)$$

2.4 Linking between MANAGE and OSeMOSYS

For energy analysis there has been a move towards hybrid modelling (Faehn et.al., 2020); since it "brings CGE models one step closer to more detailed, engineering-based, bottom-up models" to be able to have the "comprehensiveness" of the CGE models and the "technological detail" of energy models. According to Hourcade et al. (2006) and Bataille (2005) a high-quality hybrid model system should incorporate at least three properties: (1) technological explicitness, (2) microeconomic realism and (3) macroeconomic completeness.

Faehn et. al (2020), also points out that baselines projections in models that are hybrid present 3 different methodologies: a) the hybrid models has characteristics that are designed for "integrating technological bottom-up features and endogenizing the responses of investment and utilization of technologies to costs, prices and restrictions"; b)the model exogenous parameters and variables of the model come from external information sources, i.e. Ministry of Energy; c)the resulting hybrid model provides a new model that is consistent values for the parameters and variables.

The top-down models allow feedback effects between different economic agents and the energy sector, while allowing to examine the broader economic framework, but does not detail the technological specifics of energy system. In top-down models model the different sectors, including the energy sector have a smooth production functions reflecting substitution and transformation by the elasticities of substitution and transformation. Given that we wanted to have both the comprehensiveness as well as the technological detail, we have done a hybrid model.

Though the move has been towards hybrid modelling, there are few papers that combine both models, and even fewer that are centered on the developing world. One of those few papers are Merven and Arndt (2017). This paper presents two linked models, SATIM and eSAGE, using the linked model to illustrate two scenarios: a) improving the energy efficiency utilization and an ambitious CO_2 reduction scenario for South Africa[13].

MANAGE and OSeMOSYS are soft linked to form a hybrid model. For this purpose, we have used the input from OSeMOSYS that provides a detailed specification of the energy sector. MANAGE has disaggregated electricity generation technologies, with the shares being determined by the PE model. Therefore, all the relevant economic factors such as fixed and variable operating cost, maintenance cost, overnight cost, etc., as well as important technological features, such as size of plants (we have a discrete investment size), efficiency and availability factors that are prominent in energy models but are not present in CGE models. We have matched the levels of output (in physical units) for the electricity sector, as well as the evolution and structure of technology costs. The linkage between MANAGE and OSeMOSYS models requires that both models use the same macroeconomic variables that are feeding the model, GDP growth, population growth.

To incorporate energy data into MANAGE we have followed similar procedure to Malcom and Truong (1999). Just like GTAP, MANAGE is expressed in terms of value units (i.e. dollars), where value is the composite of multiplying volume and price. However, only two of the three sources of information value, price or volume can be independent of each other at any point in time. So, we cannot really incorporate both the energy volume and the price information at the same time in MANAGE without running into problems of either internal inconsistencies. We have chosen to adjust based on volumes. Just like Malcom and Truong (1999) we have checked for consistency in the volume and price data in OSeMOSYS and made sure that the same volume were reflected for energy volume and price data in MANAGE. We reconcile the derived energy volume trade flows with the targets for total volume that we have in OSeMOSYS. We also reconciled volume trade flows into value trade flows using the price of energy data. Moreover, we also use as targets the values of final consumption, imports, exports and fit it, as well as our data on energy prices and volumes. We use cross entropy to “fit” the targets with the rest of our information to prepare our SAM table for Nicaragua and making it consistent with the 2014, our base year.

The linking procedure to create our hybrid model consisted of harmonization in the base year of the following:

- Consumption and production of energy
- Volume and share of power generation and energy trends
- Explicit representation of the different energy technologies (thermal, hydro, geothermal, biomass and wind)
- Implementation of the same assumptions in both models
- GHG emissions (CO_2, CH_4 and N_2O.

The data for electricity generation (physical units) flows from OSeMOSYS into MANAGE in order to represent the different energy generating technologies. The production function of the electricity follows a Leontieff structure since there is no substitution between factors. We have adjusted the rest of the power share of each generating technology to the data in OSeMOSYS that is based on the information and reports of the Ministry of Energy of Nicaragua. The renewable

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[13] There is a previous paper based on South Africa, that uses a “hybrid” model to understand South Africa mitigation objectives and key challenges (Schers et al, 2015).

share should be 80 percent by 2030 according to the reports of the Ministry of Energy, but there are several scenarios discussed in this paper.

3. Data

Nicaragua is a highly unequal country, with a Gini Coefficient of 0.48 (WB, 2019b). The richest 20 percent accumulates 45.4 percent of the total income, while the poorest 20 percent get only 6.8 percent of the total income. In 2014, the reference year of our simulations, as well as the base year of the Living Standards Measurement Study (LSMS)[14] survey, the national per capita income averaged at around US$1,513. A high percentage of the population lives in the rural areas (42 percent) with a higher incidence of poverty, as 71 percent of the poor are coming from rural areas and 29 percent from the urban.

3.1Data inputs and reconciliation approach

MANAGE was tailored to reflect the Nicaraguan economy using the Nicaraguan social accounting matrix (SAM).[15] SAM is a characterization of macro and micro economic accounts that include transactions and transfers among all economic agents. In a SAM each account is represented by a row and column, where each cell represents the payment from the account of its column to the account of its row. The income of the account always are appear along its row, expenditure of the account appear along it column. SAM, like other economic accounting systems captures a year, and are the basis of the CGE model.

The 2010 SAM of Nicaragua was provided by the Central Bank of Nicaragua.[16] The SAM was updated to a 2014 SAM by using information from the Central Bank about macro aggregates, as well as using cross entropy, to minimize the differences and maintain consistency in the data. The cross-entropy approach matches the information for different macro and sectoral targets such as GDP, consumption, investment and energy balances. We use a cross entropy approach since it provides a flexible method for updating and estimating a SAM, allowing the user to take advantage of prior information to be used efficiently in the estimation (Robinson et al., 2000). The SAM provided by the Central Bank provides an ample disaggregation, with 115 activities (ranging from agriculture to public sector, including as well as disaggregated electricity generation technologies[17]). 118 commodities and factors such as capital, labor (self-employed and employed), land, and natural resources. The SAM provided by the Central Bank of Nicaragua had a single household, however, a disaggregated household was necessary for our analysis, so we disaggregated the single household into 20 different households, 10 rural and 10 urban. We use information from the latest Nicaraguan LSMS survey of 2014 as well as a cross entropy approach, to maintain consistency and achieve certain macroeconomic indicators. .

