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Quantifying cross-sectoral impacts of investments in climate change mitigation in Ecuador

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ABSTRACT

This study investigates whether a key conclusion of the *Stern Review on the Economics of Climate Change*, that is, an annual investment of 1% of Gross Domestic Product (GDP) to mitigate the negative economic impacts of climate change, would allow for the reduction of greenhouse gas (GHG) emissions in the Republic of Ecuador (Ecuador). An integrated modeling approach to support climate policy evaluation, consisting in the Threshold 21 (T21) model and other methodologies, is employed to carry out a country-wide, cross-sectoral analysis of Ecuador's energy, social, economic and environmental sectors. The investigation assumes an investment of 1% of GDP in energy efficiency and renewable energy technologies to measure the potential to stabilize carbon emissions from fossil fuel electric power generation. Results of the study indicate that while investing 1% of GDP annually through 2025 would reduce GHG emissions in the electric power sector, it would not stabilize national emissions. On the other hand, avoided electricity costs realized from the investment in energy efficiency, amounting to over USD 5 billion by 2025, could contribute significantly to poverty alleviation, job creation, and to the improvement of social services. Finally, the authors find that these positive economic and social results are likely to increase energy consumption, making the goal to reduce GHG emissions more challenging.

Introduction

The Stern review, released in 2006 by economist Sir Nicholas Stern, Head of the Government Economic Service and Adviser to the Government of the United Kingdom, offers a comprehensive survey of the evidence on the economic impacts of climate change resulting from the anthropogenic release of greenhouse gases into the Earth's atmosphere (Stern, 2007).

A key position advocated in the review is a global investment equivalent to 1% of world GDP per annum to make a transition from carbon-based fossil fuels to a low-carbon economy. The Stern review argues for the stabilization of emissions at 500–550 ppm CO_2 in order to avoid the environmental, economic and social impacts of catastrophic climate change. The review further cautions that the failure to invest in greenhouse gas mitigation represents a serious economic risk: "Analyses that take into account the full ranges of both impacts and possible outcomes – that is, that employ the basic economics of risk – suggest that BAU [Business-as-Usual] climate change will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%... now and into the future. Taking account of the increasing scientific evidence of greater risks, of aversion to the possibilities of catastrophe, and of a broader approach to the consequences than implied by narrow output measures, the appropriate estimate is likely to be in the upper part of this range" (Stern, 2007).

Growing scientific evidence concurrent with and subsequent to the release of the Stern review details an even greater potential risk of BAU climate change on environment, economy and society. Given that the review's estimated cost of mitigation is small relative to the projected economic risks of unmitigated climate change, the authors argue that it is incumbent upon all nations to conduct risk assessments and evaluate appropriate mitigation policies consistent with the recommendation of the Stern review: an annual investment of 1% of world GDP for the development of a low-carbon economy.

This paper provides a general overview of how an integrated approach utilizing Millennium Institute's (MI)[2] Minimum Country

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[2] The Millennium Institute (MI) is a not-for-profit development research and service organization headquartered in Arlington, Virginia, USA. Founded in 1983 by Dr. Gerald O. Barney as follow up to the Global 2000 Report to the President, MI is committed to finding practical means to promote sustainable development. MI's mission is (1) to develop and provide advanced analytical tools for national and global development; and (2) to formulate values-related questions and analyses on the consequences of alternative development strategies. www.millennium-institute-org.

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Model (MCM) (Pedercini et al., 2008) was applied to a country-wide analysis of the energy sector of the Republic of Ecuador. The intent of the country-wide analysis was to demonstrate the efficacy of utilizing an integrated approach to modeling utilizing MCM could provide useful decision support services for climate change mitigation utilizing "a broader approach to the consequences than implied by narrow output measures." (Stern, 2007).

The analysis focused on investments in electricity subsector to project reductions in carbon emissions from fossil fuel power generation. Outcomes across spheres of the model – environment, society and economy – were projected through 2025. Ecuador was selected for analysis due to research conducted by SolarQuest® (Chelsea, VT) in the Province of the Galapagos under agreement with e8 Network for Expertise on the Global Environment (e8), Fideicomiso Mercantil San Cristobal (San Cristobal Wind Project Commercial Trust), and agencies of the United Nations and Ecuador. SolarQuest® researched energy supply and demand models subsequent to planning a proposed Renewable Energy Application Laboratory (REAL) of the Galapagos Archipelago. The proposed REAL will provide technical assistance services in energy efficiency and renewable energy technologies for developing nations. MCM emerged as an integrated modeling software under consideration by SolarQuest® for core laboratory services.

While global climate change models exist which forecast key elements of environmental, economic and/or social impacts, few models apply an integrated systems approach equivalent to the capacity of Millennium Institute's Threshold 21 (T21) (Millennium Institute, 2005) and MCM to examine consequences across a broad spectrum of output measures. Moreover, the methodology utilized for data collection and the assessment of the output measures confirmed by MCM, a simplified version of T21, demonstrated the efficacy to accelerate climate mitigation deploying an education-based human capacity building mechanism, the primary mechanism examined for the proposed REAL.

