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Bram Smeets

EcoMod and University Libre de Bruxelles

Ali Bayar

EcoMod and University Libre de Bruxelles

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Sustainability of economic growth in Abu Dhabi - a Dynamic CGE Approach

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Bram Smeets^{a,*}
Ali Bayar^b

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^aEcoMod, Brussels (Research Fellow) and Université Libre de Bruxelles (Ph.D. student)

^bEcoMod, Brussels (President), Université Libre de Bruxelles (Professor), and ERF (Research Fellow)

Abstract

The UAE have shown spectacular economic growth during the last decades, making it one of the wealthiest countries in the world. However, the environmental footprint per capita in the UAE also ranks among the highest in the world. Recent developments show that the concept of sustainability is gaining attention among policy-makers in the region. Focusing on Abu Dhabi, this paper intends to bring a contribution to this discussion, by projecting carbon emissions under several growth scenarios, and analyzing the expected impact of a set of policy measures aimed at an abatement of carbon emissions. Using a dynamic multi-sectoral CGE model, tailored to the Abu Dhabi economy, it shows that emissions are expected to grow by 85% over the next decade, under a baseline growth scenario. Results show that the impact of taxation and price liberalizations will to a large extent depend on their effectiveness in stimulating behavioral change among consumers. In industry, the water desalination and power generation sectors show specific improvement opportunities.

Keywords: Sustainable development, Abu Dhabi, Carbon emissions, Dynamic CGE

JEL codes: C68, E27, O53, Q01, Q56

*Corresponding author: Bram.Smeets@ecomod.net

1 Introduction

The United Arab Emirates have witnessed an impressive economic growth during last decades. The Emirate of Abu Dhabi, as largest of the seven emirates in the federation, has played an important role in this development. Its substantial stocks of national resources, which rank amongst the highest in the world, have fueled an unprecedented economic development that has brought great prosperity for the local population in Abu Dhabi and other Emirates, and besides attracted large numbers of expatriates.

However, the increases in economic welfare and the expansion of its population have come at a cost: as shown in figure 1, the United Arab Emirates have the highest ecological footprint per capita in the world. (GFN, 2010) Although the indicator for Abu Dhabi alone is not included in any comparative statistics, the Emirate can be expected to have a footprint that is even higher, having the largest economy and the highest level of oil production of the Federation. Two areas on which Abu Dhabi has a particularly poor environmental track-record concern i) greenhouse gas emissions and ii) unsustainable water management. The first is driven by a high energy-intensity in the industrial sector together with an abundant residential consumption of energy commodities; the second is caused by a combination of climatological conditions and very high water consumption levels. In order to provide a solution for the water shortage, Abu Dhabi is dependent on seawater desalination at a large scale, which is an energy-intensive process and as such makes another contribution to the carbon-footprint.

Historically, the concept of sustainability has received little attention on the policy agenda of Abu Dhabi and other governments in the Gulf region. However, there are various factors that make it a relevant issue to consider for future growth strategies. Several countries (and individual Emirates) in the Gulf face energy shortages, primarily due to abundant gas consumption, and besides the pollution from heavy industry and large-scale desalination of seawater have adverse effects on the local environment, threatening the health condition of the citizens.¹

At the same time, there are major challenges to overcome before the environmental footprint of Abu Dhabi and other regions can decline. Improvements will in the first place depend on reductions in energy consumption; since both population growth and economic growth are anticipated to remain high over the next decade, this implies that significant behavioral changes are required (by private consumers as well as the industry). Several authors

¹There are other, more strategic factors as well, e.g. the role that renewable energy sources could play to sustain the important position that Gulf countries play in global energy policies.

identify low utility prices, imposed by governmental price controls, as most important factor explaining high energy consumption levels and thus emissions in the region (c.f. Hertog and Luciani, 2009), since they have triggered a mindset among consumers that fails to recognize the scarcity of energy and water. However, the access to low-cost energy for the citizens is an essential ingredient of the political contract between the government and the people, and modifications are therefore a sensitive topic in the public debate.

Nevertheless, authorities in Abu Dhabi have started to recognize the relevance of the sustainability of growth, which led to the formulation of a renewable energy policy in January 2009, for the first time in the region, calling for at least 7% of total power supply in 2020 to come from renewable resources. (Mezher et al., 2010) At the same time, the existing academic literature on sustainability issues in the Gulf region in relation to economic growth is limited. As far as the authors are aware, there are no quantitative studies that project emissions or other aspects of the environmental footprint.² Such analyses are crucial in order to get a better understanding of the expected impacts of various policy options.

This paper intends to provide first insights in this area, by presenting an analysis of a set of policy measures aimed at reducing the carbon footprint. It aims to understand what will be the impact of economic growth and an expanding population on carbon emissions during the next decade. By endogenizing greenhouse gas emissions in a multi-sectoral computable general equilibrium model³, the evolution of emission levels is linked to economic growth at the sectoral level. Consequently, according to variations in the energy intensity of production sectors and differences with regards to the pollution levels of specific energy commodities they use, the paper analyzes the impact of different growth scenarios on carbon emissions, as well as a set of specific policy options, including: i) the taxation of utility consumption (or, equivalently, reducing the subsidies on these commodities); ii) abandonment of price controls in utility markets; iii) improvements in energy-intensity of production sectors.

The paper is structured as follows. Section 2 provides an overview of the literature on sustainability issues in the Gulf region. Section 3 presents the modeling methodology, followed by a specification of the data sources in section 4. Section 5 reports the policy scenarios under consideration and the simulation results, and section 6 concludes.

²The Environmental Agency Abu Dhabi has done a study in this field called *Enviro2030*, but neither the methodology nor the results of this work are publicly available.

³The CGE model is specifically tailored to the specificities of the Abu Dhabi economy and calibrated on the most recent data.

2 Literature Review

The academic literature on issues related to environmental sustainability in the Gulf region is of a limited size. The regional focus of the existing works, that were mostly written during the last decade, varies, and few contributions focus on Abu Dhabi in particular. Besides, the lion's share of this literature either is of a descriptive nature, or presents technically oriented evaluations of new technologies. The few contributions that look at the topic from a macroeconomic perspective, present qualitative proposals for policy measures that could be adopted by governments in the region; quantitative models to study the impacts of these proposed policy measures are largely lacking.

At the same time, a vast strand of the literature studies sustainability in a different regional context. There are plentiful examples of quantitative models that study the relationship between economic activity and greenhouse gas emissions, and a rich set of methodologies has been pursued to provide projections, scenario analyses and policy comparisons. There are also various authors who give an overview of these methodological approaches.⁴

This section intends to give an overview of the first set of contributions. Its goal is to provide a context for the study of sustainability of growth in Abu Dhabi that is presented in the following sections. Given that other countries in the Arab Gulf face comparable economic, political and environmental circumstances, these regions are also included in the scope of this literature overview.

2.1 The relevance of sustainable growth for the Gulf region

Since the beginning of the 2000s, scholars have shown a growing interest in the topic of environmental sustainability in the Arab Gulf, reflecting in the first place the increased importance of the topic on the policy agenda in the UAE and other countries. Davidson (2009a) and Ouis (2002) provide overviews of the development of environmental policy in the UAE. O'Brien et al. (2007) describe how legislation relevant to the natural environment came into force only in 2000.

The literature describes several challenges that make this topic relevant from a policy perspective. In the first place, the energy crisis that several countries in the Gulf are facing has emphasized the need to diversify the energy portfolio, and in particular the power generation. This will enhance a switch towards less energy-intensive technologies. Dargin (2010) describes

⁴See Bergman (2005) and Conrad (2003) for examples.

the domestic energy crisis that the UAE is currently facing, which is primarily caused by excess demand for gas, due to sharp increases in demand for electricity and desalinated water during the last decades. Hertog and Luciani (2009) argue that, given domestic shortages in several Gulf States, a diversification of the power supply towards renewable resources is a rational choice.

As a second argument, there are local threats for the UAE and other countries in the Gulf that are related to the large-scale water desalination plants that are used to provide potable water. Lattemann and Höpner (2008) describe the environmental impacts of seawater desalination in general. Mohamed et al (2005) report on the adverse impacts of desalination in the context of the UAE.

A third factor concerns the potential effects of anthropogenic climate change on the Gulf region, including i) increasing temperatures and declining levels of precipitation (c.f. Richer (2008), Yagoub (2004)); ii) rising sea levels (Dasgupta et al, 2009); and iii) mass migration from poor neighboring regions (Kumetat, 2009).

As a fourth argument, several authors point at the opportunities that international environmental protocols provide, to improve the environmental conditions as well as benefit in economic terms. Patlitzianas et al (2006), Woertz (2008) and Ramaswamy et al (2005) describe how the Clean Development Mechanism⁵ can provide a source of income for the countries in the Gulf Cooperation Council⁶ (GCC).⁷

Besides the literature describing rationales for more sustainable growth strategies, there are several contributions that deep-dive on the role of the Gulf States as *drivers* of anthropogenic climate change. In this context, the countries in the Gulf play a non-negligible role, in the first place because of the size of their energy sectors⁸ (and, as a result, their importance as oil and gas suppliers to large parts of the world), but second and more importantly due to the extraordinary high energy consumption levels per capita that

⁵The CDM is one of the instruments under the Kyoto protocol, and allows developed countries to reduce their footprint by investing in emission reductions in developing countries (i.e., outside their own territories).

⁶The GCC members are the UAE, Kuwait, Qatar, Saudi Arabia Oman and Bahrain.

⁷We should note that several authors have also emphasized the threats that emission trading by industrialized countries pose to international trade with oil-exporting countries. (c.f. Babiker, 2003)

⁸The conventional energy sectors have played a crucial role in the development of the economies of the UAE and several other Gulf States. Butt (2001) gives an overview of the development of the oil and gas sector in the UAE. Al Sadik (2001) comments on the role that the energy sector played in the overall economic development of the UAE since the establishment of the country in 1971.

most of the countries exhibit. Shams El Din et al (1994) and Qader (2009) provide insights on the role of electricity consumption as a driver of GHG emissions in the GCC countries. Kazim (2007) identifies an exponential growth of the population, the rapid economic development, urbanization and the dependency on desalination for the potable water supply. Hertog and Luciani (2009) add the heavy industrialization and the low consumer prices of utilities as important drivers of energy consumption and thus GHG emissions in the Gulf countries.

2.2 Towards a more sustainable energy policy in the Gulf region

Various authors have focused on alternative technologies and energy resources to reduce the environmental footprint in the Gulf region. Doukas et al. (2006) provide a status review of the various renewable energy initiatives that were rolled out in the GCC countries until 2005, and identify business opportunities for further investments. Kumetat (2009) provides an updated overview of existing sustainability initiatives in the Gulf region.