Since we need to simulate climate change policies, we paid particular attention to the energy flows among industries, and consumers as well as energy sources. Nicaragua's electricity supply comes from multiple activities: oil, hydro, wind, solar, and biomass. We have kept these

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[14] The LSMS 2014 for Nicaragua is a representative survey of the entire population of Nicaragua and comprises a total of 7570 households that cover all of the areas of the Nicaraguan territory.

[15] A Social Accounting Matrix is an Input-Output matrix that also includes economic transactions of the economy. The cells show payments from the accounts in the columns to the accounts in the rows.

[16] Given for research purposes only.

[17] The disaggregation included: thermal public generation, hydroelectric public generation, thermal private generation, geothermal private generation, hydroelectric private generation, biomass private generation, wind private generation, transmission services, distribution services, refined oil.

sectors in the MANAGE model. The electricity sector was included already in the Nicaraguan SAM so we did not need to perform data manipulations to adequately portray the electricity flows from industries and consumers[18].

Table 1 provides consumption shares by deciles for urban and rural households. As we can see, the richest deciles, both in the rural and urban areas, spent less (as a percentage of their income) on food, agriculture and forestry compared with poorer households. In the case of rural households in the first decile, public services, which include free education, health services, as well as other public services such as programs to fight poverty, are an important part of the income of these households. Given that these are the poorest households, it makes sense that the importance of social programs as well as public services is high. The share of private services (which includes private health and private education, but also computing, law, insurance services among others) increases as the households are richer. Chemical's share (which includes fertilizer, ethanol, chemical products, pharmaceutical products, tires, plastic products, among others) is relatively constant for both rural and urban households. It averages around 11 percent in rural households and 8.7 percent in urban households. Poorer rural households tend to spend more on fertilizer and chemical products used in agriculture, while richer households spent more on pharmaceutical products, tires, among others. Richer households, in both rural and urban areas spent more of their income on manufacture goods (includes machinery, medical equipment, transport equipment, electrical and electronic equipment). The tenth urban decile spends as much as 13 percent of their income on manufacturing goods. Electricity expenditure share is slightly higher for richer urban households. Expenditure in sectors such as construction is negligible for the poorer households and a very small fraction of the total expenditure of richer households.

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[18] Emissions were calculated using information from IEA as well as taking into account energy volumes and emission factors.

Table 2: Budget shares for aggregate consumption categories, %

Urban											
Group\decile	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Average**
Agriculture	12.3%	11.8%	11.7%	11.1%	10.5%	10.1%	9.7%	8.8%	7.5%	4.7%	9.8%
Forestry	6.9%	5.2%	4.5%	3.2%	2.5%	1.3%	0.9%	0.8%	0.3%	0.1%	2.6%
Mining	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.1%
Food	32.2%	32.8%	33.1%	33.1%	31.4%	29.4%	29.5%	28.9%	25.2%	16.7%	29.2%
Apparel and textiles	2.6%	2.8%	3.3%	3.4%	3.6%	3.5%	3.4%	3.4%	3.1%	2.7%	3.2%
Wood	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
Paper	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.8%	0.6%	0.9%
Chemicals	8.8%	8.5%	9.4%	8.8%	8.4%	9.1%	9.2%	8.6%	8.6%	7.1%	8.7%
Non-metals	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Metals	0.1%	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Manufacturing goods	2.2%	3.0%	3.0%	3.8%	4.3%	4.3%	4.9%	4.8%	5.8%	13.0%	4.9%
Electricity	1.9%	2.1%	2.0%	2.0%	2.0%	2.2%	2.3%	2.4%	2.2%	2.4%	2.1%
Construction	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%
Land Transport	2.9%	4.4%	4.1%	4.8%	4.5%	4.5%	4.5%	4.8%	4.5%	2.9%	4.2%
Water transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%
Air transport	0.2%	0.4%	0.1%	0.4%	0.5%	0.6%	0.2%	0.4%	0.7%	3.2%	0.7%
Public services	7.6%	4.7%	4.1%	3.7%	3.9%	4.4%	4.7%	4.7%	5.4%	6.0%	4.9%
Private services	18.8%	19.9%	19.7%	20.9%	22.9%	24.7%	24.9%	26.3%	29.2%	32.3%	24.0%
Refined oil	2.6%	3.2%	3.8%	3.6%	4.3%	4.5%	4.4%	4.8%	6.4%	7.9%	4.6%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Rural											
Group\decile	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**Average**
Agriculture	11.0%	16.1%	16.3%	15.1%	16.1%	14.0%	13.8%	11.9%	11.9%	6.8%	13.3%
Forestry	2.0%	1.9%	1.3%	3.5%	2.4%	1.7%	1.5%	2.1%	0.8%	0.7%	1.8%
Mining	0.2%	0.2%	0.2%	0.2%	0.2%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Food	26.1%	32.9%	37.7%	32.7%	32.2%	32.5%	34.0%	30.4%	28.2%	20.9%	30.7%
Apparel and textiles	2.6%	4.5%	3.9%	4.6%	4.6%	5.1%	4.6%	4.5%	4.6%	4.1%	4.3%
Wood	0.0%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%
Paper	0.6%	0.9%	0.9%	1.0%	1.0%	0.9%	0.8%	0.8%	0.8%	0.7%	0.8%
Chemicals	10.6%	11.2%	10.5%	12.2%	12.3%	10.1%	10.7%	12.4%	10.3%	10.9%	11.1%
Non-metals	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Metals	0.3%	0.6%	0.4%	0.7%	0.3%	0.3%	0.1%	0.3%	0.2%	0.1%	0.3%
Manufacturing goods	2.2%	2.9%	2.6%	3.6%	4.2%	4.3%	4.0%	5.1%	4.9%	5.6%	3.9%
Electricity	1.9%	1.7%	1.3%	1.5%	1.5%	1.2%	1.3%	1.3%	1.1%	1.1%	1.4%
Construction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.0%
Land Transport	2.5%	5.1%	5.3%	5.7%	6.4%	6.9%	6.3%	6.1%	6.1%	5.1%	5.6%
Water transport	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.0%
Air transport	0.1%	0.0%	0.6%	0.6%	0.0%	0.1%	0.1%	0.0%	0.2%	9.5%	1.1%
Public services	26.1%	7.3%	3.6%	2.9%	3.1%	2.3%	2.5%	3.2%	3.3%	5.2%	5.9%
Private services	13.4%	14.2%	14.9%	14.9%	14.9%	18.8%	18.4%	18.7%	22.2%	23.0%	17.3%
Refined oil	0.4%	0.3%	0.4%	0.7%	0.8%	1.6%	1.6%	3.0%	5.1%	5.8%	2.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Author’s own construction.