Based on the preliminary outcomes of this analysis, the MCM model proved useful to understanding the key position advocated in the Stern review and demonstrated its usefulness as a tool for inclusion in the technical services portfolio for the proposed REAL. The authors further concluded that national energy assessments aggregated into an integrated T21 or MCM-based System Dynamics global energy model can provide participants of the United Nations Convention on Climate Change (UNCCC) and the Conference of Parties (COP) critical decision support services – in situ – to assess global climate change mitigation policies as they face the challenge of formulating a legally-binding agreement(s) to limit or reduce greenhouse gas emissions in advance of the expiration of the Kyoto Protocol in 2012.

Policy support tools

A large number of models with unique attributes are available for either analysis of energy or integrated national planning. Two categories of energy–economy models are commonly accepted: i) market and behavior-oriented models and ii) bottom-up optimization models (Bunn and Larsen, 1997). Examples of the first category are POLES (LEPII-EPE, 2006) and PRIMES (NTNUA, 2005, 2006). These models rely on adaptive expectations to simulate the dynamics of energy systems. They take into account the introduction of new technologies and attempt to represent their adoption process. Agent Based Modeling (ABM) is becoming increasingly used for this purpose.

Examples of the second category are MARKAL (MARKet ALLocation) (Fishbone et al., 1983; Loulou et al., 2004) and MESSAGE (Model of Energy Supply Systems Alternatives and their General Environmental Impacts) (Messner et al., 1996; Messner and Strubegger, 1995). These models operate under perfect foresight and optimize energy flows given demand and an objective function. NEMS (National Energy Modeling System) (EIA, 2003), proposed by the Energy Information Administration (EIA), and WEM (World Energy Model) (IEA, 2004), built by the International Energy Agency (IEA), belong to this category. These models are much more detailed than the model used in this study; however, given their focused use for energy related projections, many feedbacks among society, economy, and the environment are not constructed into the model dynamics. In fact, even such crucial variables as economic growth, population dynamics, employment, technology, and prices are treated as exogenous inputs to the models. Therefore, the projections shown in the Annual Energy Outlook (EIA, 2007a) and in the World Energy Outlook (IEA, 2006) are limited to energy and a few economic indicators, and they derive much of their output from the exogenous assumptions concerning society and the economy.

Computable Global Equilibrium (CGE) models, as in the case of PRIMES (NTNUA, 2005 and 2006) and MESSAGE (IIASA, 2002) represent the economy and energy through an iterative process based on econometrics and linear optimization (Loulou et al., 2004); consequently, they do not capture medium and long-term trends dynamically (Bunn and Larsen, 1997; Sterman, 1988). Rather, their projections (extended to 2030) are adjusted according to the latest data available on technology, investment, etc.

System Dynamics energy related models include the IDEAS model (AES Corporation, 1993), an improved version of the FOSSIL models originally built by Roger Naill (Backus et al., 1979), the Energy Transition Model (Sterman, 1981), the Petroleum Life Cycle Model (Sterman et al., 1988; Davidsen et al., 1990), and the Feedback-Rich Energy Economy model (Fiddaman, 1997). However, these models do not encompass the interactions between energy, society, economy, and environment, which constitute one of the major innovations introduced by the Millennium Institute (for what concerns society, economy and environment) and the present study, which focuses on energy. In fact, FOSSIL, IDEAS and the Life Cycle models consider energy in isolation, Sterman's model includes only energy–economy interactions, and Fiddaman's FREE model exclusively focuses on economy–climate interactions. Nevertheless, both FOSSIL and IDEAS models made important contributions, notably their use by the Department of Energy for policy planning during 1980s.

T21 and MCM combine these two categories into one holistic framework. They offer a complementary approach that allows for optimization flows while simultaneously simulating the interaction of a large number of feedback loops across the environment, economy and society.

The Minimum Country Model is a Systems Dynamic model primarily developed by Dott. Matteo Pedercini at the Millennium Institute on a Vensim software platform (Ventana Systems, Inc. Harvard, MA). MCM, a simplified version of MI's flagship model Threshold21, is a quantitative tool for integrated, comprehensive national planning utilizing an integrated modeling approach to support policy formulation and evaluation. T21 and MCM are often used to support the overall process of national, regional and global strategic planning by facilitating the collection of cross-sectoral information and simulating potential longer term impacts of public policies on social, economic and environmental indicators.

MCM is constructed on a software platform that allows for the representation and interaction of a complex network of feedback loops, which underlie the development mechanisms common to developing and industrialized countries. T21 and MCM are organized in spheres, sectors and modules and can be customized following a modular approach. MCM-Ecuador is largely focused on energy, which is considered to be a sphere, together with society, economy and environment, and accounts for a total of 20 modules, 8 of which belong to the energy sphere as shown in Table 1.

The creation of MCM-Ecuador begins with the customization of and initial general model, called "Starting Framework". A specific set

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Table 1
Modules, sectors and spheres of MCM-Ecuador.