With regards to the future governmental policy to enhance sustainable growth, three categories of actions can be distinguished in the literature, that are discussed below: i) Stimulating renewable energy, ii) adapting energy standards and iii) abandonment of energy subsidization by governments.

- Stimulating renewable energy

Woertz (2008) presents how renewable energy can provide great opportunities for the GCC countries to stretch the lifeline of their fossil fuel exports. Perkins (2009), Qader (2009) and Reiche (2010) consider the role of the Masdar Institute and Masdar City as catalyzers of the implementation of renewable energy.

Most contributions concerning non-conventional energy resources in the Gulf region focus on solar or nuclear power. Kazim and Veziroglu (2001) show how investments in solar capacity can provide a useful complement to the UAE's energy supply, in order to maintain its share in the global energy supply.⁹ Harder and Gibson (2011) and Alnaser and Alnaser (2009) identify the low energy prices in the region as major obstacle for the profitability of investments in solar power.

⁹Various other authors focus on the technical and economic feasibility of solar power generation in the region; c.f. Taleb and Pitts (2008), Majid (2011) and Al-Alili et al. (2010).

Luciani (2009) analyzes the increasing interest that GCC countries have shown in nuclear energy during last years, which resulted in the construction of four nuclear power plants in the UAE.

- Adapting energy standards

Al-Iriani (2005) and St Clair (2009) identify various demand-side measures for the UAE that can reduce private consumption of energy commodities.

- Abandonment of energy subsidization by governments

Dargin (2010) discusses solutions for the domestic gas deficit in the UAE¹⁰, arguing that the UAE government should strive for a rationalization of gas prices, which would imply an abandonment of subsidization policies for the retail sector in particular. Qader (2009) recommends the introduction of taxation-and-subsidization programmes to stimulate more efficient electricity consumption by domestic users.

The policy measures as described above should be considered in the context of the political and social systems that are in place in the Gulf States. Hertog and Luciani (2009) argue that the technocratic nature of most governments implies that enclave-based, project-focused initiatives aimed at introducing renewable power generation capacity are most likely to be successful. Spiess (2008) provides a more critical analysis of the current political and social conditions in the Gulf area and points at a lacking awareness among policy-makers as well as citizens and an unrealistic thrust in oil money as a short-term solution to the threats that environmental change is posing.

Chedid and Chaaban (2003) note how in the early 2000s, lacking awareness among policy-makers of the unsustainability of economic growth to date and the potential advantages of renewable energy sources formed a major obstacle towards the implementation of renewable energy initiatives. Besides, many policy-makers perceived a conflict of interest between investments in renewables and the future financial returns from their fossil fuel stocks. During the 2000s, this mindset changed and Alnaser and Alnaser (2011) give an overview of how, less than a decade later, various large-scale renewable energy projects are either planned, under construction or operational in the GCC countries.

¹⁰Dargin (2010) notes that, currently, gas imports exceed the domestic production, and thus the UAE are a net importer of gas.

3 Methodology: Model description and specification of assumptions

This paper projects the impacts that anticipated economic growth¹¹ will have on CO₂ emissions between 2009 and 2020, and investigates how several policy measures can affect this development. As a tool to generate these projections, the multi-sectoral, dynamic CGE model AdSusMod was constructed, which models the economy of the Emirate in a recursive general equilibrium framework. The model is extended by an environmental module to provide the link between economic development and the evolution of greenhouse gas emissions. This section provides a specification of the key methodology that was employed and the assumptions that were made for the construction of this model.

3.1 AdSusMod: A dynamic CGE model to analyze the sustainability of growth in Abu Dhabi

The CGE model that is used for the scenario analyses of the Abu Dhabi economy in this paper includes the following agents:

- (i) **Production firms** - AdSusMod contains 12 production sectors, which are aggregations of all firms in those sectors within the Abu Dhabi economy. In line with this sectoral disaggregation, the representative firms in the model produce 12 commodities. A specification of the sector and commodity disaggregation can be found in table 1. This disaggregation puts particular emphasis on sectors and commodities that are important for the analysis of greenhouse gas emissions: energy supply and utility generation (including water) are analyzed in detail, whereas services and other industrial activities are aggregated into general categories. All branches of activity are assumed to be perfectly competitive.

The branches of activity in AdSusMod produce their products according to a nested production structure, consisting of 5 nesting levels. This combination of production functions defines how the production factors and intermediate inputs are employed in the production process, and how they are combined to produce the sectoral output XD_s . The nested

¹¹The anticipated growth levels are obtained from the strategic governmental document *Abu Dhabi Economic Vision 2030* (The Government of Abu Dhabi, 2009)

structure of this production function is reported in figure 2.¹² It shows how domestic production by sector, XD_s , is determined as a combination of two components: first, a bundle of capital, labor and energy KLE_s ; second, a fixed share of other intermediates $IO_{s,1}, \dots, IO_{s,M}$, including all commodities other than energy.

The top level of the firms' production function is assumed to behave according to a Leontief function, which implies that the three inputs are complementary to each other.¹³ At the second nest level, the capital, labor and energy bundle is disaggregated into value added and an energy bundle. These two components can be substituted according to a CES function.

Before elaborating a detailed elicitation of the nesting structure for value added, it is useful to consider one important aspect of the Abu Dhabi economy: the differences in nationality and skill set amongst the population. The society in Abu Dhabi is characterized by large differences in factors such as wealth, income, living conditions, consumption patterns and labor skills. In the first place, there is a major group of low-skilled foreign workers, originating mostly from East-Asia, who work for low wages, live in large collective houses, and are untrained or trained for a very specific task, making them inflexible if it comes to working in other sectors. Second, there is a much smaller group of high-skilled expatriates, who work predominantly in the financial services sector or in other high-profile jobs, and who receive much higher wages and live in luxurious apartments. Third, there is a minority of nationals, who are descendants from the tribes that originally populated the area. This last group is characterized by high wage levels, excessive wealth, a lower labor participation rate and luxurious living conditions.

Due to the large differences between the different groups, and due to the inflexibility of low-skilled expatriate workers to work in other sectors, the labor market in Abu Dhabi is highly segmented, both horizontally (in terms of the allocation of the available labor to specific sectors) and vertically (in terms of the skill-set of workers and the according wage-levels and social status). In order to reflect this, AdSusMod includes 6 types of labor, that are split according to i) nationality (nationals vs.

¹²In this representation, rectangular brackets refer to a Leontief function, whereas diagonal lines refer to a Constant Elasticity of Substitution (CES) production function.

¹³In the appendix, technical details are provided on the assumptions regarding the production functions, and the implications this has for demand functions for factor inputs.

expatriates) and ii) skill-level (high-skilled vs. skilled vs. unskilled).¹⁴

Based on these considerations, value added is disaggregated into 3 additional nesting structures: At the third nest level, value added is disaggregated into capital and high-skilled labor on the one hand, and skilled and unskilled labor on the other. Both of these bundles are decomposed into their constituents at the fourth level: the capital stock vs. high-skilled labor on the one hand, and skilled vs. unskilled labor on the other. These splits reflect the different role that high-skilled labor plays compared to lower skill-sets.¹⁵ Finally, the three types of labor are disaggregated into a component of nationals and a share of expatriate workers. All these disaggregations are assumed to take place according to CES production functions.

The energy bundle is further disaggregated into electricity and a bundle of non-electric energy commodities at the third level. At the fourth level, this latter bundle is decomposed into gas and refined petroleum.

- (ii) **Consumers** - In AdSusMod, there are three representative households, to reflect the differences in income and spending patterns amongst them:
- (a) Local households, consisting of UAE-nationals
 - (b) Non-local households, referring to expatriates that live in single-family apartments
 - (c) Collective households, referring to expatriates that are typically low-skilled workers that live in large collective housing units

These household groups play three roles in the model. First, they provide labor and capital that are used as production factors by the firms. As a result, the households are receivers of income from three sources: i) as remuneration for their role as labor force in the production process; ii) as remuneration for their role as investors in the firms; and iii) they receive transfers from the government and firms.

The second role played by the households is that of consumers: they spend part of their income on the consumption of the commodities in

¹⁴This categorization is made by SCAD (2011).

¹⁵The rationale for this nesting structure is that high-skilled labor, in combination with capital, is complementary to lower-skilled labor categories. By choosing low values for the elasticity of substitution at this nesting level, the lacking substitution possibilities can be mimicked.

the model. The allocation of this consumption budget is assumed to take place according to a Stone-Geary utility function.¹⁶

The third role of the households is related to their saving behavior: households do not completely allocate their income to the consumption expenditures, but tend to save part of it. In the model, each of the household types is assumed to have its own marginal propensity to save (*mps*), as a fixed share of their income¹⁷.

- (iii) **The government** - the government in AdSusMod comprises the local government of Abu Dhabi Emirate. This government generates revenues that are primarily derived from royalties from the exploration of oil and gas. Other sources of governmental income are the return on capital that is invested in production firms, collected taxes and received transfers. The government consumes commodities in the model according to a Cobb-Douglas utility function, and besides spends part of its budget on (social) transfers. In the current version of the model, the total governmental expenditures are fixed as a share of GDP. Consequently, government revenues and savings are determined endogenously.
- (iv) **The central bank** - the central bank solely plays the role of an investment bank in AdSusMod: It collects savings from households, production firms, the government and the rest of the world, and according to the savings-investment balance invests the aggregate amount of savings in investment commodities. It is assumed to allocate the aggregate savings to specific commodities according to a Cobb-Douglas utility function.
- (v) **The Rest of the World** - The connection to the rest of the world is based on interactions on world commodity markets - for imports and exports - and besides incorporates a definition of the current account balance, to model modifications in the exchange rate that could occur as a consequence of scenario simulations. Demand for imports is determined according to the Armington assumption (defining how imports and domestic production are combined as supply to the domestic market), whereas the supply of commodities for export is determined according to a Constant Elasticity of Transformation (CET) function (determining what share of domestic production is allocated to the

¹⁶In the appendix, details are provided on the demand functions for commodities.

¹⁷In AdSusMod, these household type-specific propensities to save were calibrated based on the baseline data for 2009 in the SAM

domestic market and what share is exported). Since the SAM only captures the domestic economy of Abu Dhabi, the other 6 Emirates in the UAE, as well as the Federal government, are part of the agent Rest of the World.¹⁸

3.2 Endogenous modeling of greenhouse gas emissions

AdSusMod models CO₂ emissions by linking them to the consumption of energy. By specifying the energy consumption by the different agents and branches of activity in the model in detail, this link provides a detailed insight in the contribution that each agent makes to total emissions. The CGE model provides this detailed disaggregation into different agents and multiple sectors, and particularly takes into account how the various agents interact. As a result, it provides a useful tool to acquire insights in the evolution of CO₂ emissions in general, and more particularly into the impacts that developments in specific sectors or household types will have on energy consumption and thus emissions.