The BAU scenario in OSeMOSYS uses the projections from the Ministry of Energy that use the investment and operations cost for the period 2015-2035.The BAU scenario uses the Expansion Plan of Electricity Generation for 2015-2022, as well as projections for energy demand, electricity projects to be implemented, plan of retirement for power plant and projection of fuel prices[19]. We have also 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 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 also come from information provided by the MEM. The model uses a discount rate of 5 percent and two modes of operation[20]. The projections made for MANAGE and OSeMOSYS are from 2011-2030.

In the case of the wind centrals, the annualized rate -0.49% and -0.02% in the period 2014-2030 and 2030-2033, respectively. In the case of the solar centrals the annualized rate that was assumed is -3.9% in the 2015-2030 period.[21]. The investment cost, we have assumed a reduction in the wind and solar technologies, while we have assumed that the rest of technologies keep their cost rather constant in time[22].

Final energy is available in the form of liquid, solid and gas fuels and electricity. Nicaragua is a tropical country so there is no need for heat in the winter. As with every other energy model, the demand is exogenous to the model. In our case, we are making them consistent with the demand coming from the different industries and sectors as well as with MANAGE's demand whenever possible.

3.2.1 Other user-input data

Some of the other information needed for the model pertains to the exogenous variables that dictate the dynamic dimension of the model: projections for population and growth. The projections come from 3 different sources: the Shared Socioeconomic Pathways (SSP), International Institute for Applied Systems Analysis (IIASA) and the government of Nicaragua. In the case of the SSP projections, we only include the SSP2 or the middle of the road scenario. In our BAU scenario and subsequent scenarios, we use the projections from the government of Nicaragua, since we believe they provide the best present and future projections.

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; Balistreri, 2003; Antras, 2004; van der Werf, 2007; Okagawa and Ban, 2008). We have provided a detailed list of the elasticity's values in

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[19] The projections are based on the reports and projections from the Ministry of Energy in which the price of fuel goes from $40.72 per barrel and reaches $96.59 per barrel in 2033. In the case of diesel, the Ministry of Energy, the projections are expected to go from $62.22 per barrel to $112.1 per barrel in 2033 which also match the projections from the Central Bank of Nicaragua, which is another source for our macroeconomic projections.

[20] 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"".

[21] When we run it to 2035 or 2040, we assume that for the period 2030-2035, or 2030-2040.

[22] The assumptions about the different cost for the different technologies is based on the studies made by the National Renewable Energy Laboratory. For the variation in the price of fuel, the projections from the Annual Energy Outlook 2014, 2015 from the Department of Energy of the United States.

Appendix 1 as well as those used in other CGE models. In the case of price and income elasticities we have also used a combination of estimates available in the literature (Regmi, 2001; Regmi and Meade, 2013; Regmi and Seale, 2010; Seale et al., 2003).

We tested different types of income elasticities and perform sensitivity analysis, to determine how the different households react to the different elasticities. Our first set of elasticities comes from the literature Seale et. al. (2003) and the second from Gharibnavaz and Verikios (2018). In the case of Seale et. al. (2003) we use the different categories provided to match with the sectors in the Nicaraguan economy. The sectors provided by Seale et.al. (2003) are: (a) Food, beverage and tobacco, b) Clothing and footwear, c) Gross rent, fuel and power, d) House operations, e) Medical care, f) Education, g) Transport and communication, and h) Recreation and i) Other. Since there are no decile categories, we use the different country categories, where we use low income countries for the lower deciles, middle income countries for the middle deciles, and for the last two deciles we use high income countries elasticities. The elasticities from Gharibnavaz and Verikios (2018) provide 21 sectors that range from Agriculture, forestry and fishing to Wholesale trade and Art, sports and recreation. The estimates from Gharibnavaz and Verikios (2018) are by quintile, so we use the quintile elasticities and the different sectors as a blueprint for the income elasticities of our Nicaraguan model. For the baseline scenario (BAU) and subsequent scenarios we used for the income elasticities the estimates from Gharibnavaz and Verikios (2018) since they provide elasticities by deciles, rather than by countries.

Table No. 3: Income elasticities used

	Gharibnavaz and Verikios (2018)	*Seale et.al.(2003)*
Agriculture and food	Range (0.88, 0.40)	Range (0.88, 0.40)
Natural resources	Range (1.58, 0.47)	Range (1.42, 1.16)
Energy	Range (0.84, 0.32)	Range (1.37, 1.15)
Wearing apparel	Range (1.22, 0.49)	Range (0.93, 0.90)
Other Manufacturing	Range (1.26, 0.40)	Range (1.36, 1.15)
Transportation services	Range (0.94, 0.30)	Range (1.41, 1.16)
Construction	Range (1.42, 0.66)	Range (1.36, 1.15)
Private services	Range (1.24, 0.46)	Range (1.59, 1.22)
Public services	Range (1.08, 1.06)	Range (1.08, 1.06)

The income elasticities of Gharibnavaz and Verikios (2018) and Seale et. al. (2003) differ very little. The biggest differences are observed in the sectors: private services and energy, but in general both papers provide income elasticities very similar to each other. The highest elasticity is for natural resources and the lowest is for the sectors of manufacturing and agriculture and food. The price elasticities came from Seale et. al. (2003).

Table No. 4: Price Elasticities Used

	Seale et.al.(2003)
Agriculture and food	Range (-0.65,-0.40)
Natural resources	Range (-1.14,-0.94)
Energy	Range (-1.01,-0.95)
Wearing apparel	Range (-0.77,-0.74)
Other Manufacturing	Range (-1.00,-0.93)
Transportation services	Range (-1.41,-1.16)
Construction	Range (-1.04,-0.93)
Private services	Range (-1.20,-1.00)
Public services	Range (-0.88,-0.87)

The model has also been adapted to make sure that there is no substitution between the natural resource factor and the net output bundle for the electricity generating activities. There is also no substitution across the factors of production for the energy generating activities, nor between capital and the skilled labor bundle for the electricity generating activities.

4. Results

4.1 Benchmark data

In scenario 1, we set up a benchmark scenario from 2014-2030[23] with the values of the elasticities are kept constant. The main exogenous variables include the rate of economic and population growth. In the baseline simulation, the growth in real per capita GDP is exogenous. Investment is savings driven. Household and government savings are endogenous.

Model dynamics are driven by three factors similar to most neo-classical growth models. Population and labor force growth rates (the labor force growth rate is typically equated to the growth rate of population, which has been divided into 3 different categories, 0-14, 15-64, and over 65 years of age).The second factor is capital accumulation. The aggregate capital stock in any given year by KStock, which equals to the previous year capital stock, less depreciation, plus the previous period volume of investment.