Society	Economy	Environment
Population sector:	*Production sector:*	*Land sector:*
1. Population	6. Firms	10. Land
Education sector:	*Household sector:*	*Water sector:*
2. Education	7. Households accounts	11. Water demand and supply
Health sector:	*Government sector:*	*Energy sector:*
3. Access to basic health care	8. Government accounts	12. Energy prices
	9. Banks	13. Energy demand
Infrastructure sector:		14. Electricity demand
4. Roads		15. Electricity production
Labor sector:		16. Energy consumption
5. Employment		*Emission sector:*
		17. GHG emission, CH4, N2O, SOX
		Sectors for analysis
		18. Electricity production capacity
		19. Energy demand reduction
		20. Energy conversions

of issues, as well as selected geographical boundaries, define the structure of the Ecuador model. The content of individual modules is based upon accepted peer reviewed research within its designated field and targeted to a specific governing dynamics isolated by the research inquiry. By example, modules in the economy sphere are based upon the Social Accounting Matrix and Cobb-Douglas production functions, and government accounts are created to replicate International Monetary Fund and World Bank accounting practices. Selected studies are then translated into stock and flow models and integrated with ad-hoc research and/or national policy determinants. The distinctive characteristic of T21 and MCM is the manner in which various determinants are linked together forming a complex link of feedback loops in which ad-hoc research and/or policies can then be analyzed and weighted as driving or limiting a country's development agenda.

Model logic within the MCM-Ecuador model is driven by national, or as in the case of global climate change, international policy objectives. MCM-Ecuador provides a platform for evaluating policy intervention strategies in order to move a nation's development agenda towards a desired outcome(s), and it serves as a monitoring tool to assess the impact of policy implementation over time in order to plan corrective actions.

Data collection and model customization

A project aiming at analyzing the impacts of national energy policies on the development of a country has to account for social, economic and environmental factors. While the latter are mainly accounted for as energy consumption and generation of emissions in the present study, a few more causal relations are considered in the two remaining spheres. In fact, on the socio-economic side, investments in energy efficient technology influence, among others, domestic energy consumption, which in turn has a positive impact on disposable income. Similarly, in the case of industrial sectors the avoided cost for energy consumption can be reinvested in more efficient capital to boost production, while demand for goods increases due to higher households spending. On the public sector side, lower energy expenditures and increased revenues (stimulated by higher spending and therefore higher GDP) allow the government to increase investments in infrastructure, such as roads, education and health. Better infrastructure and social services increase productivity of labor, by improving health, education and providing adequate infrastructure to stimulate commerce (e.g. roads).

It has to be noted that in the case of energy efficiency, reductions in energy consumption can be immediately seen when new appliances are bought and installed. On the other hand, increases in spending can be seen in the medium term, while improvement in social infrastructure and the impact of education on total factor productivity will be evident in the longer term. Changes in the demographic structure of the country, due to increasing income, literacy and access to basic health care, will be visible as well over the longer term.

Data collection

The data necessary for the customization of MCM-Ecuador were obtained mainly from the United Nations Population Statistics (UN, 2007), Banco Central del Ecuador (BCE, 2007), US Energy Information Administration (EIA) (EIA, 2007b) and Ministry of Energy and Mines (CNCE and Cenance Corporation, 2005; CNE, 2006). Data on energy efficiency have been estimated by SolarQuest and local Ecuadorian students under a UN and e-8 funded project started in 2003 (Baer, 2007; UNDP, 2006). The MCM uses these data to estimate the impact of investments in energy efficiency in Ecuador, with the assumption that appliances and infrastructure are similar to the ones available in the Galapagos.

In 2003, Solar Quest, the Ministry of Education and Culture (MEC) and Colegio Tecnico Ignacio Hernandez (CTIH) collaborated on the development of an educational pilot program called: Action, Communications, Technology, and Science (ACTS). ACTS is a productivity-center, service-learning (PCSL) curriculum developed by SolarQuest. The ACTS curriculum was designed to fulfill the community service requirement of the MEC for students in the fifth-level (11th grade by U.S. standards) while strengthening core academics and introducing students to computer sciences. In the ACTS pilot program each student provided 200 h of community service to monitor and analyze energy consumption on the San Cristobal electric power grid. Students researched the potential for end-use energy efficiency to reduce electricity demand and consumption within the residential and commercial sectors.

As part of this project (ACTS 2004 — see Table 2), students coordinated a public information campaign on refrigerators, radio and television, and distributed audit request forms through the utility administrative office, public schools and commercial shops. The audits concluded that 36% of the 500 refrigeration units tested within the city of Puerto Baquerizo Moreno, San Cristobal, failed to cycle off over a 24-hour test period. Utilizing household census data and survey information, students estimated the number of refrigerators on the four inhabited islands of the Province at 6,000 units. Based on the results of tests, and the total number of refrigerators in the Province, it was extrapolated that approximately 2,160 refrigerators could have been consuming energy on a continuous basis. Utilizing the survey results and previous household audits, students estimated the potential to decrease energy demand in the Galapagos to be in the proximity of 1.4 megawatts (including lighting measures), reducing the costs of the Global Environment Facility (GEF) umbrella program (ECU/02/G41), Renewable Energy for Electricity Generation – Renewable Electrification of the Galápagos Islands (ERGAL), by approximately $4.5 million. ERGAL is a $33 million capital investment aimed at replacing the production of nearly 50% of the combined electricity consumption in the Province with electricity primarily from wind and solar photovoltaic (PV).

Table 2
Energy consumption measurement exercises carried out in the Galapagos between 2004 and 2006.

Study	Area	Methodology
ACTS 2004	Island of San Cristobal	Household appliance inventory, billing data analysis, end-use metering, and factory appliance performance data.
MEM 2005	Island of Santa Cruz	Survey, billing data analysis, and factory appliance performance data.
ACTS 2006	Island of Santa Cruz	Actual appliance inventories and actual measurements of appliances operating under field conditions replaced the MEM 2005 survey-constructed appliance inventory and factory appliance performance data.