AdSusMod distinguishes between household emissions, as a result of energy consumption by the households, and industrial emissions, stemming from the consumption of energy as a production factor by the production sectors in the model.

In order to link the economic data on consumption and the physically oriented data on emissions, the consumption of energy commodities needs to be expressed in units of energy, rather than in monetary terms. Therefore, the implicit price related to the energy vector is included in the model, as ratio between energy consumption in monetary terms and energy consumption in physical terms (expressed in ktoe). Subsequently, the ktoe-consumption of each type of energy commodity by each type of emitter is linked to actual CO₂ emissions through emission factors. These are expressed in kt per ktoe and describe the amount of CO₂ emissions that is associated with combustion of each of the particular energy commodities.

3.3 Dynamic linkages

AdSusMod is a recursively dynamic model. This implies that the model is solved year by year, and the model's solution consists of a sequence of temporal equilibria. The link between subsequent years is provided by the capital stock, which develops over time based on investments and depreciation. The

¹⁸Since commodities can be transported freely within the UAE, there are no data available regarding inter-Emirate trade. Besides, this affects the accuracy of trade data for Abu Dhabi, because imports and exports cannot be linked exclusively to this specific Emirate.

endogenous determination of investment behavior is essential for the dynamic characteristics of the model. Investment and capital accumulation are determined according to an approach presented in Thurlow (2004). Depreciation is determined as a constant, sector-specific share of the total capital stock in a sector.

Next to capital, labor supply also develops over time. The annual growth rate of the total domestic labor force (by skill type) is controlled exogenously, based on historic population growth rates and assuming the same growth rates for each of the three skill types.

3.4 Model closure assumptions

In AdSusMod, the closure rule for the government specifies that the share of government expenditure to GDP is constant in real terms. Compared to other alternatives, this closure rule resembles the linkage between economic growth and the government finances; during last decades, the Abu Dhabi budget balance has varied strongly, and governmental expenditures were determined primarily according to general development purposes rather than dependent on the level of revenues.

The savings-investment balance is closed in several steps. As a starting point, the evolution of total investments is determined exogenously.¹⁹ By definition, this determines the level of total savings. Since household savings, firms' savings and the governmental savings are determined endogenously, the foreign savings (as last element in total savings) serve as residual. This choice reflects the important role that foreign savings (specifically through Sovereign Wealth Funds) play as investment vehicles in the domestic economy, and the ease with which funds can be allocated to domestic investments when this is required.

Closure in the equations related to the labor markets in the model is achieved by controlling the domestic labor supply exogenously; foreign labor supply is assumed to be perfectly elastic and thus responds directly to labor demand.

3.5 On the suitability of the CGE methodology

Like any modeling methodology, the general equilibrium (GE) paradigm has several pros and cons in the context of the analyses in this paper. Although there are numerous examples of other authors that employ a GE approach, it is worthwhile to put advantages and disadvantages in perspective.

¹⁹Total investments are assumed to grow at the same rate as the real GDP.

For the analysis of greenhouse gas emissions, the most important aspect of economy activity is the level of energy consumption, since the combustion of the various types of energy is the direct driver of emissions. The CGE-approach is particularly appropriate for such analyses, because of its level of granularity: by modeling various production sectors (that can vary with respect to the way they consume energy) and various energy types (that vary with respect to the degree with which they cause pollution), greenhouse gas emissions can be decomposed into many different subcategories and -drivers, which allows for a detailed analysis of energy-related scenarios. Particularly because many of these scenarios - such as taxation instruments, efficiency gains and behavioral changes among consumers - have economy-wide effects, CGE models are an appropriate tool.

Nevertheless, the GE approach also has its weaknesses. Examples include their dependence on static data (to the extent that SAMs typically contain data for a single year, which is used as base year for dynamic extensions), and the validity of assumptions such as market clearing, price flexibility or perfect competition. Several of these points are addressed in the model specification; others will be addressed in future extensions of our work. Some other challenges can be better addressed as research makes progress in this field. Overall though, a profound understanding of the attractiveness and limitations of any model is essential when using it as a tool for policy analyses.

As a final remark with regards to the usefulness of CGE-based results, we should note that CGE models are not a tool that should be used to generate "hard" forecasts regarding macroeconomic indicators such as economic growth; rather, it should be used as a tool that provides insights in the relative impacts of various policy shocks, compared to a benchmark scenario.

4 Overview of baseline data and assumptions

For the general equilibrium analysis of the Abu Dhabi economy in combination with its GHG emissions, two types of data are required. In the first place, a Social Accounting Matrix (SAM) is used to provide the benchmark data for the calibration of the CGE model²⁰; next to that, detailed data with regards to the energy consumption and GHG emissions are needed, in order to provide a benchmark situation for the environmental module in the CGE model.

²⁰The authors owe sincere gratitude to Masudi Opese (EcoMod) for sharing and explaining his SAM for Abu Dhabi for 2009. Elasticities of substitution and other parameters that could not be calibrated were also obtained from this study.

The collection of these data brings along several challenges, that are related to the developmental state of the data infrastructure in the Emirate. In recent years, the Statistics Centre Abu Dhabi (SCAD) has strongly improved the availability of key statistics of the Abu Dhabi economy. Nevertheless, this progress is part of an ongoing development, and several key statistics are not available yet. Therefore, a better understanding of the economy in Abu Dhabi, in many facets, can be realized when the range of available data and their quality improves.

4.1 Baseline growth scenario

The goal of the policy analyses is to understand the impact of policy measures on CO₂ emissions and, as a driver, the structure of the economy. In order to derive this impact, a baseline growth scenario needs to be defined that can be used as a benchmark. A sensible forecast of the development of the economy in Abu Dhabi can be found in the strategic document *Abu Dhabi Economic Vision 2030* (Government of Abu Dhabi, 2009). Table 2 specifies the evolution of real GDP and the inflation rate that are projected between 2011 and 2020, according to the strategic document.²¹ The national population is assumed to grow at the historical growth rate of the last decade. (SCAD, 2011) It should be noted here that 2010 is an exception which corrects for the fact that during the base year of our model, 2009, the Abu Dhabi economy was in the midst of a strong recession due to the global financial crisis, and thus the number of people employed underestimates the size of the labor force during recovery. The evolution of world energy prices is based on latest estimates by the International Energy Agency (IEA, 2011).

4.2 Energy consumption and greenhouse gas emissions

In its report 'Energy Statistics of Non-OECD Countries - 2010 Edition', the International Energy Agency reports energy consumption statistics for the UAE. (IAE, 2010a) These data are used to derive energy consumption statistics for Abu Dhabi, in the same disaggregation of energy commodities as the one used in the SAM. This derivation is done in 3 steps:

1. Aggregation of energy consumption (total domestic energy supply in 2008, in caloric terms) by 3 energy commodities in the SAM: refined petroleum, natural gas and electricity (at UAE level)

²¹The growth rate and inflation rate for 2010 are based on the most recent estimates by the Statistics Center Abu Dhabi (SCAD, 2011)

2. Derivation of the caloric consumption in Abu Dhabi, based on total energy consumption in the UAE and by assuming an identical energy intensity of GDP in the Emirate as in the UAE
3. Derivation of the link between the SAM-data and the IEA caloric energy data, based on the result of step 2 and data on the monetary value of energy consumption in the SAM

Emission data, too, are only available at the Federal level for the UAE. (IEA, 2010b) As a starting point for this paper, aggregate emissions data and energy resource-specific emissions factors were used. Assuming that these emission factors are identical in Abu Dhabi and the UAE, and combining that with the assumption under step 2 above that the energy intensity in the Emirate is equal to that in the Federation, the implication is that the CO₂ emission intensity of GDP in Abu Dhabi and the UAE is assumed to be equal. As a consequence, the share that is represented by Abu Dhabi in total emissions by the UAE is equal to the share that Abu Dhabi contributes to the Federation's GDP: 56 %. This implies that as benchmark, the model uses a total emission level of 81.8 million tonnes of CO₂ in Abu Dhabi, based on Federal emissions of 146.8 MtCO₂.

Figure 3 reports the resulting derived energy consumption in Abu Dhabi, together with the derived GHG emissions. It shows how conventional electricity and water desalination, when combined, are the largest consumer of energy in the production side of the economy. Among the households, 'nationals' have a much higher consumption pattern than the two other household types.

5 Simulations and results

The CGE model AdSusMod is used as a tool for a set of policy studies, that can help the Abu Dhabi government when aiming to reduce or control the greenhouse gas emissions in the Emirate. Before turning to the results of these analyses, this section first presents the specification of these scenarios, in the context of the model definition as exposed in the previous section.²²

5.1 Specification of policy scenarios

The CGE model is specified in a level of detail that facilitates the analysis of a wide range of policy simulations. This paper focuses on three types

²²Analytic details on each of the scenarios can be found in the appendix.

of policy that should lead to a reduction of greenhouse gas emissions, and evaluate their effect on emissions as well as economic growth:

- **Taxation of consumption of utilities**

The effect of the introduction of a utility tax is analyzed under two scenarios with regards to the energy intensity of household consumption. In the first case, this intensity is determined endogenously, implying that any reduction in energy consumption levels comes solely from substitution of other commodities by final consumers due to high consumption prices. In the second case, the effects of levying utility taxes are analyzed together with an exogenous 20 % decline in energy intensity of household consumption. This could be interpreted as a change in households' consumption behavior: the effect of the effective price increase is that the households will change their preferences, resulting in a modification of the parameters of their utility functions as well as changes in utility demand due to substitution effects. Both of these lead to a decline in the consumption levels of utilities and thus to a reduction in emission levels.

- **Price liberalizations in utility markets**

One of the mechanisms through which the government distributes the wealth from natural resources of Abu Dhabi across its population, is the below-market pricing of energy commodities. As a result, utility prices are artificially kept low in Abu Dhabi. In the model, this is simulated by controlling the price evolution of utilities, and fixing the price in real terms. Under the policy scenario that studies price liberalization, this mechanism is stopped and utility prices are endogenously determined by supply and demand, in the same way as other commodity prices are determined.

