Key Issues for Long Term Climate Policy Design in GCC Countries (with Focus on Qatar)

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Abstract

We analyse the challenges and options of designing an efficient long term global climate policy for GCC countries. We review the exposure of GCC countries to climate risks and the mitigation and adaptation options at their disposal. We look at the macroeconomic cost of realizing the emissions abatement implied by the Paris agreement and we evaluate the possibility to balance the burden through an allocation of emissions permits in an international emissions trading system. Focusing on Qatar we do a bottom-up analysis to see how this country could drastically reduce the GHG emissions. We show how the polity of energy has to be modified in GCC countries to permit this global transition to a net-zero emissions regime to take place. In particular, in this context we do a first assessment of the comparative advantage of GCC countries in harnessing negative emissions technologies that are necessary to reach the Paris agreement target.

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1 Introduction

Gulf Cooperation Council (GCC) Countries, and in particular Qatar were parties in the COP-21 that has led to the Paris agreement. Because they are so much exposed to climate change threats these countries must participate actively in the forthcoming climate negotiations that will define the regime leading to the fulfilment of the 2^oC objective. This rises three key issues that are interrelated: (i) how can the GCC economies adapt to the world-wide transition to a decarbonised regime and how will their polity adapt to this global socio-economic stress ; (ii) how can GCC countries adapt their own energy system to reduce drastically GHG emissions; (iii) what outcome could GCC countries expect from negotiations leading to a fair international agreement on burden sharing in the driving of world economy to a net-zero emission regime in 2070 (the ultimate goal in the Paris agreement).

Currently, of the energy used in the world, 34% comes from burning oil, 27% from coal and 24% from gas. Nuclear power, hydroelectric power and all other renewables combined provide just 15%. The result of all this fossil fuel use is an annual flow of 10 Gt of carbon (36.7 Gt of CO_2) out of the ground and into the atmosphere. The Paris agreement of 2015 calls for increases to the atmosphere's carbon-dioxide level caused by fossil fuels to end by the second half of this century. The IPCC AR5 defines the limit for total cumulative emissions since the onset of the industrial era, if humanity is to have a 66% chance of avoiding dangerous climate change (2oC of warming), as 1,000 Gt of carbon (3,670 Gt of CO_2) and notes that the world has already used up to 52% of this budget[1]. Since some fossil-fuel emissions may be very hard to eliminate from the economy, they could be counterbalanced by "negative emissions" that take carbon dioxide out of the atmosphere at a similar rate[2]. In several integrated assessment models recently developed this appears as the only way to meet the Paris goal of stopping any further increase to the carbon-dioxide level [3]. Two methods have emerged as the most effective in achieving this. One is Direct Air Capture (DAC), which involves trapping carbon dioxide from the atmosphere by drawing air through an absorbent material. The other is Bio-Energy with Carbon Capture and Storage (BECCS), where absorption is done by trees and crops as they grow. This biomass is then burned to produce energy and

[1]See [Stocker et al-2013] [46]

[2]Available forms of negative emissions include: farming in ways that make the soil richer in organic carbon; restoring degraded forests and planting new ones; harnessing photosynthesis to industry; growing plantation crops, burning them to generate electricity and sequestering the carbon dioxide given off underground, rather than letting it out into the atmosphere, an approach called bioenergy with carbon capture and storage, or BECCS. Then there is the idea of stripping carbon dioxide out of the atmosphere with Gas or renewably powered open-air chemical engineering: "direct air capture", or DAC. And there is also the possibility of helping along the chemical weathering process by grinding up silicate rocks into fine dusts, thus speeding up the reactions that store carbon dioxide away in stable minerals. Quote from The Economist

[3]See e.g. the Sky scenario proposed by Shell corp, [Shell-2018].

the resulting carbon dioxide is captured. In both cases, the carbon dioxide is stored underground, permanently removing it from the atmosphere.

Two key drivers in the energy transition, worldwide as well as for GCC countries, will thus be (i) the introduction of carbon capture and sequestration (CCS) in industry, associated with CO_2 direct removal (CDR)[4] and (ii) the advent of smart cities (SCs), associated with the emergence of smart energy systems (SESs) leveraging the development of the Internet of Things (IoT). Indeed, CCS in industry [47, 27] with renewables penetration [3, 8, 12] fostered by SCs and SESs will enable Gulf region economies to become low emission and sustainable. At the same time, these game changing developments will modify worldwide the economy of fossil fuels on which GCC states currently heavily depend. In the forthcoming climate negotiations the share of a global safety carbon budget [**?**, 6] that could be claimed by GCC countries is related to unburnable fuel risk [33]. In the very long term GCC countries could count on comparative advantage in harnessing direct air capture DAC technologies. These technologies producing negative emissions will be of high economic value, when the price of permits reaches very high levels, in a range \$500- \$1000 per tCO_2 as envisioned in integrated assessment models after year 2050[5] [13, 32].

Our analysis will be along three axes: In a first part we develop a socio-political assessment of the exposure of GCC states to climate change damages in the long term and their ability to adapt to the economic disruption due to global decarbonization of the economy; this includes, in particular an evaluation of the necessary change in the energy polity in this region to permit dealing with this game changing transition [39, 42, 30, 1, 34, 2, 43]. In a second part we focus on Qatar and analyse, with a bottom-up technology rich model [5], a scenario of transition to a low emission economy showing the determining role of CCS, SCs and SESs technologies. In the third part of the paper we deal with a macro-economic analysis, based on GEMINI-E3, a top-down general equilibrium model [7]. We evaluate the possible welfare losses for GCC countries if stringent abatement policies were adopted world-

[4] CDR technologies encompass in particular Bioenergy with CCS and direct air capture (DAC) with CCS.

[5] See IPCC, 2018: Summary for Policymakers. In: Global warming of 1.5^{o}C. An IPCC Special Report on the impacts of global warming of 1.5^{o}C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Water eld (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

wide along a 2 ^oC pathway; we also explore the possible advantages that the GCC states could obtain from participating actively in the governance of climate negotiations in order to obtain an appropriate compensation through the allocation of emissions rights. In conclusion we put together the insights gains in these different viewpoints.

2 A needed change in environment and energy polity

The GCC countries have been engaging in climate negotiations since the 1990s. They were classified as developing countries, [30]. Until recently, developing countries and GCC countries in particular have refused to consider an upper-limit for their emissions of CO2. However, as the concept of a global residual cumulative budget seems supported by solid earth-science studies, there is no possibility for GCC countries to escape the dilemma of abiding to a limiting cumulative emissions budget or trying to adapt to very high temperature change.

The IPCC AR5[6] defines the limit for total emissions since the onset of the industrial era, if humanity is to have a 66% chance of avoiding dangerous climate change (2^{o}C of warming), as 1,000 Gt of carbon (3,670 Gt of CO_2) and notes that the world has already used up to 52 % of this 'budget' [46]. Until recently, developing countries and GCC countries in particular have refused to consider an upper-limit for their emissions of CO_2. However, as the concept of a global residual cumulative budget seems supported by solid earth-science studies, there is no possibility for GCC countries to escape the dilemma of abiding to a limiting cumulative emissions budget or trying to adapt to very high temperature change.

Climate change will have a double impact on Gulf countries: first, directly a severe distortion of climate on their own territory (even, possibly, a change in suitability for human habitation) and indirectly, and second, a big disruption of their economic model based on the extraction, production and export of hydrocarbons and derivative products. Given that their environment is already very engineered, the main impact is through the transformation of their business model and the resulting decrease of revenue and increase of stranded asset risks. The possibility to harness vast amount of solar energy and the availability of large storage potential in depleted oil

[6]UNFCCC, United Nations Framework Convention on Climate Change (1992), article 2.

and gas reservoirs make that DAC activities could be an attractive option for GCC countries by the middle of the century.