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The results of the ACTS 2004 program prompted the Ministry of Energy and Mines (MEM) to conduct demand and consumption study on the electricity grid on the island of Santa Cruz in 2005. The MEM study was based upon consumer surveys and standard appliance consumption data rather than on data collection methodology as deployed in the ACTS 2004 pilot project. More specifically, the ACTS 2004 study used several methodologies: household appliance inventory, billing data analysis, end-use metering, and factory appliance performance data. The MEM 2005 study methodology used a survey, billing data analysis, and factory appliance performance data. MEM consultants concluded that refrigeration represented 38% of the electricity demand in the Galapagos residential sector.

ACTS 2006 students were given the task by SolarQuest to verify the results of the MEM study. After two months of intensive remedial training, students were able to undertake a more comprehensive analysis of ACTS 2004 data in order to assess the conclusions of the MEM study. Their analysis focused primarily on residential electricity end-use appliance demand and consumption. Using the survey-constructed appliance inventory and factory appliance performance data in the MEM 2005 study as framework for comparison, the students replaced MEM data with the actual appliance inventories and actual measurements of appliances operating under field conditions. Also, they conducted additional appliance energy audits to substantiate the ACTS 2004 data and close any data gaps between the ACTS 2004 data and MEM 2005 survey data. The consumption models obtained from this study were then based upon whole house metering combined with concurrent appliance metering in order to achieve a data driven energy consumption pro-forma (audited energy demand and consumption balance sheet).

ACTS students and SolarQuest staff then interpolated the results of the ACTS 2006 research. These indicate that current household consumption is allocated as follows: refrigeration 63%, lighting 25% (12% for incandescent, 11% for fluorescent and 2% for CFL lightning), and other appliances (12%). Household consumption was then recalculated based on ultra-high efficiency refrigerators and replacement of inefficient incandescent bulbs with compact fluorescent lighting (CFL), resulting in 26% consumption allocated to refrigeration, 29% to CFL lightning and 45% to other appliances.

Model description

The core of the Economy sphere of MCM-Ecuador is represented by GDP, as one aggregated item, which is characterized by a Cobb-Douglas production function with inputs of labor and capital, but also technology, infrastructure (roads), energy prices, literacy (education) and life expectancy (health). A Social Accounting Matrix (SAM) (Drud et al., 1986) is used to elaborate the economic flows between the main actors in the economy: government, households, producers and banks. The government sector collects taxes based on economic activity and allocates expenditures by major category, which then impacts the delivery of public services, subject to budget balance constraints. Standard International Monetary Fund (IMF) (IMF, 2001) and Banco Central del Ecuador (BCE) (BCE, 2007) budget categories are employed, and key macro balances are incorporated into the model.

The Social sphere contains detailed population dynamics by sex and one-year age cohort, health and education programs. These sectors take into account, for example, the interactions of family planning, health care and adult literacy on fertility and life expectancy, which in turn determines population growth. Population determines the labor force, which shapes employment. Education, health levels, and other factors influence labor productivity. Employment and labor productivity affect the levels of production from a given capital stock. And these factors all affect the levels of saving for investment and consumption expenditures.

The Environment sphere tracks pollution impacts on the environment. It estimates the consumption of natural resources – both renewable and non-renewable – and can estimate the impact of the depletion of these resources on production and prices. Energy demand and supply are calculated endogenously. Particular attention is devoted to electricity generation, especially when fossil fuels need to be utilized. More specifically, the energy sources considered in the model are oil, natural gas and electricity (which in Ecuador is generated from oil, natural gas and renewable energy sources, mainly hydro) (CNCE and Cenance Corporation, 2005; CNE, 2006). Energy demand is calculated for oil, natural gas and electricity (Fig. 1). The factors influencing demand are population, GDP, technology and energy prices. Energy consumption is assumed to equal demand given the large availability of oil and natural gas in Ecuador. Energy prices