- **Improvements in the energy-intensity of the water desalination sector and the rest of the economy**

This scenario simulates exogenous improvements in the energy intensity of the production process by sector, where energy efficiency is defined as the total amount of energy consumed in the production process of sector s , by unit of value added.

It is important to note that all policy simulations are run under the baseline scenario of economic growth. As a result, the outcomes, in terms of emission levels, should be compared to the benchmark emission projections that are presented in the next section. Besides, the policy scenarios will

have no impact on economic growth by definition, since this is exogenously controlled.²³

5.2 Results of policy simulations

5.2.1 Baseline emission projections

As a starting point for the analysis of the simulated results of the policy studies, table 3 reports the development of the GDP and its decomposition over the next decade. The total GDP growth is fixed to follow the same path as the forecasts in the strategic document 'Vision 2030', and will grow by 92 % in real terms between 2009 and 2020. The recovery of GDP in 2010 is primarily driven by restored international fuel prices, that had plunged during the base year of the model 2009. As a consequence, the strong growth of the economy in 2010 is mainly fueled by a growth in the foreign balance. Over the rest of the decade, the evolution of the government budget mimics the GDP development, as imposed by one of the closure rules in the model. Similarly, the gross fixed investment is closely linked to overall GDP growth as a result of the closure rule in the savings-investment equation. The foreign balance continues to grow at a higher-than-average growth rate during most of the decade, whereas the household income grows, as a result, at a rate that is slightly below average.

Table 4 reports the forecasted evolution of CO₂ emissions under the baseline growth scenario. Total emissions, reaching a level of 81.5 million tonnes of CO₂ (MtCO₂) in 2009, are projected to grow by 85% in the period 2009-2020, which comes from increases in household emissions (+91%) as well as industrial emissions (+83%). Since the compound average growth rate of total emissions, which amounts to 5.8%, exceeds the anticipated population growth rate, the strong growth in emissions will be reflected in a further increase of per capita emissions.

In order to analyze the linkage between emissions and economic growth, two simulations were run with different growth paths imposed: 'Vision 2030 +' is a scenario in which economic growth exceeds the baseline growth path by 2% in the period 2012-2020, whereas in the scenario 'Vision 2030 -', economic growth is 2% lower than the baseline scenario in the same period. Figure 4 reports the results of this analysis, showing that total emissions in 2020 range between +18% and -16% of the baseline growth path. It is interesting to note that, even though total emissions grow by 56% under the low-growth

²³In future analyses based on this model, welfare effects of the proposed policy measures will be analyzed.

scenario, per capita emissions are declining in this case, due to the high rate of anticipated population growth.

5.2.2 Taxation of utilities

Figure 5 reports the simulated effects of the introduction of a commodity tax on the final consumption of on utilities. When the energy efficiency of the households' consumption budget is determined endogenously (i.e., the parameters of the utility function remain unaffected, and reductions in energy demand will solely stem from substitution effects due to effective increases in the cost of utilities), the introduction of a utility tax will lead to a one-off effect on emissions during the year of introduction, followed by a smaller permanent effect of about two thirds of the emission reduction during the first year. The magnitude of these effects depends on the tax level: under a 20% tax rate, household emissions can be reduced by 5.8% during the first year, and by 3.1-3.5% annually afterwards.

The simulation results in figure 5 show how improvements in energy efficiency can have a much stronger impact on household emissions over time. The three dashed lines show the effect of a gradual improvement in efficiency that reduces the amount of energy consumed (in physical terms) per Dirham of the total household consumption budget by 20% between 2010 and 2020. Without taxation, energy efficiency gains have a proportional effect on household emissions: they approach 20%. When combined with utility taxes, we again see an incremental one-off effect during the first year of taxation, followed by a continuous additional reduction in emissions with a magnitude that is comparable to the scenarios discussed above, when the energy efficiency of household consumption was not improved. In combination with a 10% utility tax, this can reduce household emissions by more than 21%; combined with a 20% utility tax, it can even lead to a 23% drop.

It is important to put these simulation results in the proper perspective. In the first place, the results show the effects of taxation policies and energy efficiency gains on *household* emissions, compared to the baseline scenario. When analyzing the effects on *total* emissions, the effect will be smaller, since households in Abu Dhabi are responsible for 30% of total emissions in 2009. Besides, the overall effect of a taxation policy is to a large extent dependent on the way the government will spend the incremental revenues as a result of the levied taxes. In the current model specification, the closure rule for the government states that governmental expenditures as a share of real GDP are fixed. As a result, an increase in tax revenues will primarily lead to an increase in governmental savings (or equivalently, a reduction in the deficit, which is the case currently in Abu Dhabi).

The policy implications of these scenario studies require some specification. Under current circumstances, the introduction of utility taxes in Abu Dhabi is unlikely. State involvement is strong throughout the production and distribution chain, and several of the production companies as well as the distributors of utilities are (partially) state-owned. Many of the investments in new capacity are funded by the government, and therefore the capital costs (i.e., interest or foregone dividend) that are covered by the government can be seen as production subsidies. Besides, the consumer prices for energy commodities are controlled through implicit subsidies, and as a result utilities are priced below market values. This state-involvement is partly related to the massive stocks of fossil fuels in Abu Dhabi - the government controls the exploration of energy sources and extends its involvement into the exploitation - but is also one of the many exponents of the *allocative state* (cf. Davidson, 2009b): low prices ascertain accessibility of utilities for the citizens, and this status-quo is deeply embedded in the political system.

Explicit taxation of energy consumption, as is common practice in other regions, is therefore a very sensitive issue. However, at the same time, the low prices have triggered large-scale overconsumption of energy commodities, and a lacking awareness of the scarcity of utilities among the citizenry. The use of pricing policies as a natural economic instrument to enhance the awareness of scarcity is a natural choice. In the absence of taxation as a feasible policy option in the short to medium run, a first step towards a financial incentivization of lower utility consumption is the (partial) abandonment of the subsidization policy. In line with this argument, the introduction of commodity taxes as a policy scenario can be interpreted as a de facto reduction in subsidy levels.

The improvements in energy efficiency of the household consumption budget are unlikely to develop based on price increases alone, given that even under a 20% taxation policy, the user costs for utilities will continue to be modest by international standards. Therefore, behavioral changes (that can be reflected in the model by modifications to the utility function that will trigger a reduction in energy efficiency) will need to be encouraged by additional policies. A potential method is the introduction of awareness campaigns, that need to improve the perception of utilities as scarce resources. Another role can be played by the education system, in which students need to be educated about the need for conservation. A third option concerns reward systems, that can maintain low utility costs for consumers, but only conditional on efficient consumption patterns.

5.2.3 Price liberalizations in utility markets

An alternative way of approaching the use of economic instruments to enhance the awareness of energy-scarcity is by focusing on the price controls. In the current model, these price-controls are modeled by keeping the price of utilities fixed in real terms. Instead of exogenously setting a tax rate that can be interpreted as a subsidy reduction, another policy simulation was run in which the model endogenously determines the market price of utilities.²⁴ This implies that the current subsidies on energy commodities would remain in place, but future modifications that would be required in order to cancel out increases in the consumer price - through increases in production costs or as a response to increased demand - will not be imposed.

Figure 6 reports the impact of the simulations of loosened price control. Overall emissions can be reduced by 12%, which is mainly driven by a drop in industrial emissions whereas household emissions drop by 3%. Yet, in line with the previous policy simulation regarding taxing utilities, the impact of a abandonment of the policy of price controls can have much larger impacts when it triggers behavioral change. When combined with an improvement in the households' energy efficiency by 20%, household emissions show a much stronger decline of 18% by 2020, causing overall emissions to drop by 17%.

5.2.4 Improving energy efficiency in production sectors

A third set of policy simulations concerns improvements in the energy efficiency in production sectors. One simulation focuses on efficiency gains in the water desalination and electricity production sectors specifically; a second simulation considers broader energy efficiency improvements in all production sectors of the Abu Dhabi economy.

The water and electricity sector deserves special attention because of the important role it plays in Abu Dhabi. Due to the limited (largely absent) supply of natural freshwater, the Emirate is dependent on desalinated seawater to provide in its tap water requirements, like many of the other countries in the Arab Gulf region. This process is energy intensive (in its current application), which, combined with the large scale at which the process is applied, makes the power generation and water desalination activities an important

²⁴More specifically, we ascertain that the price PDD_c for energy commodities (the price of domestically produced commodities that will be sold at the domestic market as part of the composite good X_c , which also includes imports) is not only linked to the consumer price P_c , but also to $PDDE_c$, the producer price of commodity c . This is in line with the approach that was followed for all other, non-utility, commodities in the model - c.f. the appendix for details.

consumer of energy.²⁵ In Abu Dhabi, water and electricity production almost solely use gas as energy source, and together, the sector is responsible for 21% of the total gas consumption in the Emirate. As a result, it contributes 17% to total CO₂ emissions.²⁶

There is room for improvement though, particularly since the dominant technology for generating potable water from seawater in Abu Dhabi (Multi Stage Flash desalination) is one of the most energy intensive ways to distill water at a large scale; employing readily available alternatives such as Reverse Osmosis (RO) could already bring a reduction in the energy intensity of the sector by a factor 3 (Ettouney and Wilf, 2009). Other alternatives, such as desalination based on solar or nuclear energy, can further reduce the energy requirements, but these technologies are still in a testing phase.

The first set of simulations therefore analyzes the effects of improvements in energy efficiency in the desalination and power generation sector ranging between 0 and 65%. Figure 7 shows the impact this will have on emissions at three levels: the specific sector, the entire industry and the whole economy. A complete shift towards the RO technology would allow desalination emissions to drop by 40%, despite an increase in production levels by 90% by 2020.²⁷ The more realistic policy simulations show how sectoral emissions respond more or less proportionally (26%) to an energy efficiency gain of 25 %. When considering total emissions by the industry (including emissions by all other production sectors) and in the entire economy (by also including households' emissions), one can observe that the curves have very similar shapes. This is mainly driven by the fixation of energy prices: although demand for energy (most notably: gas) decreases thanks to efficiency gains in one specific sector, this does not lead to a decline in prices. As a result, the other sectors are largely unaffected.

Figure 8 shows how broader efficiency gains in all production sectors would affect emissions. The curves in these charts - reflecting the impact on total industrial emissions and aggregate emissions in the economy - have similar shapes, because household emissions (which form the difference between the two) are not affected by the policy shock. The response of emissions to energy efficiency improvement is driven by two developments that affect

²⁵Because of efficiency gains from synergy, the desalination process is combined with electricity generation in all production plants in Abu Dhabi.

²⁶Source: SCAD(2011) for energy consumption statistics; IEA (2010b) and author's calculations for derivation of emissions.