These two-pronged threats should motivate GCC member countries to participate actively in the coming climate negotiations in order to push for a fair burden sharing in a strategy aimed at containing the temperature increase to less than 2^{o}C, or even 1.5^{o}C. The energy transition induced by international agreement and technical progress will have a large impact on Gulf countries economies but they only started to address the issue comprehensively.

2.1 Climate change environmental impacts

The key physical impacts from climate change are variations in temperature [15], precipitation and sea level rise. This creates water stress and increased surface temperature in GCC countries [48]. There is also an acute dust issue in these countries that could be amplified by climate change [38, 24]. Water scarcity increases agricultural production cost, higher food import bill and overall food insecurity given the highly subsidized domestic agriculture and high dependency of GCC countries on foreign food products [9]. As well, to continue to enjoy a comfortable life style, cooling capacity will need to increase in line with the rising temperatures. Apart from physical impacts, climate change imposes a stress on resources and on their distribution among the populations in GCC countries. This will multiply the socio-economic tensions that preexists in the Gulf monarchies [29], [30].

2.2 The energy transition and its impacts on GCC countries

Currently the GCC states, and in particular Qatar, are among the largest per capita emitters of GHGs. Indeed, CO_2 emissions are linked to economic growth of these countries [40]. The tradition of free or quasi free access to fossil fuel energy makes very difficult to implement a policy based on economic incentives. A solution to this quandary could be provided by the development of Smart Cities (SCs) associated with Smart Energy Systems (SESs), where, through the advent of the Internet of Things (IoT) the technologies of use, like appliances, cooling systems, PHEVs, etc, will communicate with energy producers and distributors and use “virtual” energy prices and “smart contracts”to implement demand response, provide reserve and participate efficiently in the system service duties. So doing, without extra charge to the consumers the penetration of variable renewable energy will be fostered.

Worldwide the expected energy transition leads to a peak of fossil fuels demand. In a competitive market, the rent collected by each oil barrels sold will disappear and will be replaced by a normal return on investment (real interest rate) [20]. The revenue of Qatar and Gulf countries will drastically decrease. All the subsidized economic activity will tend to disappear as well. The energy transition put at risk the way of life enjoyed in Qatar and in other surrounding oil and gas producing countries. Some countries (Norway, Qatar, UAE) have constituted a sovereign fund to share the wealth created by hydrocarbons with the future generation. As well these countries look to diversify their economy towards other value creation activities. Meanwhile none of that will create as much revenue as the oil and gas business has generated over the previous years. The pace of transition will determine what will be the effort and speed that oil and gas countries need to develop in their move towards diversification.

The strategic analysis framework sketched in Fig. 1 below summarises the challenges facing Middle East countries.

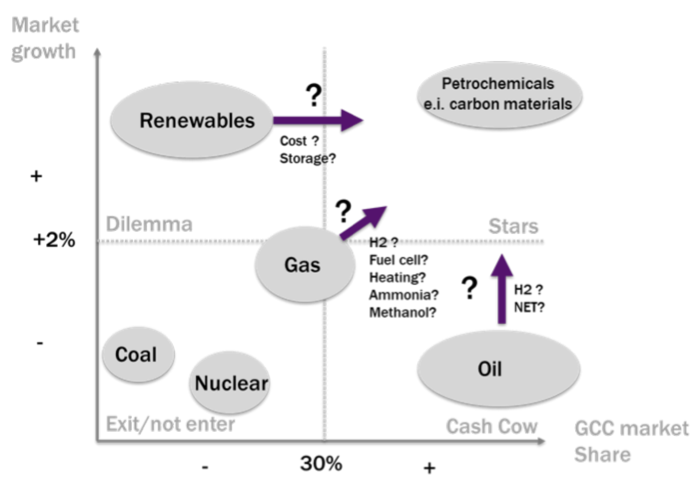

Figure 1: SWOT analysis

In an historical perspective, past energy transitions (biomass to coal and to oil) have been triggered by new technologies becoming economically more competitive. In these cases, the transition is slow as the energy industry is very capital intensive and the time to depreciate past infrastructures investments slows down the energy transition. [44]. Meanwhile, counter examples exist when political urgency is created (e.g. transition to nuclear in France) or a new type of end use or energy service is created (e.g. Ford T diffusion in early 20^{th} century) [41]. The current energy transition is more specific as it is driven by climate polity [45]. The energy transition is a political answer to a global problem: the transformation of climate, a collective good shared by humanity. The problem is to create a mechanism to select the right energy technologies that permit compliance with the political goals. A politically driven transition could happen more quickly than economics-based transition. For instance, pro-active pricing policies will influence the speed of technology diffusion and foster the energy transition[7]. Fast or slow transitions do not have the same effect on wealth transfers from developed countries to emerging countries or from consumer countries to oil and gas countries [18] .

Oil and gas producing countries have important stakes in the forthcoming energy transition as being among the most impacted economies. They face some strategic dilemmas: should they invest in domestic renewable energies to increase export of oil and gas; will oil and gas reserves and infrastructure investment get stranded? Will they be able to diversify their economies in time? Should they invest massively in negative emission R&D? Is natural gas a transition or a destination fuel? Is LNG-to-power a competitive option? what should be their positioning and proposals in COP agreement discussions? and many other questions regarding the uncertain outcomes of energy transition.

2.3 Towards an Unburnable oil

Several analysts highlighted that in order to reach the 2^{o}C target at the end of the century, maybe up to 50% of the oil reserve should not be burnt [31]. Even with Carbon capture and Sequestration (CCS) the question of "unburnable oil" remains at the top of the agenda of the energy transition [33]. In the framework of UNFCCC, compensation for oil left in the ground was raised the first time by Ecuador in 2012. This idea is starting to gain momentum as GCC states have understood that revenue losses from reduced demand, low prices, oil rent loss and trade barriers are only the near term consequences of a loss of wealth from the potentially stranded oil and gas assets. Energy transition worldwide leads to a significant shrinkage of the oil rent. New energy sources like solar or wind power generation are increasingly competitive with fossil fuel power generation [23]. Electric vehicles

[7] e.g. price subsidies for solar implementation in Germany or elsewhere in Europe

threaten oil demand in the new needs for mobility and may lead to a peak oil demand as soon as 2030 [36]. As shown by the transition from horse powered cart to internal combustion engine this electric vehicle transition could be a matter of one decade only ([41]) if the value added for the end user is significant. Autonomous vehicles pilot experiments in smart cities demonstrate that urban users could unload significant value in time saving and safety [16]. An inherent dichotomy exists between GCC states vast oil and gas wealth and international potential climate change mitigation objectives. [30]. Meanwhile Gulf countries are hesitant to fully embrace the 'Green Growth' concept. Despite their announced INDCs, many GCC countries are not yet committed to a drastic transformation of their economies, where energy efficiency, climate resilience and sustainable economic development are combined. In recent years, GCC countries recognized the synergy between climate action and economic diversification. Green Growth plans have been drawn in UAE, Qatar, Saudi Arabia and Oman (Hiwar, 2013). Following the oil price fall, every GCC countries took the opportunity to increase the price of energy domestically [49]. They are experimenting with a new approach combining partial subsidy programs and partial fossil fuel price adjustments. This could gradually move towards market-based efficient pricing over the medium to long-term when energy subsidies are eventually phased out [37]. A low carbon transition will require not only to reduce emission from the fossil fuel sector but also to transform the economic activities in GCC countries. As such, at COP 18 in Qatar, some GCC countries proposed to add economic diversification as a climate change mitigation instrument. (UNFCCC, 2012). The effort to introduce national components into international agreements are now a well-established strategy to mitigate impact of energy transition and climate policies.