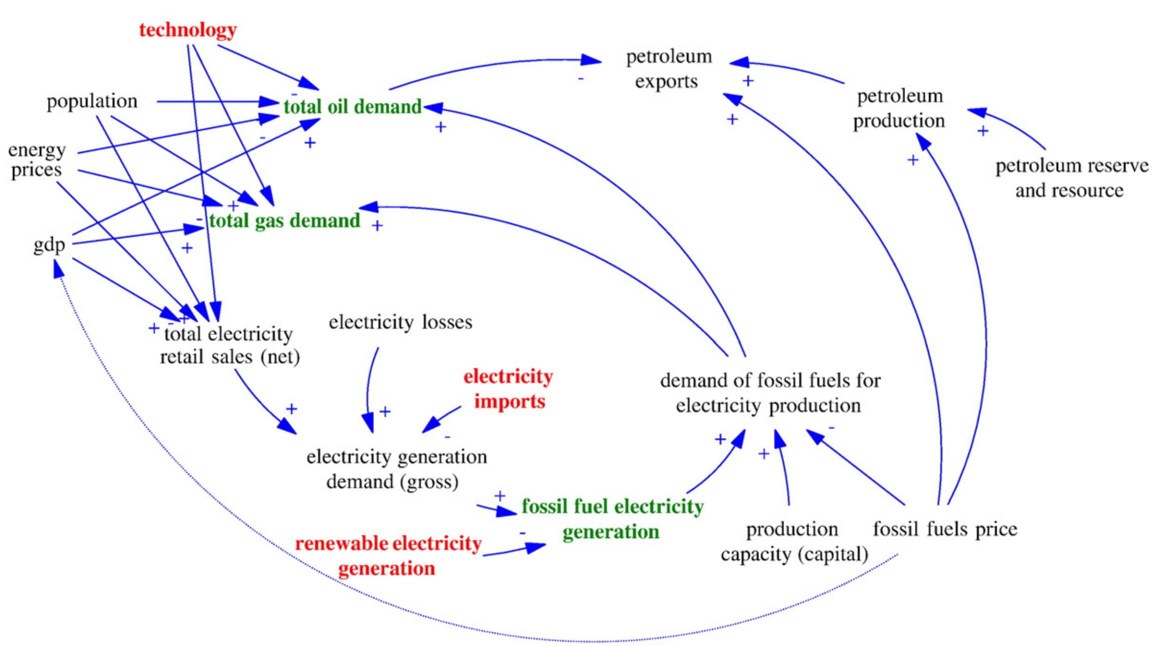

Fig. 1. MCM-Ecuador, conceptual overview of the energy sector, highlighting main output variables (in green) as well as policies and assumption simulated (in red). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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and costs are based on projections made using Threshold21 customized to the United States, which largely focus on the national and global energy sector and where world demand and supply are calculated to obtain global fossil fuel prices (Bassi, 2008). Energy technology addresses energy efficiency and it is calculated based on the field study carried out in the Galapagos by SolarQuest (Fonseca, 2007). Air Pollution includes emissions (CO_2, CH_4, N_2O, SO_X, and total greenhouse gasses). Pollution is based on fossil fuel consumption only.

Under the leadership of the Millennium Institute and in collaboration with a group of students from Middlebury College, the team created the following causal loop diagram to determine which factors affect electricity use and greenhouse gas emissions, and what feedback loops exist among them (Fig. 2).

Simulation results

The baseline scenario assumes no changes in any of the current patterns or policies and projects the behavior of these variables from 1990 to 2025. Results of the simulations show that greenhouse gas emissions will continue to rise well into the 21st century, driven by growing fossil fuel consumption. The latter is driven by increasing energy demand, which is projected to grow both as a result of population trends and continued growth in GDP. Projections also indicate that improvements in energy efficient technology will lower energy demand by increasing the efficiency of consumer appliances. Average energy efficiency was exogenously set to generate a 37.5% reduction in electricity demand in the residential sector, all else equal.

Assuming that current trends continue in Ecuador, which assumes that electricity imports are being held constant at 2007 level (6% of demand), greenhouse gas emissions are projected to increase to 35.6 million tons/yr by 2025, a 50% growth from 2007 (23.63 million tons/yr) levels.

The immediate cause of this rise is an increase in fossil fuel consumption from 309.2 trillion Btu in 2007 to 472 trillion Btu in 2025 (or 325 PJ and 500 PJ respectively). The projected increase in fossil fuel consumption occurs partly due to rise of energy consumption, growing from 424.6 to 676.6 trillion Btu (or 448 PJ and 713 PJ respectively), driven by GDP and population — projected to grow from 10 million in 1990 to 17 million in 2025.

Retail sales of electricity in the residential sector begin at 4 million kWh in 2007 and grow to 7 million kWh by 2025. Electricity sales are growing at a faster rate than overall energy demand, reflective of a disproportional increase in the demand for residential electricity as population and income grow. Hydroelectric generation shows minimal potential to increase in Ecuador (CNCE and Cenance Corporation, 2005), meaning that increased demand for electricity must be met by augmenting fossil fuel capacity or other renewables, e.g. wind. As a consequence, in order to meet rising electric power demand, fossil fuel (thermal) installed capacity is projected to increase from 1,800 MW in year 2006 to 5,500 MW in 2025. Correspondingly, the fraction of electricity generated by hydro decreases to 27% in 2025 from its 50% share in 2007.

In 2006, total government expenses (in current USD) totaled $8.57 billion, $30.67 million of which are spent in the energy sector. Assuming no policy changes by 2025, government expenditures on energy will total $66.46 million. Total overall government investment in 2006 was $1.93 billion, compared with $5 billion of private investments. Per capita real disposable income in Ecuador remained nearly constant from 1990 to 2007 as the country recovered from the 1999 financial crisis. After 2007 per capita income is projected to rise, underlying the shift to the US dollar after 2000 and its likely lower volatility relative to the sucre. Ecuador's public expenditures in health, education and roads are projected to rise with increasing government spending, allowing to reach 100% average adult literacy rates by 2021 (95% in 2010). Public expenditure on roads is projected to allow for regular maintenance of the current network, with the kilometers of functioning roads reaching 55,000 in 2025, from 45,000 in 2006. Access to basic health care reaches 100% by 2010.

Concluding, maintaining business as usual policies in Ecuador will cause gradual improvements in economic conditions, also met by growth in fossil fuel consumption and carbon emissions. Part of the increase in emissions results from growing residential electricity demand.