²⁷This scenario only serves as a benchmark; it is unrealistic as a policy option, since it would require the complete existing capacity to be replaced. Besides, the costs of this operation are not modeled in the current version of the model (and the RO technology is known to be more costly for large-scale applications).

emissions in opposite ways. On the one hand, the efficiency gain will decrease the energy intensity of each Dirham of GDP, which leads to a decline in CO₂ emissions in all sectors; on the other hand, the efficiency gain will lead to a decline in production costs and as a result a drop in producer prices, which will particularly affect the energy-intensive sectors. As a result, (intermediate and final) demand for energy-intensive products will show a stronger increase than the demand for less energy intensive products, compared to the benchmark.²⁸ This will have an upward effect on emissions, such that the overall reduction is smaller than the energy efficiency gain; as an example, an efficiency improvement of 20% between 2009-2020 will trigger a decrease in emissions by 17% (and a reduction of total emissions of 11.4%).

In order to synthesize the policy implications of these results, some additional context is needed with regards to the feasibility of the simulated efficiency improvements. In the case of efficiency gain in the desalination and electricity production sector alone, this is primarily related to the employed technology to desalt the water and generate power. As mentioned before, an efficiency gain of 65 % could be achieved by replacing the complete capacity of the current method (Multi-Stage Flash) by less energy-intensive alternatives (Reverse Osmosis); any percentage below 65% could be interpreted as a stage in which only part of the existing capacity will be replaced, and another part left in place. In the case of an overall efficiency gain in all production sectors, let us put the magnitude of the improvements in perspective by comparing them with developments or strategic plans in other regions. As a benchmark, the European Union intends to improve overall industrial efficiency by 20% between 2010-2020 according to its plan 'Europe 2020'. In a decree from 2008, the Russian president Medvedev demands an overall improvement in energy efficiency by 42% between 2007 and 2020.

Given the importance of desalinated water in the total water supply, and given the sharp anticipated incline in required capacity in the following decade, a shift to more energy efficient desalination techniques is a necessity in order to control emissions below their benchmark levels in Abu Dhabi. However, the results show that, even though the power and water sector is responsible for more than 20% of the total gas consumption in the Emirate, even a strong 50% improvement in efficiency cannot avoid that total emissions increase by 69% in the time range 2009-2020, if it is not combined with strong efficiency gains in other sectors. In order to control emissions at their current per capita levels - which are the highest in the world after Qatar - the energy

²⁸With the exception of energy commodities and other utilities: reductions in production costs will not be reflected in the purchaser prices of these sectors, due to the price fixation imposed by the government.

efficiency of GDP will need to increase by 12%. In order to control emissions at their current total levels, and thus offset not only the economic growth per capita, but also the population increase, energy efficiency will need to be boosted by 59%.

These simulation results provide a first understanding of the impacts of economic growth and development on emissions, and the energy efficiency improvements that are required in order to reduce them. In the context of policy formulation, these results can be used as a starting point of approaches to establish a growth strategy that includes considerations concerning the environmental sustainability. The simulated efficiency gains were chosen without investigating in detail how the current level of efficiency - at the sectoral level - compares internationally, and without studying concrete technological opportunities for improvement. Such an analysis should be carried out as second step of the policy-making process.²⁹ Third, based on concrete proposals for improvements that should be established, additional economic studies are needed regarding the formulation of policy measures and the expected impact of policies. The AdSusMod model, together with other tools, can be used in order to understand how such policy instruments would interact with the economy.

6 Conclusions and future directions

The UAE have the highest per capita environmental footprint in the world, and Abu Dhabi, as most industrialized and natural resource-endowed emirate in the federation, is an important player in this context.

Although the lacking sustainability of current growth paths has gradually been receiving more attention on the policy agenda in the region, macroeconomic studies regarding the projected growth of the footprint or the anticipated impact of policy measures aimed at reducing it, do not exist. This paper provides first insights of policy simulations based on a dynamic CGE model that models the Abu Dhabi economy in detail.

Projections show that carbon emissions will grow by 85% over the next decade, compared to the levels in 2009, based on a baseline scenario for economic growth; they will more than double under a more optimistic growth scenario.

Using taxes as a policy instrument (or, equivalently, reducing subsidies) to reduce utility consumption levels will have a small negative impact on emission levels. A much larger effect can be expected when the tax policy

²⁹Several research projects at the Masdar Institute focus on this topic.

manages to enhance the perception of energy- and water-scarcity by consumers. The lacking awareness of this scarcity has been brought up by many as main driver of high consumption levels; according to basic economic reasoning, an increase in user costs to approach the market value will raise awareness and ascertain a more efficient and effective allocation of energy to those who assign the highest value to it. Results show that even modest behavioral changes among consumers can have major impacts on their carbon footprint. Similarly, a liberalization of utility prices can lead to a considerable reduction in the emission levels. These policies will have a direct impact, through the price elasticity of demand, and an indirect effect, through the behavioral changes they induce. The latter effect can be augmented by introducing complementary policies, that could include awareness programs, educational campaigns, rewards or bonuses for good and efficient behavior or alternative initiatives.

Due to its lack of natural freshwater sources, Abu Dhabi is dependent on the desalination of seawater in order to provide in its water needs. This introduces several challenges with regards to the sustainability of growth. First, these concern the water policy itself, which leads to high consumption levels, adverse effects of desalination on the marine environment, large-scale over-pumping of remaining groundwater aquifers and high production costs. Second, the high energy-intensity of the desalination process implies that the desalination sector, which is also responsible for power generation, is a major contributor to the Emirate's carbon emissions. There are several alternative desalination methods available that could reduce the energy-intensity of the process, compared to the current standards. These range from other fossil fuel-based methods to nuclear or renewable energy-fueled processes. Simulation results show that improvements will have a significant impact on overall emissions, because currently, the sector is an important consumer of energy in Abu Dhabi. However, other sectors of the economy, that could be affected through price mechanisms, remain largely unaffected due to the fixation of utility prices.

Overall improvements in energy efficiency in the industrial sectors, through imposed energy standards or increased investments in new, clean technologies, can abate the strong increase in emissions that is projected due to further economic growth and an expansion of the population. However, results show that a 59% efficiency gain is required in order to control emissions at their current levels.

The results presented in this paper provide a first insight concerning the expected of carbon abatement policies, based on a detailed and specifically tailored economic model for Abu Dhabi. Since this field of research, with a specific focus on the Gulf region with its particular characteristics, is largely

unexplored, there is a wide range of future directions for additional research.

For some of them, the AdSusMod model is an appropriate tool. We intend to extend this model in several ways; planned next steps include analyzing the introduction of nuclear energy as a source of power generation and modeling the water sector in detail. Besides, the welfare effects of the proposed measures will be analyzed.

In addition, alternative tools need to be built that can help to make assessments of the future developments and the impact of specific policies. Moreover, the increasing availability and quality of data in various topics will stimulate the analyses and improve the robustness of findings.

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Appendices

A Technical specification of model methodology

CGE models are based on an application of micro-economic concepts, such as utility and profit maximization, in a macroeconomic context. Their goal is to model interactions among a set of agents in an economy, by defining markets where these agents can 'meet' and trade. The interactions between agents are simulated based on a set of behavioral assumptions that describe the decision-making process that defines each agent's actions, conditional on actions of all other agents in the model. The model is solved by identifying a set of prices that brings all markets in the model in equilibrium simultaneously, and by identifying corresponding quantities of supply and demand that maximize the chosen objectives for all agents in the model.

For a quantitative analysis of the decisions that a (representative) production firm faces, assumptions need to be made by the modeller on the functional form and structure of the production functions that define the firm's behavior. In AdSusMod, two types of production function are combined in a nested structure. On the one hand, a Leontief function defines fixed proportions of complementary inputs that are required to yield a certain output. On the other hand, the Constant Elasticities of Substitution (CES) production function facilitates more flexibility, to the extent that it allows for substitution possibilities between inputs that are expressed by substitution elasticities. By combining the two functions in a structure consisting of multiple stages, the necessity to include certain (categories of) inputs and the flexibility to combine or replace others can both be sensibly represented in a nesting structure reflecting these characteristics.

A.1 Production sectors and production functions

Figure 2 specifies the nesting structure that is implemented in AdSusMod. It shows how domestic production by sector, XD_s , is determined as a combination of two components: first, a bundle of capital, labor and energy KLE_s (which are treated as production factors in the model); second, a fixed share of other intermediates $IO_{s,1}, \dots, IO_{s,M}$, including all commodities other than energy, as intermediate input into the production process:

$$XD_s = \min \left(\frac{KLE_s}{aKLE_s}, \frac{IO_{s,1}}{io_{s,1}}, \dots, \frac{IO_{s,M}}{io_{s,M}} \right), \quad (1)$$

where $aKLE_s$ and $io_{s,m}$ are Leontief coefficients defining the sector-specific amounts of each factor required for the production of sectoral output XD_s .

All representative firms are assumed to maximize profits (or, equivalently, at minimizing production costs). As a consequence, the optimal amount of inputs given a certain production level XD_s amounts to:

$$KLE'_s = aKLE_s \cdot XD_s \quad (2)$$

$$GWE'_s = aGW_s \cdot XD_s \quad (3)$$

$$IO'_{s,c} = io_{s,c} \cdot XD_s \quad (4)$$

Besides, the firms in all branches of activity are assumed to act in perfectly competitive markets, and consequently profits are zero at all nesting levels in the production function. In the model, zero-profit equations are therefore added at all levels of the production function. For the top level nest, this implies:

$$(1 - tp_s) \cdot PD_s \cdot XD_s = PKLE_s \cdot KLE_s + \sum_c (io_{s,c} \cdot P_c \cdot XD_s), \quad (5)$$

where tp_s is the production tax rate, $PKLE_s$ is the composite price associated with the capital, labor and energy bundle and P_c is the market price of commodities.

At the second nest level, the capital, labor and energy bundle is disaggregated into value added and an energy bundle. These two components can be substituted according to a CES function:

$$KLE_s = aKLE_s \cdot [\gamma KL_s \cdot (KL_s)^{\sigma KLE_s} + (1 - \gamma KL_s) \cdot (E_s)^{\sigma KLE_s}]^{\frac{1}{\sigma KLE_s}}, \quad (6)$$

where $aKLE_s$ is efficiency parameter, γKL_s is the distribution parameter, σKLE_s is the elasticity of substitution and KL_s and E_s are the bundles of capital-labor and energy, respectively.