The carbon dioxide emissions for Nicaragua in 2014 are estimated around 4502 thousand tons for the year 2014. At the end of our period, 2030, the carbon dioxide emissions are expected to almost double, to 8646 thousand tons in the BAU scenario. In this paper we have included emissions from carbon dioxide (CO_2), methane (CH_4) as well as nitrous oxide (N_2O).

In scenario 2 Nicaragua meets its unconditional target of 60 percent share of renewables in TPES by 2030. However, an increase of renewables in electricity generation does not produce significant reductions in emissions. This scenario deviates from the projections of the Government of Nicaragua, that expects a significant reduction via increases in renewable share in electricity

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[23] We have some scenarios not included in this paper that have been extended to 2040.

generation. However, our estimations indicate that an accumulated reduction in emissions for the period 2014-2030 with respect to the BAU scenario average 0.04%[24]. The reductions are small, especially when we compare it to scenario 3, an additional reduction in emissions consistent with keeping global warming below 2°C. The reductions in emissions in scenario 3 are around 12.29% by 2030. However, a reduction in C02 emissions comes at the price of lower GDP in the shorter term, as well as lower exports and imports compared to the BAU scenario. Scenario.4, where the share of renewables grows to at least 85 percent by 2030, does not produce significant reduction in emissions when compared with scenario 2. The reduction of emissions coming from oil generation is offset by emissions by other sectors under scenario 4.

Table No. 5: Macroeconomic results of climate change scenarios

% change from BAU, 2030	*Emissions*	*GDP*	*Export*	*Import*
Scenario 2 : >60% of ely renewable by 2030	-0.04%	-0.04%	-0.04%	-0.04%
Scenario 3: emissions consistent with 2°C	-12.29%	0.15%	-1.57%	-1.17%
Scenario 4 : >85% of ely renewable by 2030	-0.04%	-0.04%	-0.04%	-0.04%

Source: Author’s own construction

Scenario 3, a scenario consistent with keeping global warming below 2°C is achieved by imposing a uniform carbon tax of C$1300 (around US$46 per thousand ton in CO2 emission). Unlike the other scenarios, imposing a carbon tax produces tax revenues, which are then allocated back to the households, but are not enough to offset the losses in GDP and exports when compared with the BAU scenario. Figure 1 shows the marginal abatement cost for carbon tax for the year 2030. As we can observe, to be able to obtain sizable reductions of 1000 $MMTCO_2$ or more, we need to impose a tax of at least US$40 per $MTCO_{2.}$ Table No. 3 shows that a carbon tax may be the only way to obtain a considerable reduction of emissions consistent with 2°C. Not included in Table No. 3, but important to mention is that under scenario 3, the electricity matrix is around 60 percent of the electricity generation being produced by renewable sources by 2030, very similar to

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[24] The government of Nicaragua projects that by 2030 the accumulated percentage variation from emissions under scenario 2 are around 52.88 percent lower than under the BAU scenario.

scenario 2. However, the differences in emissions reductions achieved in the two scenarios are very different.

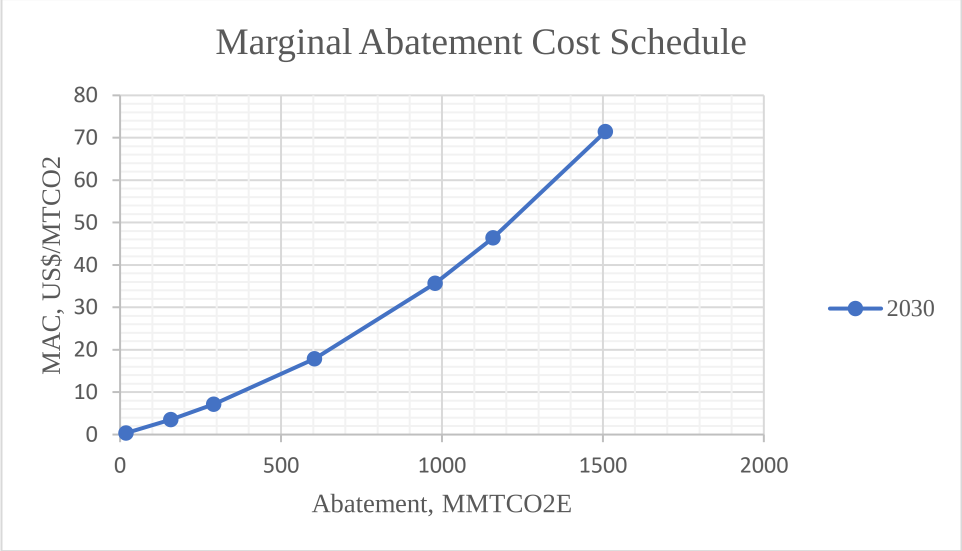

Figure 1: Marginal abatement cost for carbon tax

Another very important aspect to note is the fact that households impacts under the 3 different scenarios. In scenario 3, where we imposed a US$46 per thousand ton in CO2 emission, we see that the richest deciles suffer the most from a carbon tax, especially deciles 9 and 10 from both rural and urban areas. The impact on rural decile 1 and 2, under scenario 3 is positive, small, but positive, given that the tax revenue is redistributed, which outweighs the tax. Under scenario 2 and 4, there are losses for all of the different households, but they average less than 1 percent, with richer households in general more affected than poorer household. It might seem surprising that by 2030, household impacts are felt harder in scenario 2 than under scenario 4, a more ambitious goal. However, this is because the painful adjustment are felt especially in the earlier years by the households under scenario 4, and hence, by 2030, no more painful adjustment are needed[25].

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[25] This is a direct result of how we modelled scenario 4, where we have asked the model to significantly reduce electricity generation from oil sources from year t+1, which is felt in the model right away (which in our case is 2015).

Table No. 6: Household impacts of climate change scenarios

% change from BAU	*Scenario 2 : >60% of ely renewable by 2030*	*Scenario 3: emissions consistent with 2°C*	*Scenario 4 : >85% of ely renewable by 2030*
		2030	
R_hh1	-0.12%	0.07%	-0.05%
R_hh2	-0.16%	0.80%	-0.06%
R_hh3	-0.15%	-0.16%	-0.05%
R_hh4	-0.23%	0.73%	-0.04%
R_hh5	-0.17%	-0.54%	-0.04%
R_hh6	-0.17%	-0.49%	-0.04%
R_hh7	-0.17%	-0.48%	-0.04%
R_hh8	-0.33%	-1.18%	-0.06%
R_hh9	-0.19%	-2.40%	-0.08%
R_hh10	-0.32%	-6.03%	-0.11%
U_hh1	-0.16%	-0.16%	-0.05%
U_hh2	-0.18%	-0.05%	-0.05%
U_hh3	-0.17%	-0.42%	-0.05%
U_hh4	-0.18%	-0.39%	-0.05%
U_hh5	-0.19%	-0.55%	-0.06%
U_hh6	-0.18%	-0.85%	-0.06%
U_hh7	-0.19%	-1.33%	-0.06%
U_hh8	-0.19%	-1.36%	-0.06%
U_hh9	-0.23%	-2.10%	-0.08%
U_hh10	-0.24%	-2.97%	-0.09%

Source: Author’s own construction.