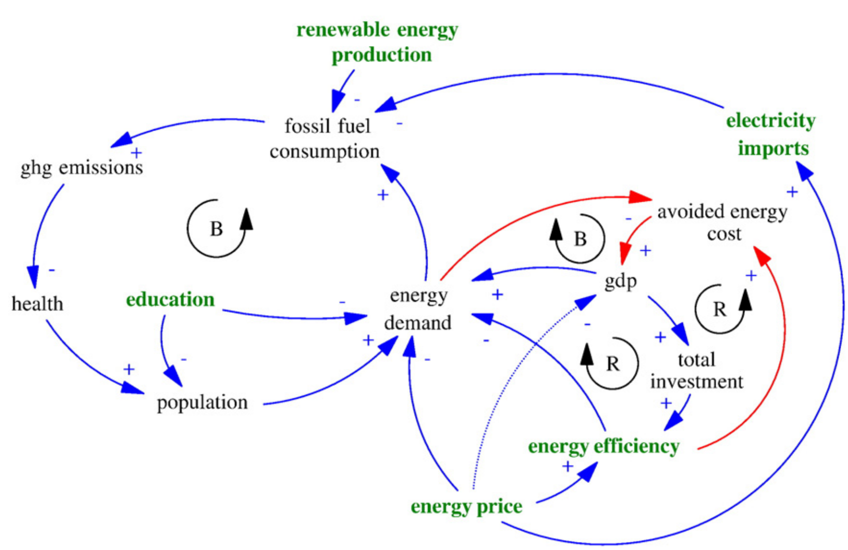

Fig. 2. MCM-Ecuador, causal loop diagram representing the linkages between the power sector and the rest of the model. Being fossil fuels consumption the main cause for the generation of greenhouse gas emissions within the power and energy sectors, emphasis has been put on the main factors influencing energy demand. This is correlated, and causal related, with GDP, energy prices and energy efficiency as well as population and education. While GDP and population are positively related to energy demand, with population – health – being impacted by emissions (balancing loop), increasing energy efficiency, prices and education curb it. Specifically, targeted education tends to decrease the use of energy, both by influencing behavioral change as well as by decreasing fertility and therefore population growth. On the other hand, second order impacts of education increase energy demand, because higher education normally leads to higher income. Similarly, while energy price and energy efficiency generally tend to decrease energy demand, energy efficiency, under certain circumstances, may allow the main actors in the economy to save – and spend – enough resources to push demand further up (balancing loop). In fact, high avoided costs have a positive effect on GDP, through increased consumption and investment, which in turn increases energy demand and total investment (reinforcing loop). On the supply side, renewable energy production and electricity imports, when high oil prices justify it, decrease fossil fuel consumption for domestic electricity generation.

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The following sections analyze the impact of several policy initiatives within the energy sector and their social, economic and environmental impacts.

Subsidizing electricity

Ecuador's elected president R. Correa has indicated that he will advocate government subsidies to reduce the price of electricity. Lowering the cost for consumers is a political move designed to increase his draw with voters. This policy, although it is projected to increase per capita disposable income, may increase electricity demand and greenhouse gas emissions. It may also generate a short-term rise in GDP as consumption increases, but in the long-term GDP may decline due to the worsening of government accounts and higher vulnerability to energy markets.

Scenario 1 simulates a subsidy of $0.01 per kWh, paid for from government revenues. All other parameters were identical to the baseline scenario. The yearly cost of implementing this model beginning in 2007 would be $101.38 million, approximately 1.5% of total government revenues. Such a small reduction in expenditures generated no significant impacts on government services and functional expenditure as measured by average literacy rate, access to basic health care or functioning roads. There was also a negligible impact on debt. Per capita disposable income did however rise by 1.5%, or $15. Contrary to our expectations, a $0.01 per kWh decrease in electricity prices did not significantly raise electric power demand and fossil fuel emissions. A $0.04 reduction in the energy price, however, would have a noticeable effect on emissions. This level of subsidy is to be considered unlikely when compared to current prices, which range from $0.08 to $0.10 per kWh (excluding taxes and final mark-ups) depending on the customer.

Correa's rationale for introducing a subsidy is alleviating burdens on the poor, as well as increasing his popularity. Subsidies such as the one hereby proposed, which are tied to kWh consumption, as simulated, is likely to generate unequal benefits favoring the rich. Customers who consume less will receive substantially less than the projected $15 and the wealthy customers will receive far more. For this reason, additional analyses of various provisions, such as a reduction of the subsidy as consumption increases, will be considered for further research.

Applying Stern's proposition

The first policy recommendation simulated allocates 1% of Ecuador's GDP to investments in energy efficiency, specifically energy efficient appliances. We would expect that the adoption of efficient appliances, facilitated by subsidies or other public measures, corresponding to the investment of 1% of GDP annually could potentially reduce electricity demand in spite of growing population and income, as well as generate customer savings through avoided costs. These “avoided costs” are here defined as the amount of money saved on a household's electric bill through the reduction of electricity consumption. The avoided cost is eventually reinvestment elsewhere, used for consumption, or saved. Reducing electricity demand will correspondingly decrease the need for new fossil fuel capacity, allowing for decrease in emissions relative to business as usual.