3 Renewables: corner stone of energy transition

3.1 Renewables may challenge oil and gas for power generation in GCC countries.

Rising electricity demand, economic development, expanding population led to an increasing volume of hydrocarbon diverted to the power sector at price below international levels. Meanwhile, due to a rapidly growing domestic energy demand, growing concerns over the long term demand for hydrocarbons and the associated need to diversify their economies, the importance of maintaining some fiscal stability and the tightening constraints from global environmental policies, all of GCC states recognize in their long range plans that creating a more sustainable future involves implementing more renewables [28]. Resource-rich GCC economies are still lagging behind in the implementation of renewable but have a large potential. They enjoy high levels of solar irradiation. They have large amount of land available at low cost close to large electricity demand centers. Altogether, while freeing oil and gas for revenue generation, such development of renewables will also decrease the GCC carbon footprint. Economic diversification will derive from renewable implementation with a possible job creation estimated roughly at 210 000 jobs in 2030. [23]. Meanwhile not much has been achieved in the GCC region; a few large projects have been initiated (e.g. Masdar UAE, Shams Abu Dhabi, Sakaka Saudi Arabia) but renewable energy only accounts for less than 1% of the total energy mix (compare to a world 7% in high income countries) and 3.5% of the power generation in the region (IISD, 2014) or in 2016 at 5.6% of total installed capacity according to Siemens (SIEMENS, 2018). GCC countries despite their high level of revenue, and thus their capacity to invest in capital intensive renewables, are lagging behind high-income countries. [8]

3.2 A path towards sustainability through new energy pricing policies

Currently, GCC states are locked in a unsustainable usage of hydrocarbons based on two interrelated factors: (i) subsidized energy prices create an inefficient energy demand which has been fulfilled by oil and gas reserves deemed as unlimited; (ii) financing national economic activity and domestic energy consumption is supported by oil and gas export revenues. GCC states need to better manage their revenues from oil and gas in order to maintain their investment in the economic diversification and in the energy transition.

3.2.1 Getting rid of energy subsidies

Energy subsidies distort the market based signals needed to foster penetration of renewables. While widely applied in the GCC countries it has been largely demonstrated that their impact to protect the poorer part of the population is very limited. The richest part of the population will monopolize most of the subsidies [22]. The subsidies are inequitable, with households in

[8] Installed solar based power generation capacity in GCC countries Source: (Poudineh, Sen, & Fattouh, 2018); authors calculations [37]

high-income brackets (enjoying relatively higher levels of consumption), capturing most of the benefits from low energy prices [14]. Oil and gas subsidies have created a competitive advantage for the incumbent. The relative cost advantage of solar technologies due to favorable climatic conditions in GCC countries is not perceived because of fossil fuel subsidies[10]. Furthermore, energy subsidies are helping very significantly the competitiveness of energy intensive industries. For instance, in 2016 following the price reform in Saudi Arabia, SABIC reported a 5% increase of its cost in petrochemical sector. Low energy prices encouraged wasteful consumption and industrial policies biased towards investment in energy intensive projects, such as petrochemicals, steel and aluminum [17]. Energy price reform is a sensitive issue as it supports the implicit social contract between rulers and citizens: the state governs the rent distribution as long as citizens benefit significantly from it. Some flexibility can be introduced in the social contract by implementing some compensatory measures for low income citizens and mitigations for industry uses, [22] [17].

3.2.2 Pricing carbon

In a market based pricing environment, a carbon tax or a carbon price in a ‘cap and trade system could be a proper incentive policy for accelerating renewable energy development. It is seen as the most effective way to boost renewable adoption. As well such a policy would need to be adjusted with specific compensation towards the poorest. Meanwhile in GCC, such a tool would be very difficult to implement as the tax collection system is very nascent since most of the state revenue comes from oil and gas rent.

4 SES and SC development

Dr. Aisha Bin Bishr, Director General of the Smart Dubai Office, describes the impact of smart city:

> Smart Dubai: Real Impact
>
> **Social:** Car sharing and smart parking apps improve mobility and reduce both costs and emotional stress associated with driving on congested roads; free citywide Wi-Fi provides 24/7 Internet access; open data promotes transparency and opportunity for citizens; smart apps and government health insurance help ensure all residents have access to medical

care; improved mental well-being from living in a society focused on happiness.

Financial: Dubai Government saved $ 1.09B between 2003 and 2015 by adopting smart initiatives; $ 1.5 was saved for every 27 cents spent; efforts to streamline urban mobility and free citywide Wi-Fi are attractive to business; encouraging public-private partnerships drive economic growth and value; motion detecting smart streetlights reduce operational costs.

Environmental: Smart parking app was downloaded 120,000 times in first six months with usage reducing congestion, emissions and fuel usage; motion detecting smart streetlights lower energy use and carbon impact; 97 % of Dubai water and electric customers receive their bills digitally, helping the utility eliminate over 1,000 tons of carbon dioxide emissions since 2012 and reducing the number of trees required for paper bills.

Indeed, energy systems are central in the definition of resource flows and consumption in cities. The energy infrastructure is the single most important feature in any city. It is essential for all other functions. Smart grids are resilient and self-healing power transmission and distribution systems that enable the development of demand response and facilitate the harnessing of renewable resources. More generally, smart energy systems will exploit smart networks in transportation and resource delivery to achieve resilience and higher efficiency. A smart grid is a key component of a smart energy system. It provides self-healing designs, automation, remote monitoring and control, and establishes distributed microgrids. It also informs and educates consumers about their energy usage, costs and alternative options, and enables them to make decisions autonomously about how and when to use electricity and fuels. It provides safe, secure and reliable integration of distributed and renewable energy resources. In summary, it defines an energy infrastructure that is more reliable, more sustainable and more resilient.

A smart city, building on all combined data points and analysis of the smart grid will be able to coordinate the management of different networks:

- Water network: Water utilities are large consumers of energy in a city; by coordinating with the electric utility and shifting water pumping to non-peak hours, the water utility can reduce its energy consumption, help the electric utility avoid problems and allow other more critical and less flexible functions to maintain uninterrupted supply. In Gulf region cities seawater desalination is an essential part of the water management system. The two common desalination processes — distillation and reverse osmosis — require a lot of energy. The first uses the most energy — approximately 10 kWh/m3 of purified water, while the second is more economical, as it requires around 4 kWh/m3. New advanced technologies permit a reduction of energy requirements to 1.5 kWh/m3.

- Cooling networks: District cooling projects can be integrated in the global management of a regional energy system for the Gulf countries.

- Transport network: Electric mass transit networks (metro, trains) can reduce power consumption while maintaining schedules. Electric mobility can contribute to the optimal integration of solar and wind generation via the participation of building owners and the public in demand response programs. "Sustainable transportation requires smart grids". More generally, Intelligent Transportation Systems are supported by the development of smart grids and distributed and embarked communication and control systems.

- Gas transmission and distribution networks: Through the use of distributed gas powered fuel cell cogeneration units with heat storage, a connection between gas and electricity network can be realized, in order to optimize peak load generation.

- Smart transmission and distribution power networks: The smart transmission and distribution power networks will enable demand management policies responsive to time of use marginal cost. Even in a context where energy prices are subsidized, the generalization of smart appliances and demand devices, connected in real time to the power utility, will enable a demand response based on a timely information concerning the market prices, marginal line losses, reactive power implicit price, transformer & other asset life degradation cost, voltage control cost and value of power electronic dual use.