Moreover, it is important to highlight that the different scenarios would have different effects across the labor force. In the case of scenario 3, we see a significant decrease in the wages of salaried workers with tertiary education, partly given by the re-organization of the different sectors. By 2030, emissions intensive sectors have reduced their production, and many of these sectors require a highly educated labor force. Hence, the workers with a completed tertiary education are the ones that suffer the most from a carbon tax by 2030. Self-employed workers with tertiary education also suffer under scenario 3, but not as much as salaried workers. The effect on wages of scenario 2 and 4 is small across the different segments of the labor market.

Table No. 5: Wage impacts of climate change scenarios

	% change from BAU	*Scenario 2 : >60% of ely renewable by 2030*	*Scenario 3: emissions consistent with 2°C*	*Scenario 4 : >85% of ely renewable by 2030*
			2030	
Salaried	Secondary education not completed	-0.04%	-0.47%	-0.04%
	Completed secondary education	-0.05%	-0.24%	-0.05%
	Completed tertiary education	-0.46%	-19.97%	-0.46%
Self-employed	Secondary education not completed	-0.06%	1.28%	-0.06%
	Completed secondary education	-0.05%	-0.54%	-0.05%
	Completed tertiary education	-0.63%	-8.60%	-0.63%

In the BAU scenario, the main sectors are private services, food, agriculture. The private services sector encompasses financial, rental, bank, computing, wholesale, retail, accommodation, supply services (see Table No. 1 Appendix), and it is one of the driving forces of the economy. The food sector is another important sector and it includes the beef, frozen foods, baked gods, liquors and tobacco producing sectors of the economy. The third largest, agriculture, which is also the biggest employer in the country, encompasses the coffee, sugar cane, corn, beans, banana, soybean cultivation among others, as well as livestock production. In the different scenarios, as is expected, the electricity activities are the ones that suffer the greatest shift in their composition under the different scenarios, especially thermal generation under scenario 4. Scenario 4 reduces the electricity produced from thermal sources to less than 15 percent. Air transport and apparel and textile production, which are energy intensive activities, also suffer considerable reductions when compared with the BAU scenario, especially under scenario 3. The effects on the agricultural sector are small under the 3 scenarios, as well as the effects on food and apparel, with the exception of scenario 3, that benefits the food sector.

Table No. 5: Sectoral changes of climate change policies

% change from BAU	*Scenario 2 : >60% of ely renewable by 2030*	*Scenario 3: emissions consistent with 2°C*	*Scenario 4 : >85% of ely renewable by 2030*
		2030	
Agriculture	-0.05%	2.79%	-0.05%
Refined oil	-0.12%	-3.43%	-0.12%
Mining	0.01%	2.10%	0.01%
Food	-0.09%	3.23%	-0.09%
Apparel and textiles	0.01%	-7.56%	0.01%
Forestry	-0.04%	2.52%	-0.04%
Paper	-0.02%	2.68%	-0.02%
Chemicals	-0.05%	0.25%	-0.05%
Non-metals	-0.08%	0.22%	-0.08%
Metals	-0.08%	2.45%	-0.08%
Manufacturing goods	-0.06%	1.39%	-0.06%
Construction	-0.02%	2.43%	-0.02%
Trade	-0.05%	0.31%	-0.05%
Land Transport	-0.05%	-1.44%	-0.05%
Air transport	-0.16%	-25.91%	-0.16%
Public services	-0.01%	-0.69%	-0.01%
Private services	-0.08%	1.75%	-0.08%
Other services	-0.01%	-0.55%	-0.01%
Cement	-0.07%	-2.86%	-0.07%
Public thermal power	-25.05%	-4.56%	-80.01%
Public hydro power	-23.10%	6.50%	-23.10%
Private thermal power	-25.05%	-14.22%	-80.01%
Geothermal power	-0.12%	5.81%	-0.12%
Private hydro power	-0.12%	6.52%	-0.12%
Biomass power	-0.12%	6.04%	-0.12%
Wind power	-0.15%	6.83%	-0.15%
Elect. Transmission	-0.06%	5.62%	-0.06%
Elect. Distribution	-0.12%	6.31%	-0.12%
Equipment	-0.04%	0.71%	-0.04%

5. Conclusions and further work

This paper illustrates the coupling of a MANAGE and OSeMOSYS. The results show that a soft-linkage between both models improve the specification of the energy sector and provides important insights into mitigation and climate change policy. We conclude that the rapid conversion of the electricity sector toward renewable technologies, does not mean hefty increases in the price of electricity in Nicaragua, though the geothermal and wind investments (the main technologies replacing thermal generation) require significant upfront investment. The results also indicate that richer households suffer greater losses, though modest for all deciles, under the different scenarios. Under scenario 3, imposing a carbon tax, there was a greater shift in the sectors, especially energy intensive activities reducing its share and becoming less competitive. In the different scenarios, there is no significant job losses at the end of 2030, however, that does not mean that the different labor sectors suffer the same, or at the same time. We see that the unskilled labor force tends to suffer more at the beginning of the adjustment, and the skilled force at the end of the period.

The next steps for our paper are to complete a full intertemporal integration, using an iterative model approach, where we link the CGE model and the energy model via a sequential or a recursive dynamic process, and compare the results with a soft linkage as well as no linkage at all.