The MCM-Ecuador model calculated the initial energy efficiency investment, corresponding to 1% of GDP, to be $203 million in 2007 and reaching $450 million by 2025. This investment is projected to generate a 38% reduction in electricity demand relative to the baseline scenario. Total annual avoided costs will reach $600 million by 2025, around $40 annually per capita. This is three times larger than the disposable income increase produced by the subsidy simulated in Scenario 1, and consists in an increase in per capita disposable income of 2.6% as opposed to 1.5%. Annual household savings are now projected to reach $60, a four time increase with only twice the investment in the first year relative to Scenario 1. Total projected cumulative avoided costs will be nearly $5 billion by 2025.

Analyzing household consumption patterns using the system of national accounts (SNA) adopted, it can be noted that 79% of disposable income has been spent in Ecuador between 1990 and 2006 — the remaining 21% was divided into savings and investments. Since avoided energy costs directly increase disposable income, we simulated an additional, though maybe not realistic, assumption that 33% of the avoided costs ($15 per capita per year and $1.6 billion cumulative through 2025) will be spent into additional energy efficient technology. This scenario would approximate the case in which households, happy to save money on the electricity bill, would still keep replacing their appliances in a timely manner preferring energy efficient over non energy efficient appliances. This additional investment is projected to reduce electricity consumption by another 7%, yielding an overall 45% decrease in electricity demand in 2025.

These investments in energy efficiency in the residential sector allow replacing 1500 MW of fossil fuel (thermal) electricity generation capacity relative to the baseline scenario (see Fig. 3). GHG emissions, however, are not projected to significantly decline from their 2007 level. Rather, they increase at a fractionally smaller rate compared to the baseline scenario, reaching 32 million tons/yr in 2025, 10% less than in the base case (see Fig. 4). This is a 35% growth from 2007, a remarkable stabilization considering the projected economic and population growth. Further decreases in emissions in the power sector do not seem commercially viable at a significant scale. True reductions in emissions will need to be addressed in other energy intensive sectors too.

Investing in renewable energy

The second policy scenario simulated in this study adds a layer to Scenario 2. Keeping the investment of 1% of GDP in energy efficiency and the reinvestment of 33% of the avoided costs, this scenario assumes that the contribution of renewable energy (penetration rate) will be maintained at 2007 levels, or 50%. Therefore, in order to meet increasing power demand, differently from the previous scenarios, renewable energy installed capacity will have to increase alongside fossil fuel capacity. While this measure has little direct impact on population or energy demand, it is intentionally designed to further reduce fossil fuel consumption and limit the expansion of thermal electricity generation.

Results of the simulation show that by 2025, 10 TWh (million MWh) of consumption would have to be met by renewable energy. Assuming that the amount provided by hydroelectricity cannot increase much from the current 7 TWh/year output, an additional

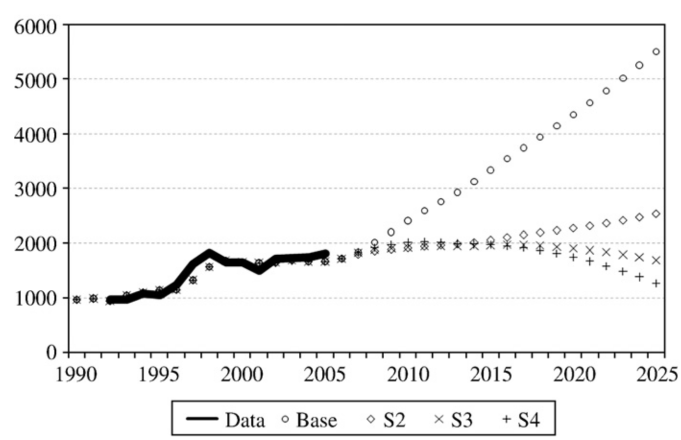

Fig. 3. Projections of thermal electricity production capacity for the period 1990–2025 (MW). Base: continuation of existing policies and trends. S2: energy efficiency investment. S3: S2 plus renewable enery investment. S4: S3 plus increase in electricity imports.

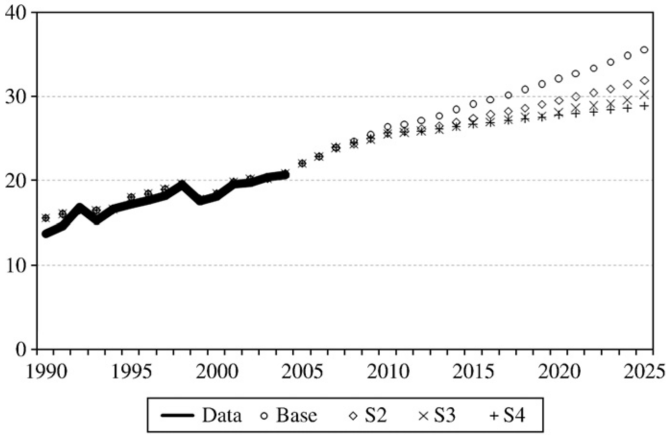

Fig. 4. Projections of total GHG emissions from fossil fuels for the period 1990–2025 (Million Ton/Year). Base: continuation of existing policies and trends. S2: energy efficiency investment. S3: S2 plus renewable enery investment. S4: S3 plus increase in electricity imports.

3 TWh/year of renewable energy infrastructure will need to be installed, representing a 45% increase from the current levels (Fig. 3). Projections indicate that these measures stabilize thermal electricity generation at 2007 levels. Furthermore, fossil fuel consumption in the power sector is projected to represent 20% of total fossil fuel consumption in 2025, stabilizing emissions from the electrical sector.