Grid-scale energy storage. In countries with hydro capacity, like e.g. Finland and Switzerland, pumped hydro storage is an efficient technology, when reservoir sites are available. This approach for energy storage involves large investment cost and irreversibility issue. Grid-scale energy storage offers an alternative based on batteries, ultra-capacitors , compressed air and flywheel technologies. They can complement intermittent renewable production units. Electric vehicles will also offer very large distributed storage capacity. In V2G , the batteries are used at idle time. This use is limited by the number of cycles of charge-discharge permitted for the batteries. In V2B one may organize the charging of batteries and the release of power at peak load in a lower number of cycles.

Managing smart power systems in smart cities. A collaborative distributed decision and control framework. The objective is to optimize the power system societal benefit through a collaborative and coordinated, distributed decision and control approach, in the presence of flexible loads, smart grid cyber-physical systems (CPSs) with fast cyber layer growth .

4.1 Managing flexible loads and grid-storage

Flexible loads include for example EVs, HVAC (heating, ventilation, and air conditioning), duty cycle appliances, grid-scale storage include also pumped hydro storage (when available) and a gamut of temporary storage technologies. In a distributed control environment one must envision a strategic behavior of the owner of the facility who will have to solve a dynamic optimization or game problem to decide when to charge and when to store energy or deliver power to the grid.

4.2 The grid management issues

Design issue. Among the main challenges and issues for future grid development when integrating a large share of renewables in the grid, developing grid-storage using smart EVs, enabling demand response, one finds:

- Define a topology for the communication network associated with the grid;
- Define aggregators and propose protocols for information exchange
- Define microgrids.

To mimic the efficient functioning of a market based management of a regional power system, with full marginal cost information shared in real time, one can formulate an optimisation problem where one minimises the consumer utility loss in deferring energy demand plus real and reactive power cost (including losses) plus asset life loss, and voltage control cost, subject to load flow, capacity and voltage magnitude constraints, and subject to capacity transfer, availability and life duration constraints. This is shown in the two parent papers [4, 5].

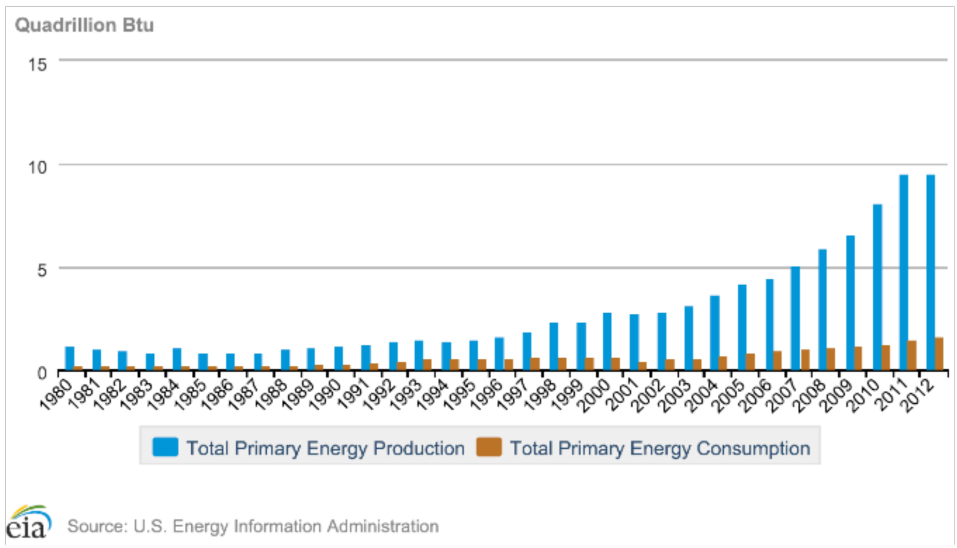

Figure 2: Total primary energy production and consumption (source: US EIA)

4.3 The role of DAC with CCS

Qatar economy competitiveness is largely dependent on the relevance of its energy policy. The evolution of total primary energy production up to 2012 is shown in figure 4.2. Qatar energy industry is facing internal challenges, as it has to cope with one of the world fastest growing economy as well as external issues with the emergence of a new paradigm on the demand side where Asia has become the fastest growing region for natural gas consumption. As well unconventional gas continue to reshuffle the global gas supply with stronger local shale gas and other unconventional production perspectives and competition getting stronger both from the US side as well as the Asian Pacific side.

The state-owned Qatar Petroleum (QP) controls all aspects of Qatar's upstream and downstream oil and natural gas sectors, including exploration, production, transport, storage, marketing, and sale of crude oil, natural gas, natural gas liquids, liquefied natural gas, gas-to-liquids (GTL), refined products, petrochemicals and fertilisers.

In 2012, Qatar's non-crude liquids production surpassed its crude oil production for the first time in the country history. Recent growth in non-crude liquids is the result of the natural gas production. Also, production of crude oil has declined in recent years as mature oil fields experienced natural decline.

Within the framework of the long-term national vision 2030, Qatar wants to build new competitive advantages beyond fossil fuels. In order to achieve this objective, Qatar has to challenge the basic stones of its current energy policy. Also it faces new challenges to achieve a sustainable development integrating in particular the goals of Paris agreements. Energy choices need to be mapped out, quantified and then simulated in order to clarify what are the long-term consequences of today energy choices.

The substantial increase of consumption of low priced gas in the Gulf countries is pushing Qatar to reconsider its regional energy policy (J. Krane, 2015). Another driver for drastic change in the use of fossil fuels in the regional energy system will be the possible trend toward a low carbon economy fostered by an international climate regime resulting from post COP-21 negotiations. Citing from the INDC document submitted by the state of Qatar for COP-21 Paris 2015:

> Despite the abundance of gas, which is clean energy, Qatar is heavily investing in other natural resources. Attempts have been made to utilize clean energy and renewable sources such as solar and wind power. Efforts have been made into solar energy generation with a view to becoming a regional supplier of solar-generated electricity. However, based on the harsh environment and weather conditions, utilizing such renewables as reliable power sources is very challenging due to the lack of access to high technology, which is necessary for using these sources effectively and efficiently. Yet, some national entities started considering solar and wind sources to generate electricity for small buildings aiming to open a new market, in the hope of strengthening the economic diversification. Utilizing clean energy and renewables is an adaptive precaution to climate change impacts that would open a window to diversify the economy and reduce emissions to the atmosphere from the fuel combustion. Some of clean energy and renewable sources are available, however,

they cannot be utilized without the needed support; especially, technology transfer.[9]

5 ETEM-SC Qatar

In this section we present the technology rich bottom-up modelling tool ETEM-SC and its application to create scenarios of a transition to NZE for Qatar. In a first subsection we recall the modelling done as part of the project *Modelling Transition to Energy Sustainability in Smart Cities* also supported by QNRF[10] in 2013-2016. In a second subsection we present the extension of the model done in the current project. ETEM-SC is a multi-sector, multi-energy, technology rich model specifically designed to analyze energy transition at regional level; its reference energy system (RES) is shown in Figure 5.3 below. The model is fully described in refs. [4, 5]

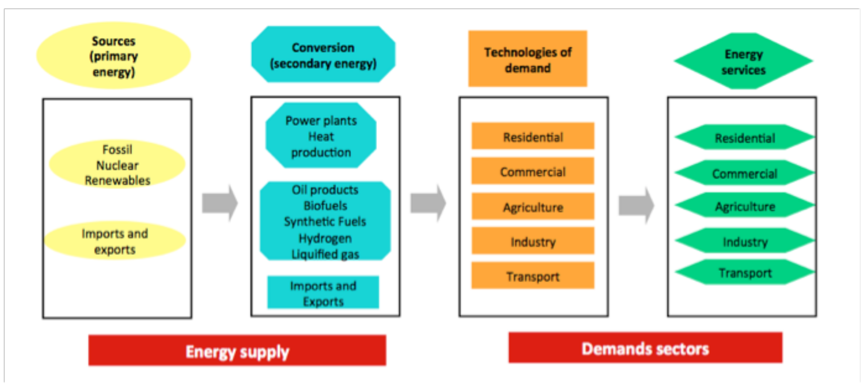

Figure 3: RES for ETEM

5.1 A first analysis of introduction of smart grids in Doha with electric cars (PHEVs) and smart cooling systems.

At COP21 in Paris, more than 160 nations, including GCCs, have agreed to reduce GHG emissions in order to reach a goal of limiting the temperature change at the end of 21st century at 1.5^{o}C. For example, as shown above in section **??**, at COP21 Qatar has made a commitment to reduce its per-capita emission level, which is one of the highest in the world.