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Table 1: Nicaragua CGE model sectors

I. Agriculture
Agriculture
which includes SAM activities
Coffee
Sugar cane
Corn
Beans
Rice
Sorghum
Banana
Soy bean

Peanuts
Sesame
Tobacco
Pasture
Vegetables
Fruits
Wheat
Other agricultural products
Agricultural services
Cattle
Pork
Poultry
Other animals
Forestry
Wood
Other forestry products
Fish
Shrimp
Lobster
Other seafood

II. Energy
Thermal Public Generation
Hidro Public Generation
Thermal Private Generation
Geothermal Public Generation
Hidro Private Generation
Biomass Generation
Wind Generation

III. Mining
Mining

which includes SAM activities
Gold and silver
Extraction of construction materials
Extraction of other minerals

IV. Public Services
Public Services
which includes SAM activities
Water and distribution
Sewerage
Garbage disposal and others
Government admin services
Primary education private
Secondary education private
Tertiary education private
Primary education public
Secondary education public
Tertiary education public
Health private
Social services
Electricity transmission
Electricity distribution

V. Private Services
Private services
which includes the SAM activities
Asociation services
Culture and sports services
Other services
Wholesale trade
Retail
Accomodation services
Supply of food and beverage
Transportation services
Truck services
Water transportation
Air transportation
Auxiliary transport
Postal services
Communication services
Cable services
Financial services central bank
Bank services
Financial intermediary services
Insurance and pensions
Real estate residential rental
Real estate non-residential rental
Commission real estate
Machinery rental
Computing services
Research and development
Law and accounting services
Other professional services

VI. Refined oil
Refined oil

VII. Petrol
Petrol

VIII. Textile and Apparel
Textiles and apparel

IX. Food
Food
which includes SAM activities
Beef
Frozen meat and others
Seafood
Sugar
Dairy products
Oils and fats
Milling products
Prepared products
Baked goods
Other prepared goods
Liquor
Wine
Malt liquors
Non alcoholic beverages
Tobacco products

X. Construction
Construction
which includes SAM activities
Residential construction
Non-residential construction
Civil engineering construction
Other construction
Construction services

XI. Manufacturing
Manufacturing
which includes SAM activities
Wood products
Paper products
Chemical products
Glass
Cement
Ceramics
Common metals
Metal products
Manufacturing of machinery and transport equipment
Furniture and others

Source: Author's own construction.

Table No. 2: Elasticities used in our different scenarios

Parameter	*Explanation*	*Vintage/Activity or Commodity*	*Value/Range*
sigmacae(h,k)	CES substitution elasticity across energy goods		0.900
sigmae(a,v)	Intra-fuel substitution elasticity	Old	0.250
		New	2.000
sigmaf(f)	CES elasticity of substitution for top level final demand bundle		1.010
sigmafaa(f)	CES substitution across non energy goods in other final demand		1.010
sigmafae(f)	CES substitution across energy goods in other final demand		0.900
sigmah1(i,h)	CES substitution elasticity between marketed and home produced commodities		1.010
sigmah2(i,h)	CES substitution elasticity for home produced goods across source activities		1.010
sigmak(a,v)	Capital energy substitution elasticity	Non-electricity activities	0.800
		Electricity activities	0.100
sigmaks(a,v)	Capital skilled labor substitution elasticity		0.100
sigmamg(j)	CES substitution for margin demand		1.010
sigmanr(a,v)	Substitution elasticity between nat. resources and net output		0.100
sigmas(i)	CES elasticity for domestic use table		1.200
sigmasl(a,v)	Intra-skilled substitution elasticity		0.500
sigmaul(a,v)	Intra-unskilled substitution elasticity		0.500
sigmav(a,v)	Capital (+E) labor substitution elasticity	Old	0.900
		New	1.015
sigmax(i)	CET elasticity	All commodities, except	3.000
		Electricity	6.000
		Petroleum	6.000
		Refined oil	6.000

sigmacae(h,k)	CES substitution elasticity across energy goods		0.900
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sigmafae(f)	CES substitution across energy goods in other final demand		0.900
sigmah1(i,h)	CES substitution elasticity between marketed and home produced commodities		1.010
sigmah2(i,h)	CES substitution elasticity for home produced goods across source activities		1.010
sigmak(a,v)	Capital energy substitution elasticity	Non-electricity activities	0.800
		Electricity activities	0.100
sigmaks(a,v)	Capital skilled labor substitution elasticity		0.100
sigmamg(j)	CES substitution for margin demand		1.010
sigmanr(a,v)	Substitution elasticity between nat. resources and net output		0.100
sigmas(i)	CES elasticity for domestic use table		1.200
sigmasl(a,v)	Intra-skilled substitution elasticity		0.500
sigmaul(a,v)	Intra-unskilled substitution elasticity		0.500
sigmav(a,v)	Capital (+E) labor substitution elasticity	Old	0.900
		New	1.015
sigmax(i)	CET elasticity	All commodities, except	3.000
		Electricity	6.000
		Petroleum	6.000
		Refined oil	6.000

Source: Author's own construction.

Table No. 3: Elasticities used on other CGE models

Nesting structure and elasticities of substitution for several models

Author(s)	*Nesting Structure*	*Elasticities*	*Technical change*
Bosetti et al. (2006)	(KL)E	$\sigma_{K,L} = 1; \sigma_{KL,E} = 0.5$	exog TFP; endog. Energy specific
Burniaux et al. (1992)^{d}	(KE)l	$\sigma_{K,E} = 0\ or\ 0.8;\ \sigma_{KE,L} = 0\ or\ 0.12\ or\ 1$	exogenous
Edenhofer et al. (2005)	KLE	$\sigma_{K,L,E}$ =0.4	endog. factor-specific
Gerlagh and Van der Zwaan (2003)	(KL)E	$\sigma_{K,L} = 1.4$; $\sigma_{KL,E}$ =0.4	endog. energy-specific
Goulder and Schneider (1999)	KLEM	$\sigma_{K,L,E,m} = 1$	endog. TFP
Kemfert (2002)	(KLM)E	$\sigma_{KLM,E}$ =0.5	endog. energy-specific
Manne et al. (1995)	(KL)E	$\sigma_{K,L} = 1;\ \sigma_{KL,E}$ =0.4	exogenous
Paltsev et al. (2005)	(KL)E	$\sigma_{K,L} = 1;\ \sigma_{KL,E}$ =0.4-0.5	exogenous
Popp (2004)	KLE	$\sigma_{K,L,E} = 1$	endog. energy-specific
Sue Wing (2003)^{e}	(KL)(EM)	$\sigma_{K,L}$ =0.68-0.94; $\sigma_{E,M}$ =0.7; $\sigma_{KL,EM}$ =0.7	endog. TFP

Source: van der Werf (2007)

Parameters: Elasticity of substitution

Goods	*Elasticity of substitution (σ)*
Exports goods vs. Domestic goods	2.5
Armington goods vs. General goods	2.5
Between non electricity energies	0.25
Non electricity vs. electricity	0.5
Inter-electricity industry	0.25-0.5 (assuming increases with time)
Consumption vs. leisure	0.8
Elasticity vs. VA and energy	0.7
Intra-fossil fuel substitution in final demand	0.5
Elasticity of substitution vs. oil and gas	2

Source: Okagawa and Kanemi (2008)