Optimization of the associated profit function according to the production function in equation 6 yields the demand equations for the value added (capital-labor) and energy bundles:

$$KL_s = KLE_s \cdot \left(\frac{PKLE_s}{PKL_s} \right)^{\sigma KLE_s} \cdot \gamma KL_s^{\sigma KLE_s} \cdot aKLE_s^{(\sigma KLE_s - 1)} \quad (7)$$

$$E_s = KLE_s \cdot \left(\frac{PKLE_s}{PENERS} \right)^{\sigma KLE_s} \cdot \gamma E_s^{\sigma KLE_s} \cdot aKLE_s^{(\sigma KLE_s - 1)} \quad (8)$$

Because of the assumption of perfect competition in all sectors, here, too, a zero profit condition applies:

$$KLE_s \cdot PKLE_s = KL_s \cdot PKL_s + PENER_s \cdot E_s. \quad (9)$$

where $PENER_s$ is the composite price index associated with energy and PKL_s

the composite price index associated with value added.

At all lower nest levels, CES production functions are assumed in a similar way. Thus, the functional form of the factor demand equations and the zero profit conditions is identical to those in equations 7-8 and 9, respectively.

Table 5 specifies the elasticities of substitution that were used for the simulations.³⁰

A.2 Consumer behavior

Consumers are assumed to determine their behavior according to a constrained utility optimization problem, where a utility function identifies how consumption of a set of commodities relates to the consumers' utility, and a budget constraint limits the consumed quantity given a set of commodity prices. These microeconomic concepts can be used at a macro level by assuming that there exist representative households: large groups of consumers in the economy are assumed to act as one agent, with one aggregate utility function and an aggregate budget constraint.

Consumers are aggregated into three household types h , that are assumed to behave according to a Stone-Geary utility function³¹:

$$U_h = \prod_c (C_{c,h} - \mu H_{c,h})^{\alpha H_{c,h}} \quad (10)$$

where $C_{c,h}$ is the consumption level of commodity c by representative household h , $\mu H_{c,h}$ is the subsistence level, and $\alpha H_{c,h}$ is the marginal budget share for the commodity.

The three household types optimize their utility subject to a budget constraint:

$$CBUD_h = \sum_c C_{c,h}, \quad (11)$$

which leads to demand equations that determine $C_{c,h}$ for all commodities c , as a function of the available budget $CBUD_h$ and the commodity prices P_c :

$$C_{i,h} = \mu H_{i,h} + \alpha HLES_{i,h} \cdot \frac{(CBUD_h - \sum_I \mu H_{I,h} \cdot (1 + tc_I) \cdot P_I)}{((1 + tc_i) \cdot P_i)}. \quad (12)$$

The households' budget $CBUD_h$ is derived based on the household income

³⁰These elasticities, that are low in general, indicating limited substitution possibilities, are based on previous work by our research team on the Abu Dhabi and are in line with other contributions in the literature.

³¹This function is also known as the Linear Expenditure System.

YH_h and the household savings SH_h :

$$CBUD_h = (1 - ty_h) \cdot YH_h - SH_h \quad (13)$$

$$YH_h = YLH_h + ykH_h \cdot YKT + YHTR_h \cdot PCINDEX \quad (14)$$

$$SH_h = mps_h \cdot (1 - ty_h) \cdot YH_h, \quad (15)$$

where ty_h is the income tax rate (which equals zero in Abu Dhabi today); YLH_h is the income from labor by household type; YKT_h is the total income from domestics capital investments in the economy; ykH is the fixed share of capital income that is allocated to households; $YHTR_h$ is the net income from transfers per household type; and mps_h is the marginal propensity to save: the fixed share of its income that each household type saves.

A.3 Labor markets

The wage rate PL_l for the three national labor types in AdSusMod (see section 3.1) is determined in the market closing equations:

$$\sum_j LSK_{j,l} = LSR_l - UNEMP_l, \quad (16)$$

where $LSK_{j,l}$ identifies labor demand, as determined in the factor demand equation for each of the production sectors. Labor supply, LSR_l , is determined exogenously for national workers, whereas for foreign workers it is equal to the labor demand; this implies perfectly elastic labor supply and thus the absence of unemployment for foreign workers. For the three foreign labor types, the wage rate is fixed in real terms.

For national workers, the unemployment level is linked to the wage rate through a Phillips-curve equation:

$$\frac{PL_l/PCINDEX}{PLZ_l/PCINDEXZ} = \phi \cdot \left(\frac{UnRate_l}{UnrateZ_l} - 1 \right), \quad (17)$$

where $PCINDEX$ is the consumer price index, $UnRate_l$ is the unemployment rate for labor type l , and ϕ is the phillips parameter, and a Z behind a variable name refers to the initial value (in base year 2009) for that variable.

Finally, each sector has a labor type-specific wage-premium $\pi LSK_{j,l}$ that specifies the labor costs for the firms.³²

³²This parameter $\pi LSK_{j,l}$ is calibrated and remains fixed in the simulations. This rigidity is required in order to allow flexibility of the number of workers per sector and per labor type.

B Analytic specification of policy scenarios

The CGE model is specified in a level of detail that facilitates the analysis of a wide range of policy simulations. This paper focuses on three types of policy that should lead to a reduction of greenhouse gas emissions, and evaluate their effect on emissions as well as economic growth:

- **Taxation of consumption of utilities**

The commodity tax rate tc_c is set to values ranging from 0 % to 20 %. This will affect consumers through the demand equation for household demand, as presented in equation 12. The effect of the introduction of a utility tax is analyzed under two scenarios with regards to the energy intensity of household consumption. In the first case, this intensity is determined endogenously, implying that any reduction in energy consumption levels comes from substitution of other commodities by final consumers due to high consumption prices. In the second case, the effects of levying utility taxes are analyzed together with an exogenous 20 % decline in energy intensity of household consumption. This could be interpreted as a change in households's consumption behavior: the effect of the effective price increase is that the households will change their preferences, resulting in a modification of the parameters of their utility functions as well as changes in utility demand due to substitution effects, that both lead to a decline in the consumption levels of utilities and thus to a reduction in emission levels.

The reduction in energy intensity is imposed by including and controlling a variable in the model:

$$ENEFFH_h = \frac{C_{eng,h}/PENinpH_{eng,h}}{CBUD_h/PCINDEX} \quad (18)$$

, where $ENEFFH_h$ is the energy efficiency by household type, $C_{eng,h}$ is the final consumption of energy commodities by household type, $PENinpH_{eng,HH}$ is the caloric amount of energy per AED (the monetary unit in the model), $CBUD_h$ is the household consumption budget by household type, and $PCINDEX$ is the consumer price index. As a result, the energy efficiency of households is determined as the caloric level of consumption by AED of the households' consumption budget, in real terms. In order to allow for the flexibility in the households' utility function that is required to be able to determine the energy efficiency exogenously, adjustment parameters $\mu EneffH_{c,h}$, $c \in \{eng\}$ and $\mu EneffHAdj_{c,h}$, $c \notin \{eng\}$ are included in the model:

$$\sum_{c \in \{eng\}} \alpha_{H_{c,h}} \cdot \mu EneffH_{c,h} + \sum_{c \notin \{eng\}} \alpha_{H_{c,h}} \cdot \mu EneffHAdj_{c,h} = 1 \quad (19)$$

- **Price liberalizations in utility markets**

Currently, utility prices are artificially kept low in Abu Dhabi. One of the mechanisms through which the government distributes the natural wealth of Abu Dhabi across its population, is the below-market pricing of energy commodities. In the model, this is simulated by controlling the price evolution of utilities, and fixing the price in real terms. Under the policy scenario that studies price liberalization, this mechanism is stopped and utility prices are endogenously determined by supply and demand, in the same way as other commodity prices are determined.

- **Improvements in the energy-intensity of the water desalination sector and the rest of the economy**

This scenario applies to an equation that defines the energy intensity of the production process by sector:

$$ENEFFB_s = \frac{\sum_{eng} ENINP_{eng,s} / ENINP_{eng,s}}{KL_s} \quad (20)$$

Where $ENINP_{eng,s}$ is the energy consumption by energy commodity eng (an index that includes gas and petroleum), $PENINP_{eng,s}$ is the price of energy per caloric unit (TJ), which helps to convert the energy consumption in monetary units to its caloric value, and KL_s is the value added by sector. As a result, energy efficiency is defined as the total amount of energy consumed in the production process of sector s , by unit of value added. Equation 20 is linked to the nested production function of sector s by a shock parameter μ in its third nest:

$$E_s = \mu_s \cdot aE_s \cdot \left(\gamma El_s \cdot El_s^{\sigma E_s} + (1 - \gamma) El_s \cdot Enel_s^{\sigma E_s} \right)^{1/\sigma E_s} \quad (21)$$

The endogenous shock variable μ_s provides the flexibility to the production function that is required to enable a scenario analysis in which adaptations to energy efficiency are simulated. The simulated modifications of energy efficiency range between 0 and 50 % compared to the benchmark value $ENEFFBZ_s$:

$$ENEFFB_s = \mu ENEFFB_s \cdot ENEFFBZ_s, \mu ENEFFB_s \in \{0, 0.5\} \quad (22)$$

C Tables and figures

Table 1: Specification of sector and commodity disaggregation in AdSusMod

Sector		Commodity	
1	Crude oil	1	Crude oil
2	Refined petroleum	2	Refined petroleum
3	Natural gas	3	Natural gas
4	Electricity generation (conventional)	4	Electricity
5	Water desalination	5	Desalinated water
6	Agriculture	6	Agricultural commodities
7	Petrochemicals	7	Petrochemicals
8	Other manufactured products	8	Other manufactured products
9	Construction	9	Construction
10	Government services	10	Government services
11	Transport and storage services	11	Transport and storage
12	Other Services	12	Other Services

Table 2: Specification of baseline growth scenario

Variable	Annual growth rate (%)					
	2010	2011	2012	2013	2014	2015
Real GDP	12.4	4.5	5	7	7	7
GDP deflator	3.1	4	4	4	3.5	3
Active national population	10	4.5	4.5	4.5	4.5	4.5
World energy prices - Crude oil	29.3	35.4	-0.6	-2.2	-1.5	-0.6
World energy prices - Natural gas	9.3	9.3	9.3	9.3	9.3	9.3
Variable	2016	2017	2018	2019	2020	
Real GDP	7	7	7	7	6.8	
GDP deflator	3	3	3	3	3	
Active national population	4.5	4.5	4.5	4.5	4.5	
World energy prices - Crude oil	0.2	0	0	0	0	
World energy prices - Natural gas	3.2	3.2	3.2	3.2	3.2	