The continued increase in non-electric petroleum demand, however, would cause CO_2 emissions to maintain their steady, incremental rise reaching 30.26 tons/yr in 2025. This level is 27% higher than 2007, but 17% lower than the baseline scenario. Despite being lower than the baseline and Scenario 2, emissions have still would not reach a point of decline.

Increasing electricity imports

In a climate of volatile oil prices, Ecuador's government generates a considerable portion of its revenues by exporting petroleum, and would rather prefer not to use it to generate electricity for domestic consumption (exploration of and recovery activities for oil accounted for more that 20% of total national revenues in the last 10 years according to the Central Bank of Ecuador — BCE) (BCE, 2007). The balance of Ecuador's energy demand is generally met by imports from Colombia and Peru. Assuming that oil prices remain at profitable levels, Ecuador is likely to continue its policy of importing electricity and may even expand it into the future. This will reduce fossil fuel consumption and emissions in the power sector, although it creates carbon leakage, without solving the problem at a global scale.

In 2006 5.8% of Ecuador's energy electric power demand was met by imports. Scenario 4 assumes that imports will linearly rise to 15% by 2025, provided that oil prices increase or remain above $50 per barrel. All other parameters were kept as in Scenario 3.

Results of the simulation show that increasing electricity imports would further decrease fossil fuel consumption used for electricity generation as well as per capita electricity demand (32 million Btu, or 34 GJ, per person per year) relative to the baseline. It also further reduced total greenhouse gas emissions, although not enough to produce a significant decline. The observed emissions were only 2.5% less than Scenario 3 in 2025 (Fig. 4), but government accounts would be healthier and social services could be improved.

Conclusions

This study focused on the analysis of various actions aimed at reducing GHG emissions, with particular emphasis on investments in the power sector, one of the most energy intensive sectors in Ecuador.

Both synergies and elements of policy resistance where identified though the simulation of a variety of scenarios. While each of them provides its own benefits and disadvantages, the most effective policy recommendation to reduce energy consumption and curb emissions should take into account the context of each intervention with respect to the spheres that comprise society, economy and environment. Thus, the political reality that President Correa will seek popularity with voters must be taken into consideration as well as the emission reduction targets set by the government and international organizations.

The integrated approach to policy formulation and evaluation proposed in this study aimed at analyzing options to reduce GHG emissions while taking the national context into consideration to provide an analysis of the present, near-future, and long-term benefits and challenges associated with each of the described and simulated interventions.

Results of the analysis indicate that, for the short term, President Correa should increase subsidies for electricity. As discussed, this will decrease energy prices and increase disposable income for the citizens of Ecuador. If this measure works as intended, it will provide more political stability for Ecuador. With respect to emissions, the danger of increasing subsidies for energy is that it will increase energy consumption, and thus increase fossil fuel emissions. However, results of the simulation show that the increase in emissions from this measure was negligible overall.

In order to reduce emissions, the authors analyzed the impacts of investments in energy efficiency and renewable energy generation. These consist in improving end-use energy efficiency through increased investment in technology, and decreasing thermal electricity generation by investing in renewable energy sources. More in details, in order to increase end-use energy efficiency, the authors simulated an annual investment of 1% of GDP in energy efficient technology, with resources being provided by the Government. Other possible means of securing this investment include taxes, private investment, and attracting industry through incentives, such as modifying interest rates. Once secured, these funds would increase technology availability, thus increasing efficient use of electricity, which would decrease demand. As a consequence of decreasing electricity demand, fossil fuel consumption for electricity generation, and carbon emissions, will decline. Because energy efficient technology is available in the market, adoption could be quick, and would have an impact on carbon emissions in the short term.

In order to reach a long-term reduction of emissions, the role of fossil fuel in the energy profile must be drastically reduced. The authors simulated the capping of the use of fossil fuels for energy production at 50%, which is its current level, to move closer to this goal. The other half of energy production would come from investment in renewable energy production. Because increasing capacity requires years of development of infrastructure, this intervention is intended to take effect in 5–10 years. Possible sources of funding for this measure were not addressed in this research work.

Results of the simulations indicate that the combination of all these comprehensive policy recommendations would stabilize carbon emissions in the power sector at 2010 level. It is worth noting that these measures, while stabilizing emissions in the power sector, do not lead to an overall decrease in national emissions from energy use, for which a larger investment in the industrial and transportation sectors would be needed. While investing in the power sector does not put a heavy load on the citizens, actions in the industrial and transportation sectors would require a strong and active participation (investment) of the government, the private sector, or households that may already be facing poverty. On the other hand, the total avoided costs from investing 1% of GDP into energy efficiency is projected to reach $5B by 2025, and additional benefits can be obtained when reinvesting part of these avoided costs into energy efficiency or social services. This additional infusion of capital may

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lead to overall better results in reducing emissions but would further stimulate the economy too, thereby increasing energy demand.

Thus, this research work indicates that a greater investment than the Stern Report's suggested 1% of GDP will be necessary to achieve significant reductions in greenhouse gas emissions from fuel use in Ecuador and that the representation of the context, through the creation of an integrated computer simulation model based on System Dynamics, such as MCM-Ecuador, can provide valuable insights to policy makers dealing with energy and climate policy formulation and evaluation.

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