Table No. 4: GTAP Income Elasticities

Target Income Elasticities of Demand

grains	otherfood	food	meatlvstk	dairy	bev_tob	textwapp	rent_fuel	other	transport	durables	services
AUS	0.16	0.14	0.24	0.09	0.93	0.87	1.02	1.14	1.13	1.06	1.1
NZL	0.09	0.41	0.09	0.09	0.89	0.83	0.98	1.13	1.12	1.04	1.11
JPN	0.09	0.34	0.71	0.54	0.9	0.85	0.99	1.13	1.12	1.04	1.12
KOR	0.18	0.59	0.64	0.71	0.94	0.89	1.06	1.29	1.28	1.13	1.28
IDN	0.41	0.66	0.77	1.08	0.89	0.83	1.03	1.39	1.36	1.11	1.41
MYS	0.18	0.58	0.36	0.36	0.93	0.87	1.04	1.2	1.2	1.09	1.2
PHL	0.19	0.64	0.66	0.5	0.96	0.9	1.08	1.33	1.32	1.15	1.33
SGP	0.27	0.22	0.46	0.4	0.96	0.9	1.05	1.17	1.16	1.09	1.16
THA	0.1	0.56	0.34	0.47	0.85	0.8	0.96	1.14	1.14	1.02	1.16
VNM	0.34	0.65	0.98	0.85	0.87	0.82	1.01	1.45	1.44	1.1	1.39
CHN	0.4	0.86	1.1	0.8	0.97	0.93	1.11	1.31	1.07	1.35	1.06
HKG	0.18	0.33	0.32	0.48	0.92	0.87	1.02	1.15	1.14	1.06	1.17
TWN	0.1	0.49	0.52	0.24	0.95	0.9	1.07	1.23	1.23	1.11	1.19
IND	0.3	0.74	0.69	0.62	0.92	0.86	1.07	1.7	1.62	1.18	1.4
LKA	0.4	0.69	1	0.67	1.02	0.96	1.16	1.49	1.46	1.24	1.56
RAS	0.32	0.79	0.83	0.68	1.01	0.95	1.15	1.5	1.47	1.23	1.31
CAN	0.14	0.14	0.17	0.09	0.92	0.86	1.01	1.12	1.12	1.04	1.12
USA	0.16	0.12	0.1	0.09	0.9	0.85	0.99	1.1	1.09	1.02	1.07
MEX	0.09	0.55	0.34	0.44	0.89	0.83	1	1.21	1.19	1.06	1.21
CAM	0.34	0.6	0.52	0.46	0.91	0.85	1.02	1.24	1.23	1.09	1.21
VEN	0.14	0.48	0.33	0.3	0.91	0.85	1.01	1.16	1.15	1.06	1.14
COL	0.3	0.57	0.49	0.35	0.87	0.81	0.97	1.16	1.15	1.03	1.13
RAP	0.26	0.58	0.62	0.51	0.89	0.83	1	1.23	1.21	1.06	1.27

ARG	0.09	0.5	0.17	0.13	0.93	0.87	1.04	1.21	1.19	1.09	1.24
BRA	0.19	0.53	0.52	0.41	0.95	0.89	1.06	1.23	1.22	1.11	1.19
CHL	0.2	0.53	0.56	0.41	0.94	0.88	1.05	1.23	1.22	1.1	1.25
URY	0.18	0.51	0.2	0.13	0.99	0.87	1.11	1.27	1.26	1.16	1.24
RSM	0.28	0.59	0.46	0.43	0.88	0.8	1	1.25	1.23	1.07	1.22
GBR	0.09	0.29	0.19	0.09	0.91	0.85	1.01	1.13	1.12	1.04	1.12
DEU	0.15	0.23	0.3	0.09	0.94	0.89	1.04	1.16	1.16	1.08	1.12
DNK	0.15	0.24	0.29	0.09	0.93	0.88	1.02	1.15	1.14	1.07	1.12
SWE	0.22	0.27	0.1	0.09	0.94	0.89	1.04	1.17	1.16	1.08	1.15
FIN	0.19	0.36	0.13	0.09	0.93	0.87	1.03	1.16	1.15	1.07	1.16
REU	0.18	0.33	0.3	0.21	0.9	0.84	0.99	1.12	1.11	1.03	1.13
EFT	0.12	0.31	0.16	0.09	0.93	0.88	1.04	1.16	1.15	1.07	1.13
CEA	0.17	0.55	0.41	0.4	1.02	0.96	1.14	1.32	1.32	1.2	1.29
FSU	0.19	0.54	0.29	0.26	0.81	0.76	0.92	1.15	1.13	0.97	1.16
TUR	0.17	0.56	0.6	0.48	0.95	0.89	1.06	1.24	1.23	1.11	1.28
RME	0.31	0.52	0.57	0.5	0.9	0.83	1.01	1.21	1.19	1.06	1.18
MAR	0.18	0.7	0.7	0.65	0.99	0.9	1.12	1.48	1.46	1.21	1.28
RNF	0.23	0.68	0.68	0.55	1.04	0.95	1.17	1.45	1.43	1.25	1.29
SAF	0.5	0.55	0.63	0.65	0.77	0.72	0.88	1.17	1.12	0.95	1.21
RSA	0.65	0.61	0.52	0.53	0.76	0.71	0.89	1.54	1.46	1	1.35
RSS	0.68	0.62	0.62	0.52	0.82	0.77	0.96	1.52	1.46	1.06	1.39
ROW	0.33	0.56	0.57	0.55	0.9	0.85	1.02	1.27	1.25	1.08	1.32

Table No. 5: Fuel/Energy types in OSeMOSYS

AGRBIO	Solid biomass used in agriculture
AGRCHC	Charcoal used in agriculture
AGRDSL	Diesel used in agriculture
AGRELC	Nicaragua agriculture electricity demand (includes fishing)
AGRGSL	Gasoline used in agriculture
AGRLPG	LPG used in agriculture
AGRWAT1	Water used in agriculture region 1 (Pacific)
AGRWAT2	Water used in agriculture region 2 (Central)
AGRWAT3	Water used in agriculture region 3 (Atlantic)
BIO	Biomass
CHC	Charcoal
COF	Coffe
COMBIO	Biomass used in the commercial sector
COMCHC	Charcoal used in the commercial sector
COMDSL	Diesel used in the commercial sector
COMELC	Electricity used in the commercial sector
COMGSL	Gasoline used in the commercial sector
COMKER	Kerosene used in the commercial sector
COMLPG	LPG used in the commercial sector
COMWAT1	Water used in commercial sector region 1 (Pacific)
COMWAT2	Water used in commercial sector region 2 (Central)
COMWAT3	Water used in commercial sector region 3 (Atlantic)
CRP	Other crops
CRU	Crude oil
DSL	Diesel
ELC001	Centrally generated electricity
ELC002	Electricity for distribution
GEO	Geothermal energy
GRN	Grains
GSL	Gasoline
HFO	Fuel Oil
HYD	Hydro energy
INDBIO	Biomass used in the industrial sector
INDDSL	Diesel used in the industrial sector
INDELC	Electricity used in the industrial sector
INDGSL	Gasoline used in the industrial sector
INDHFO	Fuel oil used in the industrial sector
INDKER	Kerosene used in the industrial sector
INDLPG	LPG used in the industrial sector
INDPCK	Petroleum coke used in the industrial sector
INDWAT1	Water used in industrial sector region 1 (Pacific)
INDWAT2	Water used in industrial sector region 2 (Central)
INDWAT3	Water used in industrial sector region 3 (Atlantic)
KER	Kerosene
LND1	Land resource region 1 (Pacific)