Table 3: Economic projections under baseline scenario - decomposition of GDP

Component	Value	Share in GDP	Growth rates					
	(Bln. AED)	(%)	Growth rates (%)					
	2009	2009	2010	2011	2012	2013	2014	2015
GDP	546.5	100	12.4	4.5	5	7	7	7
Private consumption	210.7	38.6	5.5	6	4.2	6	6.4	7
Government consumption	24.9	4.6	12.4	4.5	5	7	7	7
Gross fixed investment	79.8	14.6	8.9	4.7	4.9	6.7	6.7	7
Foreign balance	231.0	42.3	19.9	3.2	5.7	7.9	7.5	7
Exports	384.2	70.3	15.3	4.5	5.4	7.3	7.2	7
Imports	153.2	-28	8.3	6.5	4.9	6.3	6.6	7
Component			2016	2017	2018	2019	2020	
GDP	546.5		7	7	7	7	6.7	
Private consumption	210.7		6.8	6.8	6.8	6.8	6.7	
Government consumption	24.9		7	7	7	7	6.7	
Gross fixed investment	79.8		6.7	6.7	6.7	6.7	6.5	
Foreign balance	231.0		7.2	7.2	7.2	7.2	6.9	
Exports	384.2		7.1	7.1	7.2	7.2	6.9	
Imports	153.2		7	7	7	7	7	

Table 4: Emission projections under baseline scenario - evolution of CO₂ emissions

Disaggregation level	Million tCO ₂					
	2009	2010	2011	2012	2013	2014
Total emissions	81.8	86.5	90.5	94.1	99.2	105
Industry	57.6	61	63.5	66	69.4	73.3
Commodity production	54.8	58.1	60.5	62.9	66.1	69.7
Services	2.8	2.9	3	3.1	3.3	3.6
Household emissions	24.2	25.5	27	28.1	29.8	31.7
Nationals	17.8	18.8	19.9	20.8	22	23.4
Non-local	4.7	5	5.2	5.4	5.8	6.2
Collective	1.6	1.7	1.8	1.9	2	2.1
Disaggregation level	2015	2016	2017	2018	2019	2020
Total emissions	111.5	118.5	126	134	142.5	151.5
Industry	77.7	82.5	87.7	93.2	99.1	105.3
Commodity production	73.8	78.3	83.2	88.3	93.8	99.7
Services	3.9	4.2	4.5	4.9	5.3	5.6
Household emissions	33.8	36	38.3	40.8	43.4	46.2
Nationals	24.9	26.6	28.3	30.1	32.1	34.1
Non-local	6.5	7	7.4	7.9	8.4	8.9
Collective	2.3	2.4	2.6	2.7	2.9	3.1

Table 5: Specification of elasticities of substitution in AdSusMod

Sector	σ_{KLEN} ,					σ_{LHS} ,
	σ_{KL}	σ_E	σ_{ENEL}	σ_{KLHS}	σ_{LSUS}	σ_{LUS}
All sectors	0.4	0.9	0.6	0.2	0.6	0.2
Commodity	σ_Y	σ_T	σ_A	σ_E		
Crude oil	1.1	-3	N.A.	8		
Refined petroleum	1.1	-3	3	8		
Natural gas	1.1	N.A.	N.A.	8		
Electricity	1.1	N.A.	N.A.	8		
Desalinated water	1.1	N.A.	N.A.	8		
Agricultural commodities	1.1	N.A.	0.2	8		
Petrochemicals	1.1	-2	N.A.	8		
Other manufactured products	1.1	-2	2	8		
Construction	1.1	N.A.	N.A.	8		
Government services	1.1	-2	2	8		
Transport and storage	1.1	N.A.	2	8		
Other Services	1.1	-2	2	8		

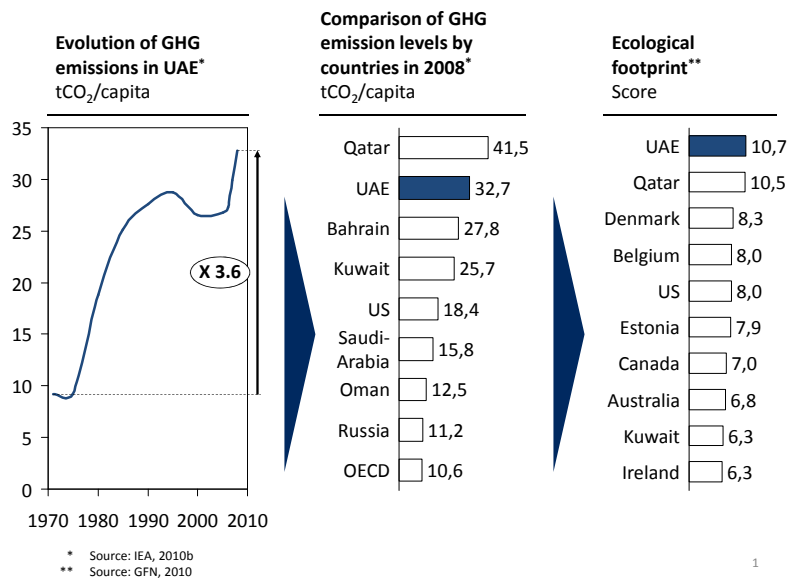


Figure 1: Examples of poor environmental performance by UAE

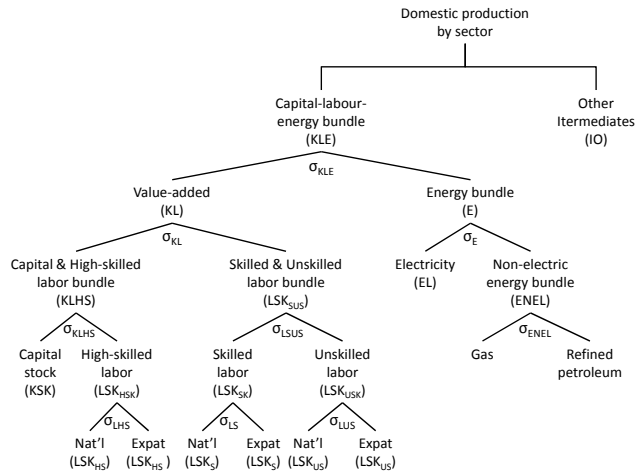


Figure 2: Specification of nested production structure in AdSusMod - Applies to all sectors

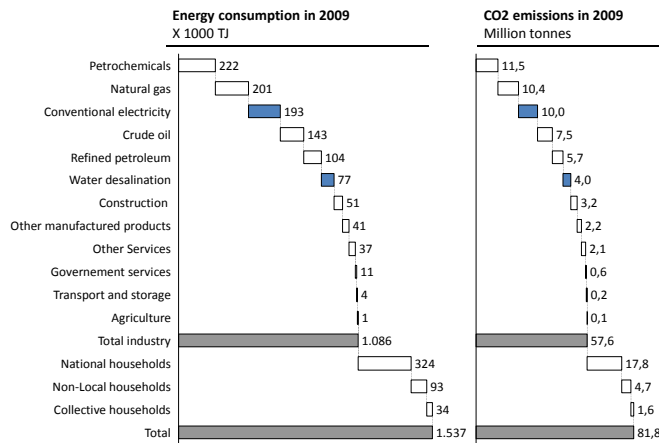


Figure 3: Energy consumption and carbon emissions in Abu Dhabi, by sector and household type - Source: IEA(2010a, 2010b) and authors' analyses

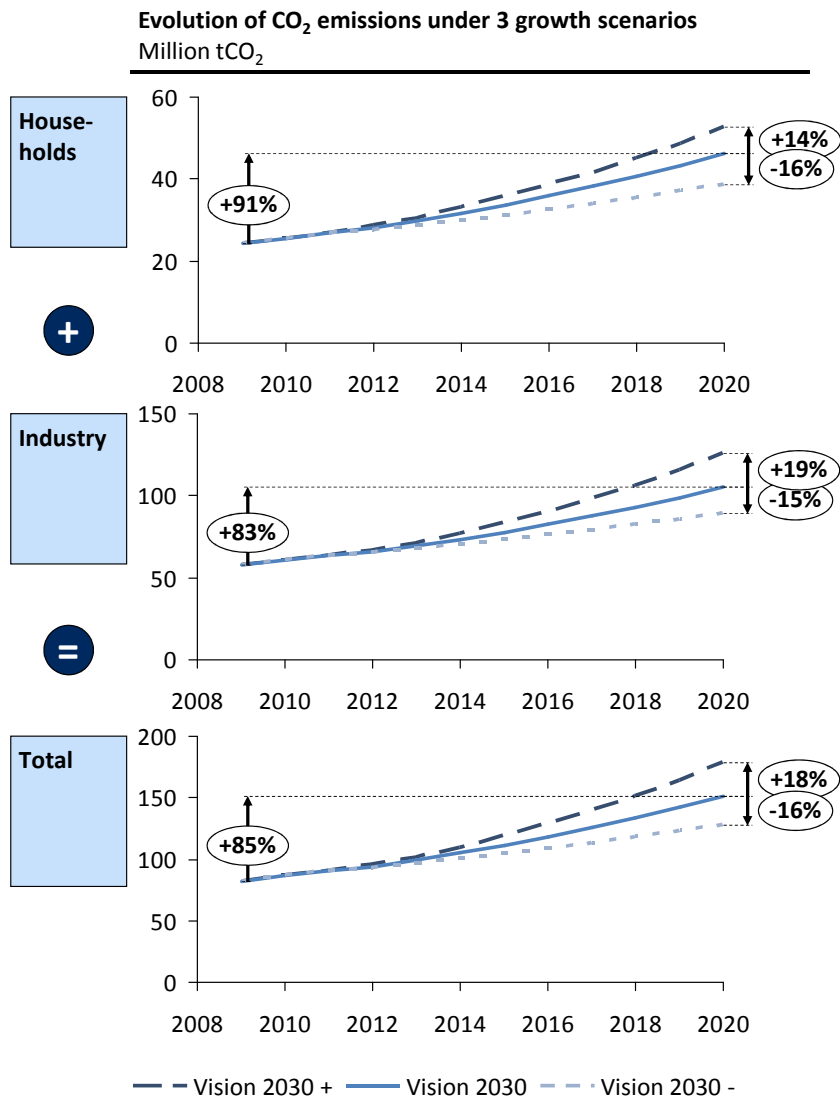


Figure 4: Evolution of CO₂ emissions under 3 growth scenarios -
 Source: Simulations based on dynamic CGE model AdSusMod