[9]quote from Qatar INDC document, 2015.
[10]NPRP No.:6 C 1035 C 5 C 126

To deal with these challenges, the Gulf countries count on a substitution from fossil fuel source to variable renewable ones (as well as, to some extent, to nuclear power generation in UAE, KSA and Iran). This is exemplified by the location of IRENA headquarters in Abu Dhabi, inaugurated in May 2015. Indeed, harnessing wind and solar energy sources seems promising in the region, with some caveats due to intermittency of wind blowing, dust and sand storms reducing the efficiency of solar panels. There is another game changing phenomenon represented by the drive toward smart cities. The cities in Gulf countries are very modern and they are ready to embrace the smart city paradigm and concept. Abu Dhabi and more generally the UAE, Qatar and Saudi Arabia have announced pilot projects for fully integrated "smart-city" districts or decentralized energy systems. The development of the "internet of things", which characterizes smart cities, will translate for the energy system into a development of smart-grid connected, distributed energy resources and this should help tremendously the penetration of variable renewable energy sources. The impact on the energy system of a transition toward smart city could take many forms: (i) by providing two-way communications between consumers and electricity producers, the smart city will foster demand response and distributed energy resource management; (ii) new forms of demand for energy services will materialize in the transport, housing and service sectors that could contribute to lower the environmental footprint of the energy sector; (iii) the smart-grid connection of distributed energy resources and the possibility to provide secondary reserve through grid storage and distributed system service, like e.g. reactive power compensation, will facilitate the penetration of variable renewable energy in the energy system.

5.2 Qatar energy system as represented in ETEM-SC

The reference year is 2012 and all energy data are given in Petajoule (PJ). Demand in private transport is expressed in thousand km per day (kkm/day) and water demand is given in Million of cubic meters (Mm3).

Gas and LNG sectors. Qatar is the second largest natural gas exporter and the world leader in term of LNG exports. Even if in 2017 the companies are merging, at the time of the study, two companies were responsible for extracting gas out of the gas fields of Qatar (mainly the North Field, shared with Iran): RasGas and QatarGas. Most of the extracted natural gas is liquefied and exported by boat. Natural gas is also exported through a pipeline connecting Qatar with the UAE and Oman (Dolphin Pipeline).

According to the IEA, Qatar has produced 6572 PJ of natural gas in 2012, of which 4912 PJ were exported of whose 738 PJ through the Dolphin Pipeline.

There are seven facilities transforming natural gas into liquefied natural gas (LNG) in Qatar. Tables below provide the input and output for each of the LNG trains in 2012. The sources are the respective websites of QatarGas and of RasGas.

Table 1: LNG train productions and efficiencies- all energy in PJ; efficiencies in % -(Source: QatarGas and RasGas websites and authors calculations)

	QGas1	QGas2	QGas3	QGas4	RLaffan1	RLaffan2	RLaffan3
NG Input	553	916	452	446	381	837	914
LNG Ouput	487	812	406	400	337	747	819
Efficiency	88.06	88.6	89.7	89.7	88.6	89.2	89.7

Regarding domestic use, natural gas is mainly used by power plants, desalination, liquefaction facilities and the industry. According to the IEA, gas consumption is summarized in the following Table. The decomposition of the Industry and Non-energy use categories are based on (Wood Mackenzie, 2014) and then we calculated sectors' consumption based on IEA figure to ensure data sources uniqueness.

Table 2: Domestic supply in 2012 (Source: IEA)

Sector	Consumption (PJ)
Industry	185.7
Aluminum	100.2
Steel	42.7
Construction	27.9
Other	14.8
Non-energy use	113.9
Methanol	19.4
Ammonia	94.5
Energy industry own use	578.2
Power plants	341.4
Other transformation	448.1
Total	1667.4

Oil sector. According to IEA, the final consumption of Qatar in 2012 for transport sector (motor gasoline and diesel) was about 147 PJ. From our estimates, we decomposed this consumption into gasoline for private transport (57.3 PJ), diesel for private transport (31.6 PJ) and other transport categories (58 PJ). IEA estimates the final consumption of Qatar in 2012 of

Industry sector around 51 PJ and of other sectors around 5.1 PJ. Power and water desalination plants. Electricity is entirely produced locally out of gas (IEA, Kahramaa). There is no import and export. Only emergency power grid is in place with neighboring countries. The 2012 production reached 34.8 TWh, i.e. 125 PJ. According to the IEA, the electricity sector produced 125.3 PJ by consuming 341.4 PJ of natural gas. The overall efficiency of the process is therefore around 37 %. Water desalination plants exploit heat generated by power plant production. Their total production in 2012 was around 436.3 Mm3 of water with an overall efficiency of 82.7 %. The list of power/desalination plants in Qatar is given in Table 3 as well as their production capacity and their total generation in 2012.

Table 3: Capacity and production of power and desalination plants in 2012

Plants	Power		Water	
	Capacity (in MW)	Capacity (in Mm3)	Production (in GWh)	Production) (in Mm3
Ras Abu Fontas A	487	2,398	91.3 58.7	
Ras Abu Fontas B	609	4,509	54.8	49.2
Ras Abu Fontas B1	417	1,928	48.1	44.8
Ras Abu Fontas B2	567	2,676	74.7	55.5
Ras Laffan A	756	3,806	66.4	54.6
Ras Laffan B	1,025	4,716	99.5	80.5
Ras Laffan C	2,730	7,883	104.5	93.6
Mesaieed	2,002	5,812	-	-
Total	8,786	34,788	528.3	436.9

According to IEA, all produced electricity is consumed in Qatar. We summarized below our estimates from different sources, e.g., IEA and Wood-Mackenzie, by sectors (industry, residential, commercial and government). Except for industry, we differentiable space cooling from captive demands for electricity consumption.

CO2 emissions. Figure 5.2 shows the CO2 emissions by sectors in 2012.

Table 4: Electricity consumption by sector -2012 (in PJ)

Industry electricity demand	35.3
Oil and Gas	3.8
Petrochemical	7.5
Construction	1.2
Metal	7.6
LNG	10.0
Other industry	5.1
Cooling demand	61.6
Residential flat	4.9
Residential villa	20.0
Commercial	12.3
Government	7.7
Other	16.7
Captive demand	20.5
Residential flat	1.6
Residential villa	6.7
Commercial	4.1
Government	2.6
Other	5.6
Total (including 7.9PJ of losses)	125.3

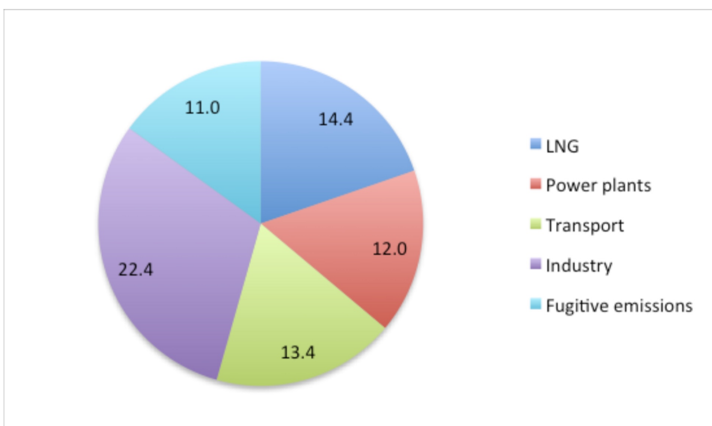

Figure 4: Emissions by sectors in 2012 (in Mt CO2)