LND2	Land resource region 2 (Central)
LND3	Land resource region 3 (Atlantic)
LNDFOR1	Forested land region 1 (Pacific)
LNDFOR2	Forested land region 2 (Central)
LNDFOR3	Forested land region 3 (Atlantic)
LNDMPA1	Permanent meadows and pastures region 1 (Pacific)
LNDMPA2	Permanent meadows and pastures region 2 (Central)
LNDMPA3	Permanent meadows and pastures region 3 (Atlantic)
LNDOTH1	Other land region 1 (Pacific)
LNDOTH2	Other land region 2 (Central)
LNDOTH3	Other land region 3 (Atlantic)
LPG	Liquid petroleum gas
OHC	Other hydro carbons
OSD	Oilseeds
PCK	Petroleum coke
PRM	Permanent crops
PWRBIO	Biomass used in the power sector
PWRDSL	Diesel used in the power sector
PWRGEO	Geothermal energy used in the power sector
PWRHFO	Fuel oil used in the power sector
PWRHYD	Hydro energy used in the power sector
PWRSOL	Solar energy used in the power sector
PWRWAT1	Water used in power sector region 1 (Pacific)
PWRWAT2	Water used in power sector region 2 (Central)
PWRWAT3	Water used in power sector region 3 (Atlantic)
PWRWND	Wind energy used in the power sector
RESBIO	Biomass used in the residential sector
RESCHC	Charcoal used in the residential sector
RESELC	Electricity used in the residential sector
RESKER	Kerosene used in the residential sector
RESLPG	LPG used in the residential sector
RESWATR1	Water used in residential sector rural region 1 (Pacific)
RESWATR2	Water used in residential sector rural region 2 (Central)
RESWATR3	Water used in residential sector rural region 3 (Atlantic)
RESWATU1	Water used in residential sector urban region 1 (Pacific)
RESWATU2	Water used in residential sector urban region 2 (Central)
RESWATU3	Water used in residential sector urban region 3 (Atlantic)
SOL	Solar energy
SUG	Sugar
TRADSL	Diesel used in the transport sector
TRAELC	Electricity used in the transport sector
TRAGSL	Gasoline used in the transport sector
TRAJFL	Jet fuel used in the transport sector
UPSDSL	Diesel used in the upstream sector
UPSELC	Electricity used in the upstream sector
UPSHFO	Fuel oil used in the upstream sector

UPSKER	Kerosene used in the upstream sector
UPSLPG	LPG used in the upstream sector
UPSOHC	Other hydrocarbons used in the upstream sector
UPSWAT1	Water used in transformation sector region 1 (Pacific)
UPSWAT2	Water used in transformation sector region 2 (Central)
UPSWAT3	Water used in transformation sector region 3 (Atlantic)
VEG	Vegetables
WATENV1	Environmental water flow region 1 (Pacific)
WATENV2	Environmental water flow region 2 (Central)
WATENV3	Environmental water flow region 3 (Atlantic)
WATEVT1	Evapotranspiration region 1 (Pacific)
WATEVT2	Evapotranspiration region 2 (Central)
WATEVT3	Evapotranspiration region 3 (Atlantic)
WATGRD1	Groundwater recharge region 1 (Pacific)
WATGRD2	Groundwater recharge region 2 (Central)
WATGRD3	Groundwater recharge region 3 (Atlantic)
WATNAG1	Water for non-agricultural uses region 1 (Pacific)
WATNAG2	Water for non-agricultural uses region 2 (Central)
WATNAG3	Water for non-agricultural uses region 3 (Atlantic)
WATPRC1	Precipitation region 1 (Pacific)
WATPRC2	Precipitation region 2 (Central)
WATPRC3	Precipitation region 3 (Atlantic)
WATRUN1	Runoff water region 1 (Pacific)
WATRUN2	Runoff water region 2 (Central)
WATRUN3	Runoff water region 3 (Atlantic)
WATSUR1	Surface water region 1 (Pacific)
WATSUR2	Surface water region 2 (Central)
WATSUR3	Surface water region 3 (Atlantic)
WND	Wind energy

Table No. 6: OSeMOSYS units

#	Parameter	Unit	Default
1	AnnualEmissionLimit	kton	9999
2	AnnualExogenousEmission	kton	0
3	AvailabilityFactor	-	1
4	CapacityFactor	-	1
5	CapacityOfOneTechnologyUnit	-	0
6	CapacityToActivityUnit	-	1
7	CapitalCost	Million $/GWh	0
8	DaysInDayType	-	7
9	DepreciationMethod	-	1
10	DiscountRate	-	0.05
11	EmissionActivityRatio	Mton/PJ	0
12	EmissionsPenalty	m$/Mton	0
13	FixedCost	m$/GW	0
14	InputActivityRatio	-	0
15	MinStorageCharge	PJ	0
16	ModelPeriodEmissionLimit	kton	99999
17	OperationalLife	Year	1
18	OperationalLifeStorage	Year	99
19	OutputActivityRatio	-	0
20	REMinProductionTarget	PJ	0
21	ReserveMargin		1
22	ResidualCapacity	GW	0
23	ResidualStorageCapacity	GW	0
24	SpecifiedAnnualDemand	PJ	0
25	SpecifiedDemandProfile	-	0
26	StorageMaxChargeRate	PJ	99
27	StorageMaxDischargeRate	PJ	99
28	TotalAnnualMaxCapacity	GW	99999
29	TotalAnnualMaxCapacityInvestment	m$	99999
30	TotalAnnualMinCapacity	GW	0
31	TotalAnnualMinCapacityInvestment	m$/GW	0
32	TotalTechnologyAnnualActivityUpperLimit	PJ	99999
33	TotalTechnologyModelPeriodActivityUpperLimit	PJ	99999
34	VariableCost	Million $	0