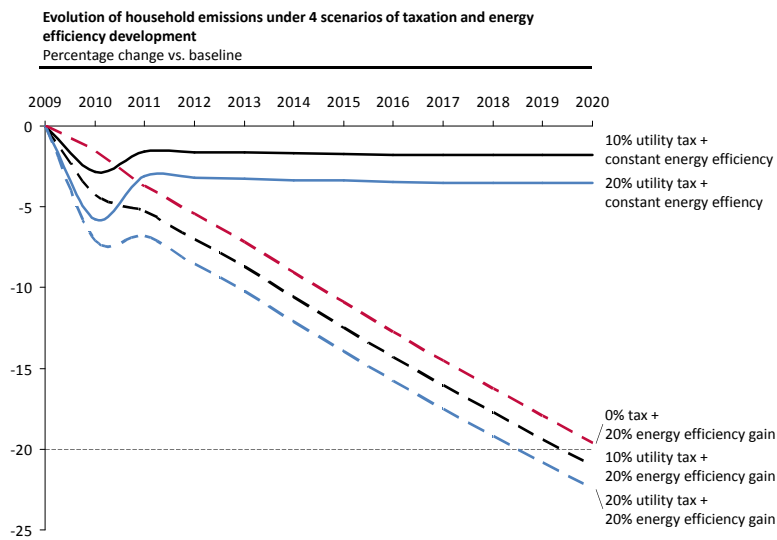


Figure 5: Analysis of the impact of taxation in combination with residential energy efficiency gains on CO₂ emissions - Source: Simulations based on dynamic CGE model AdSusMod

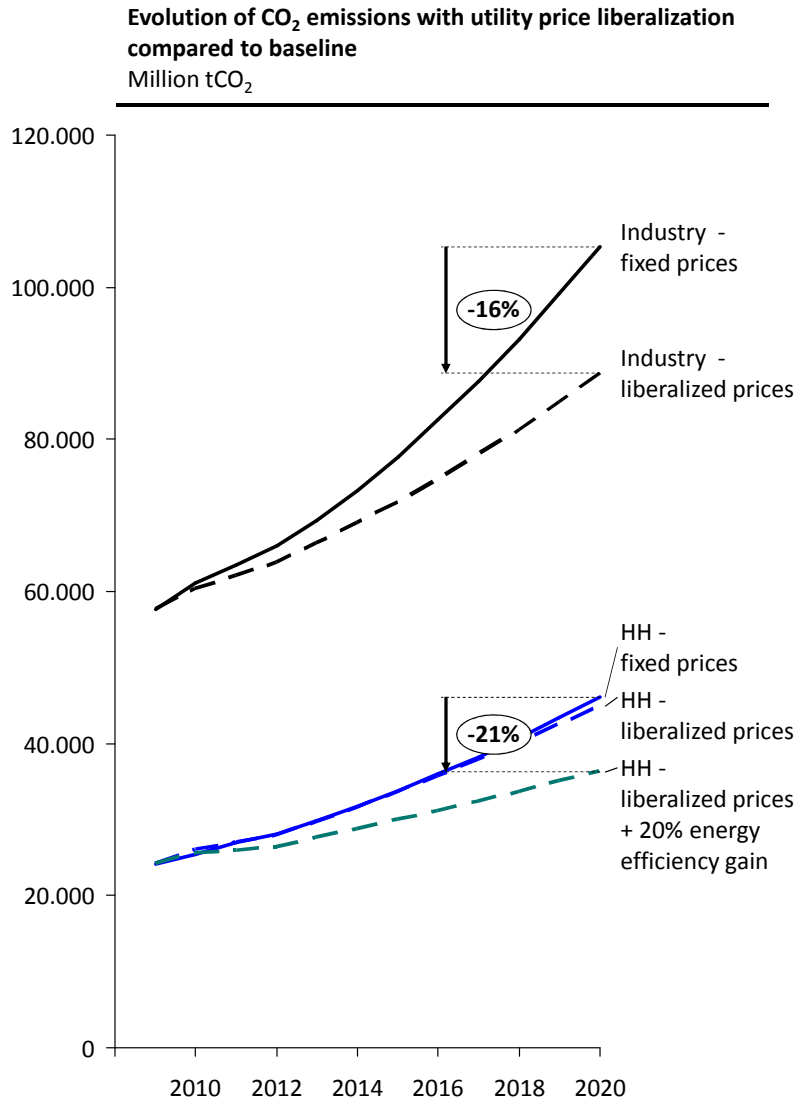


Figure 6: Analysis of the impact of utility price liberalizations on CO₂ emissions - Source: Simulations based on dynamic CGE model AdSus-Mod

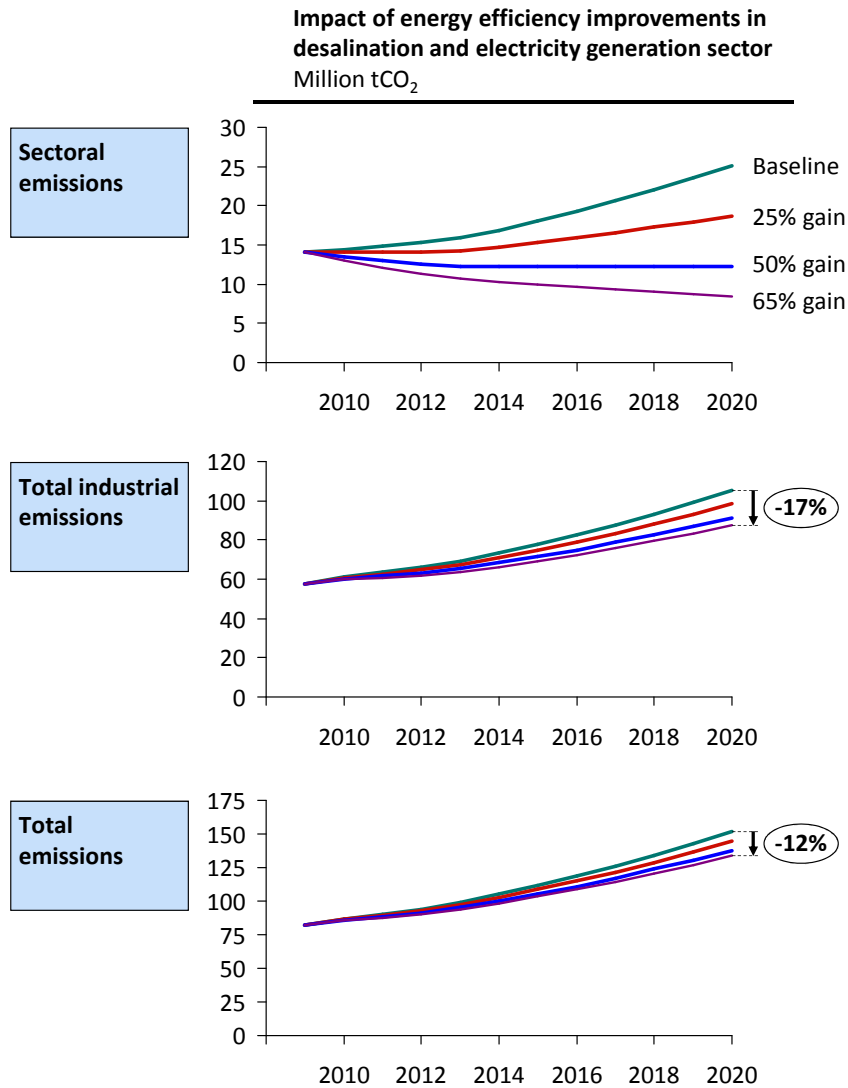


Figure 7: **Effects of energy efficiency gains in water desalination and power generation sector** - Source: Simulations based on dynamic CGE model AdSusMod

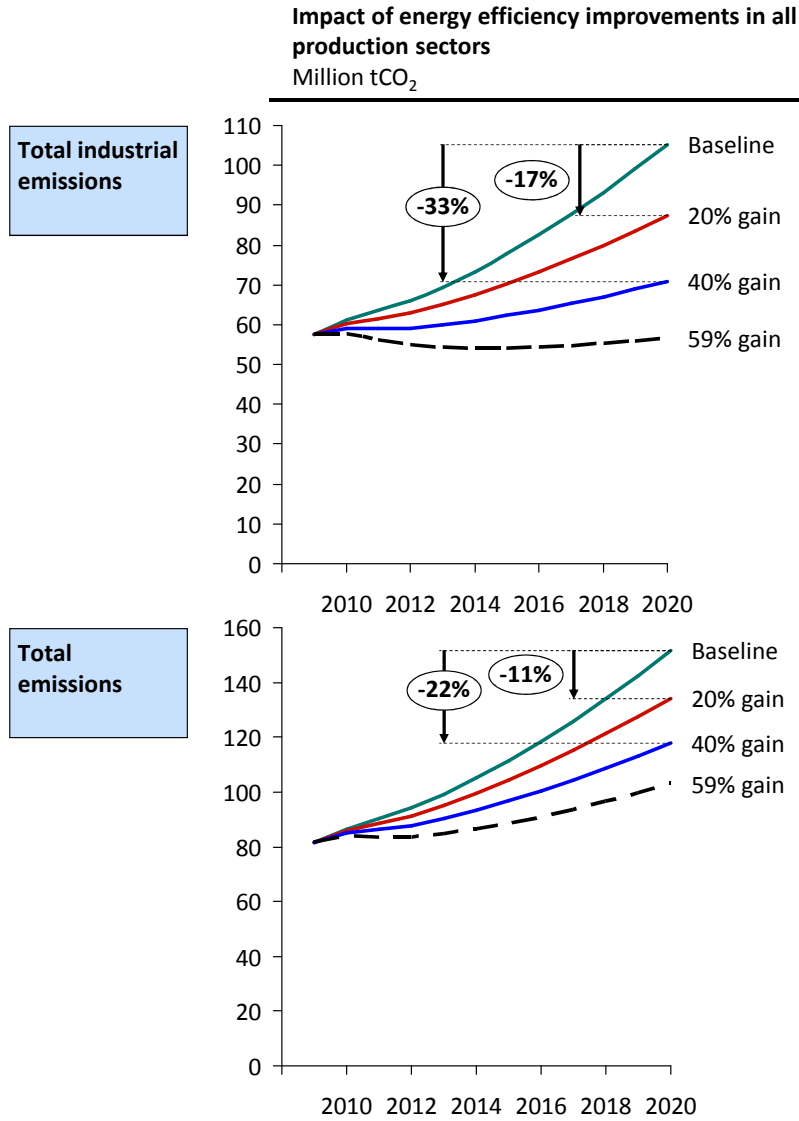


Figure 8: **Effects of energy efficiency gains in all production sectors**
 - Source: Simulations based on dynamic CGE model AdSusMod