Direct Air Capture (DAC). Quote from [26]

> *The only feasible techniques involve either absorption or adsorption on a sorbent. With such techniques, energy is required only to regenerate the sorbent. This regeneration process operates on the sorbent mass, which scales with the mass of the CO2 captured rather than the much larger mass of the air... One can break the air capture process into three steps: (i) contacting the air, (ii) absorption or adsorption on a sorbent, and (iii) recovery of the sorbent.*

5.3 Assumptions and definition of long-term scenarios

Useful demands. The evolutions of useful demands are based on population and GDP growths. Regarding population trend we retain the estimates of the medium variant scenario computed by the UN Population division. Our GDP driver is based on official GDP forecasts up to 2035 at the time of writing of the article and afterward we assume a 2 % GDP growth estimate. Figures 5.3 and 5.3 below show the estimated evolutions of useful demands[11] up to 2050 in the different sectors.

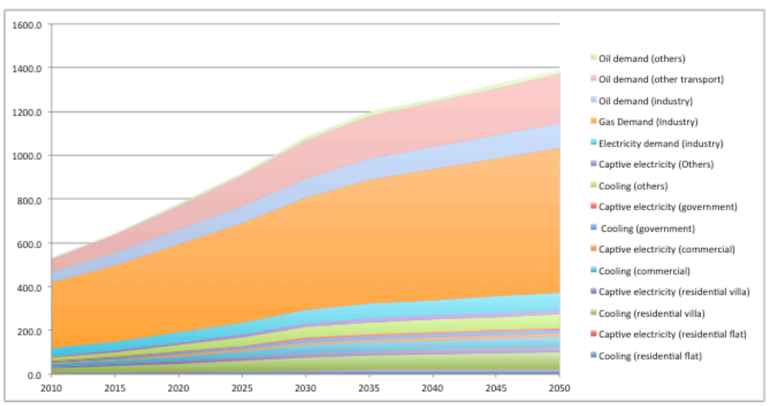

Figure 5: Evolution of useful demands (in PJ)

[11]to express useful demands in PJ we consider the existing technology mix that was used in2012 to satisfy the demand for energy services.

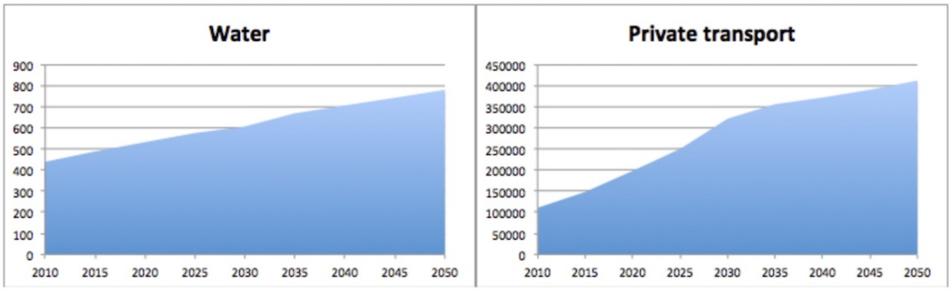

Figure 6: Evolution of demands for water (in Mm^3) and for private transport (in kkm/day)

Energy prices. Another set of important drivers of the model concerns the evolution of imported/exported energy prices. Our LNG and oil prices refer to the prices of the "New Policies Scenarios" from the 2015 World Energy Outlook. For the prices of natural gas exported through the Dolphin pipeline, we use figures given in (Dardouche, 2012) where the author mention that export are "done under long-term (25- year) agreements with heavily discounted prices ($1.3-1.5/MMBtu) resulting from the political importance accorded to the project in its early days." After 2030, as long term contracts reach their end, prices for piped natural gas should converge towards the LNG netback. As such, we take out liquefaction cost ($3/mmBtu) as well as transportation cost ($1/mmBtu) to calculate the new Dolphin Pipeline cost.

Scenario definition. In our analysis, we compare three contrasted scenarios:

- A Business As Usual (BAU) scenario, which has no emissions reduction objective and does not consider the possibility to develop smart-city and smart-technology concepts. This scenario only takes into account the objectives of the Qatar National Vision 2030 program (State of Qatar, 2008) in term of natural gas vehicles and concentrated solar power (CSP) plants deployments.

- A Green Qatar (GQ) scenario in which we limit GHG emissions in the power and private transportation sectors. This corresponds to a stringent 60 % emissions reduction in 2050 for the two sectors together compared to BAU levels. This differs strongly from the Qatar National Vision 2030 objectives.

- A Smart-City (SC) scenario, which assumes a further deployment of smart-city concepts similar to Lusail city. It imposes the same emissions reduction pathway as for the GQ scenario but assumes a new districts standardization to smart-city concepts, (e.g., integrated transport and advanced district cooling systems), contributing to a reduction of useful demands and higher efficiency. We consider, in the present simulation, that a third of new useful transport and cooling demands is located in smart-districts.

Excluding fugitive emissions, the GQ and SC scenarios are equivalent to a reduction of 34 % of GHG emissions compared to the BAU scenario, as displayed in Figure 5.3.

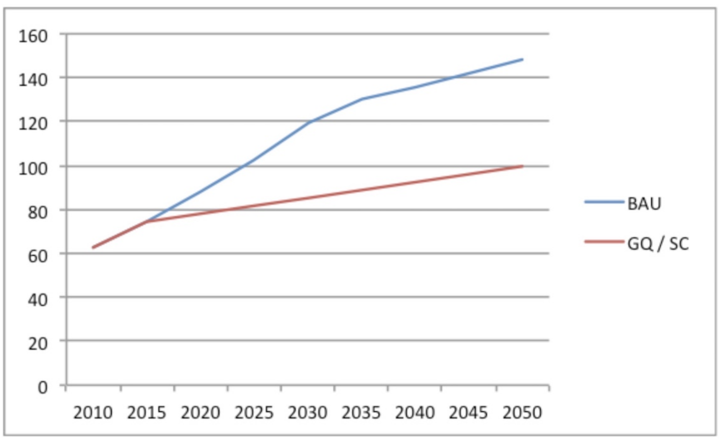

Figure 7: Emissions pathways for BAU, GQ and SC scenarios

Note that, for the moment, we do not address abatement issues in all economic sectors as the evolution of non-energy, gas and LNG industries depends mainly on political decision more than on technological choices. The emissions reduction potentials of these specific sectors are discussed later on.

5.4 Simulation results and discussions

We compare the energy system evolutions of Qatar on two contrasted scenarios, i.e., Business as Usual (BAU) and Green Qatar (GQ) scenarios, and we discuss, in particular, the role of renewable energies in power generation and electric vehicles in the private transportation sector. The evolution of other transportation, industry and gas sectors, as well as, the potential impacts of a broader cooperation with Middle East and Asia are discussed separately in the conclusion.

Comparison of BAU and GQ scenarios. Simulation results are displayed on Figures 5.4, 5.4 and 5.4 which show the evolution of emissions, of power generation and of private transport on the period 2010-2050. First,

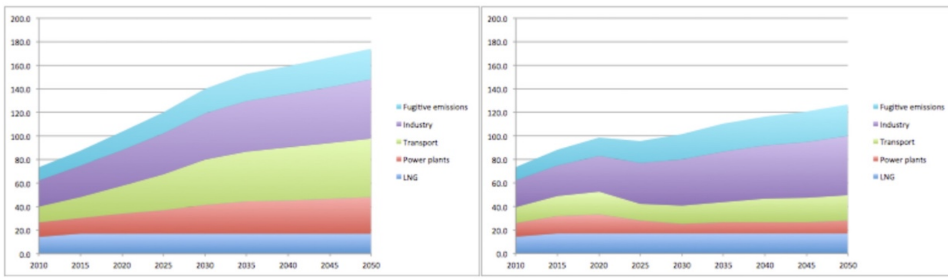

Figure 8: Evolution of CO2 emissions in BAU (left) and GQ (right) scenarios (in Mt CO2)

one observes on Figure 5.4 the respective contributions of transport and power sectors in achieving emissions reduction objectives. The private transport appears to be the main contributor. Electric vehicles help strongly from 2025, as it can be seen on Figure 4.3, with an activity share close to 95 % between 2025 and 2050. The remaining emissions in transport are mainly linked to other transport activities that are not constrained in the present study. In power generation, CSP plants are privileged technologies for reducing emissions contributing to almost 66 % of power generation in 2050. Figure 4.2 also shows a slightly decrease in the use of existing gas power plants. This due to the very stringent reduction in CO2 emissions imposed to the power sector. This would be certainly politically difficult to justify.

Regarding electricity demand and production, Figure 5.4 shows a significant increase of production in 2050 from 350 PJ in the BAU scenario to 440 PJ (without energy savings) in the GQ scenario, resulting essentially from the new EVs demand in the private transport. We also notice that in a constrained emissions context, the model exploits the potential of energy savings in residential, commercial and government buildings with investments mainly in insulation and refurbishment for reducing the needs for space cooling.

For solar production, we distinguish direct use and stored electricity. The high penetration of EVs combined with Vehicle to Grid (V2G) capability enables the optimization and rationalization of energy uses. As a matter of fact, through demand-response (DR) mechanisms, the model allows the electricity demand to adapt to implicit pricing signals. This is the case, in particular for EVs charging and the use of EVs batteries to provide temporary storage. DR is thus facilitating the demand/supply balance for electricity by smoothing production and consumption over the different time periods.

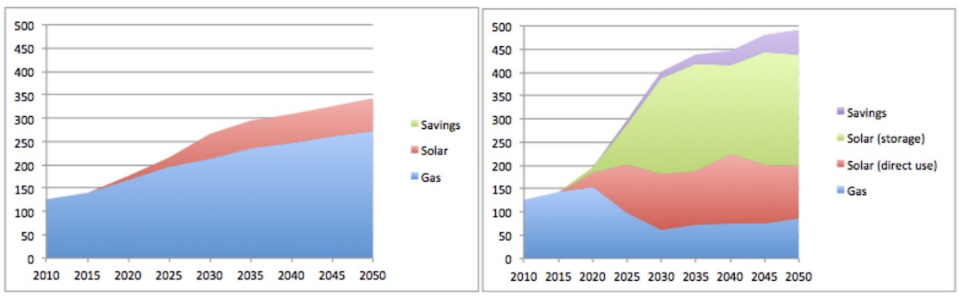

Figure 9: Evolution of power generation in BAU (left) and GQ (right) scenarios (in PJ)

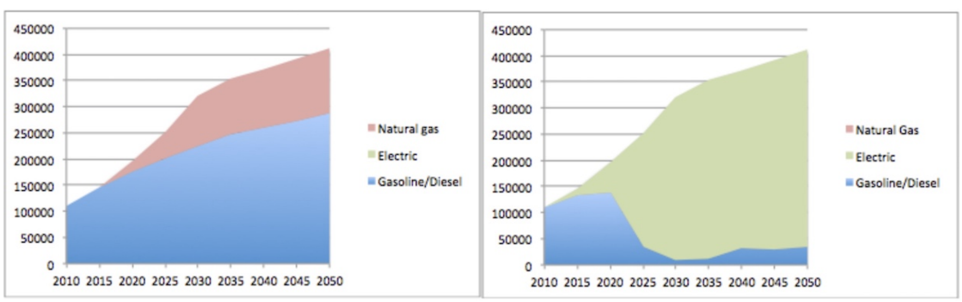

Figure 10: Evolution of private transportation in BAU (left) and GQ (right) scenarios (in kkm/day)Evolution of private transportation in BAU (left) and GQ (right) scenarios (in kkm/day)

Moreover we observe that both CSP and EVs technologies are very complementary options, EVs fostering the solar generation development. EV batteries contribute to store intermittent electricity production and thus provide the power systems with the necessary secondary reserve to cope with production variations intervening, in a fast time scale, due to intermittency of solar generation. Note that natural gas vehicles, which appear in the BAU scenario as a consequence of the Qatar National Vision 2030, no longer penetrate in the GQ scenario. First they are not compatible with the stringent emissions reduction objective and, second, contrarily to EVs, natural gas vehicles cannot provide system services such as secondary reserves needed for power network stability. Note also that, as the model does not include the carbon capture and sequestration (CCS) technologies for the production of hydrogen from natural gas, fuel cell cars cannot be a viable option. Finally, we estimate the systemic discounted extra cost associated to the GQ scenario (compared to the BAU scenario) to be around $ 60 billion for the period 2020-2050. This cost corresponds mainly to investments in CSP plants and EVs.

The Smart-City scenario We now focus on the SC scenario, which assumes a strong development of the Qatar energy system to smart-cities and smart-districts. The model does not take into account the investment costs related to new smart-districts but instead intends to estimate the avoided cost for the energy system when developing such smart-city concepts. As previously mentioned, we consider that a third of new forthcoming useful demands will be located in smart-districts.

Figure 5.4 displays the penetration of SC-based mobility on the transportation sector, which is quite significant. As for cooling, it contributes to reduce slightly the electricity demand. As shown on Figure 4.5, SC-based development reduces the need for electricity storage compared with the GQ scenario.

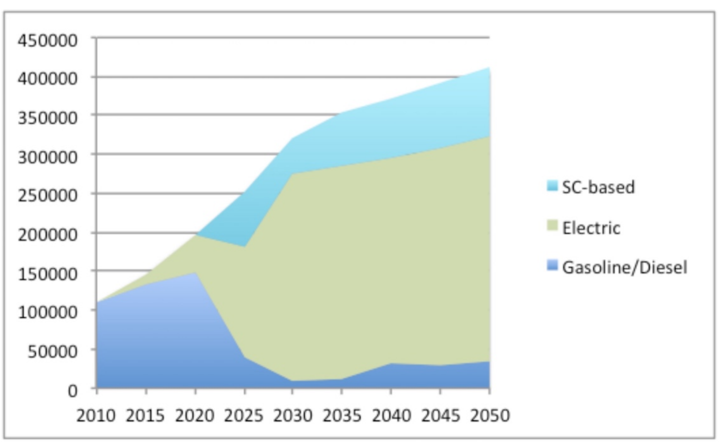

Figure 11: Impact of SC mobility on the transportation sector

We estimate a discounted avoided cost of around $10 billion on the time

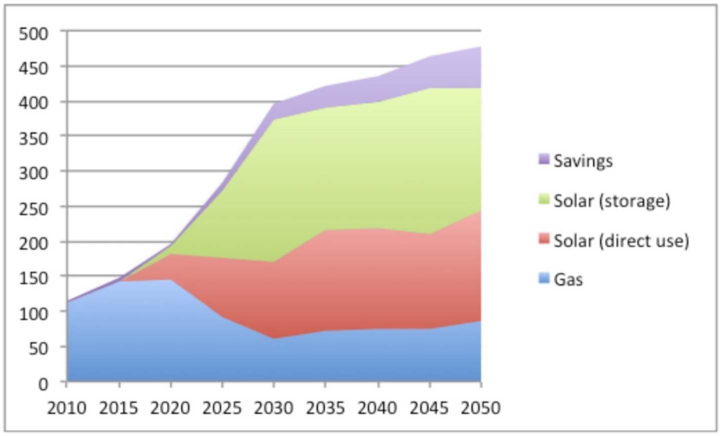

Figure 12: Impact of SC concept development on the electricity sector

span 2025- 2050, by comparing the systemic costs of the GQ and SC scenarios. This cost includes the energy savings due to the use of more efficient smart-technologies for transportation and cooling services and investment savings for standard technologies (e.g., EVs). This avoided cost should be compared to the extra development cost of smart-districts in Doha.

Main insights.

- in the context of stringent emissions reduction policies, EVs with their batteries play a key role in the penetration of intermittent solar productions as they facilitate the supply/demand balance for electricity by smoothing production and consumption and they help significantly to the stability of the power distribution systems by providing secondary system reserves.

- To reduce drastically carbon emissions, Qatar is expected to lower the dependence of its domestic consumption to natural gas, an evolution that would liberate further natural gas for LNG export.

- The systemic discounted extra cost associated to a Green Qatar scenario (compared to the BAU scenario) is estimated to be around $60 billion for the period 2020-2050. This cost corresponds mainly to investments in concentrated solar plants and electric vehicles.

- The deployment of new smart transportation and heating concepts might contribute significantly of paving the way to a low economy as they reduce slightly the electricity and mobility demands. The discounted avoided cost of smart-district development is estimated to around $10 billion on the time span 2025- 2050.

Micro level. The new technologies taken into account in the ETEM-Qatar relate to (i) opportunities for energy efficiency in smart cities [**?**], (ii) gains of energy efficiency in buildings[**?**]. (iii) monetising natural gas [**?**], (iv) developing CCS and DAC activities in industrial sector, adapting processes in industrial sector.

5.5 A scenario of transition to ZNE for Qatar.

The model ETEM-Q is driven by a forecast of useful demands that is summarised in Table 5.5.

Unit	Sector									
PJ		2020	2030	2040	2050	2060	2070	2080	2090	2100
	RC-Cool.[12]	88	93	99	104	106	110	117	120	123
	RC-CE[13]	45	48	51	54	55	57	61	63	64
	Ind. - Gas	364	368	379	390	402	414	427	439	453
	Ind. - El.	58	59	61	62	64	65	67	69	71
	Ind.- Oil	83	84	86	89	91	94	97	100	103
	Aviation	136	137	141	146	150	154	159	164	169
Mm3		2020	2030	2040	2050	2060	2070	2080	2090	2100
	WD[14]	605.72	650.59	695.46	740.32	746.36	784.61	840.55	863.97	881.43
kkmp/d		2020	2030	2040	2050	2060	2070	2080	2090	2100
	Indiv.	29526	31713	33900	36087	36381	38246	40972	42114	42965
	Metro	10017	10017	10017	10017	10017	10017	10017	10017	10017
	Bus	1500	1611	1722	1833	1848	1943	2082	2140	2183
kkm		2020	2030	2040	2050	2060	2070	2080	2090	2100
	Truck	9600	9696	9987	10286	10595	10913	11240	11578	11925

Table 5: Useful demands

Figure 13 shows the desired emissions profile (target), which converges to ZNE by 2070 and the emissions path that is realised (actual). Significant negative emissions activity develops from 2070 onwards, due to the high price of carbon on the international market. In the model one represents a possibility to buy or sell emission permits on an international carbon trading market. The price of carbon that we use is consistent with the macroeconomic simulations reported in [**?**].

Permits price								
2020	2030	2040	2050	2060	2070	2080	2090	2100
0	100	300	350	1000	1000	1200	1200	1200

Table 6: Carbon price evolution (\$/t CO_2)

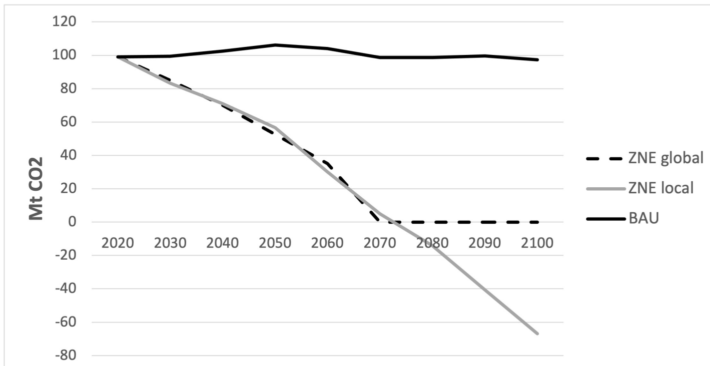

Figure 13: Emissions profile (Mt CO_2)

Figure 13 shows that, to reduce emissions, electricity generation uses less gas and develops solar sources, mainly photovoltaic and concentrated solar power plants.

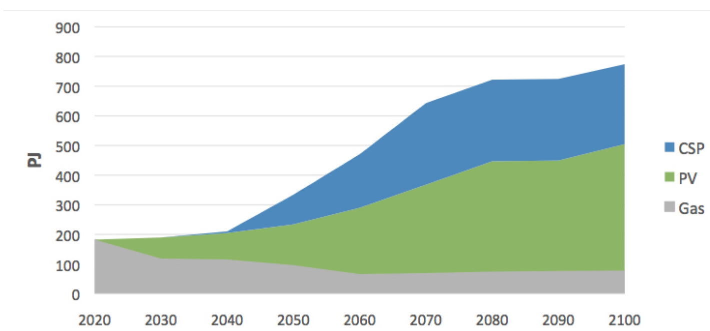

Figure 14: Electricity production by source (PJ)

For private transport, the petrol cars are abandoned after 2050 and replaced by Gas-powered hybrid cars and the, mainly by electric cars.

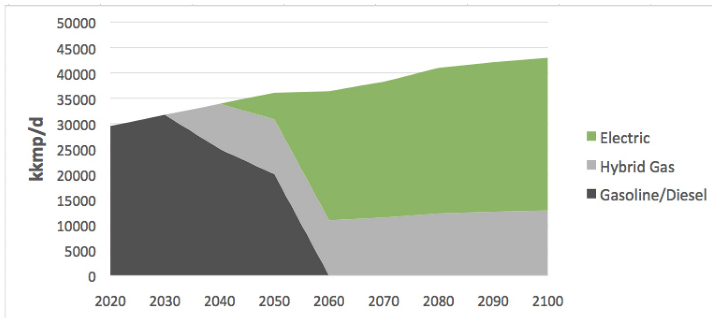

Figure 15: Usage technology for private transport (kkmp/d)

Figure 16 shows the penetration of district cooling in the residential and commercial sector.

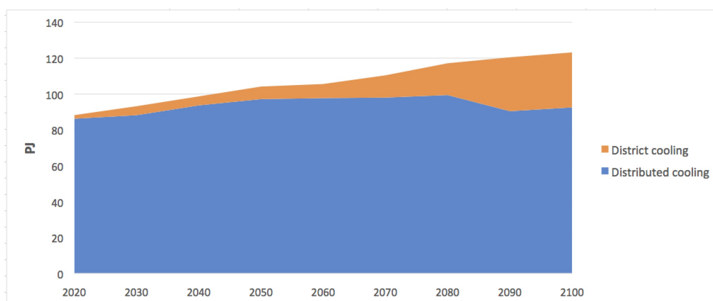

Figure 16: Usage technology for residential and commercial cooling

Figure 17 indicates that the industrial hydrogen production sector is developing strongly, with the electrolysis option and especially the SMR gas option with CCS.

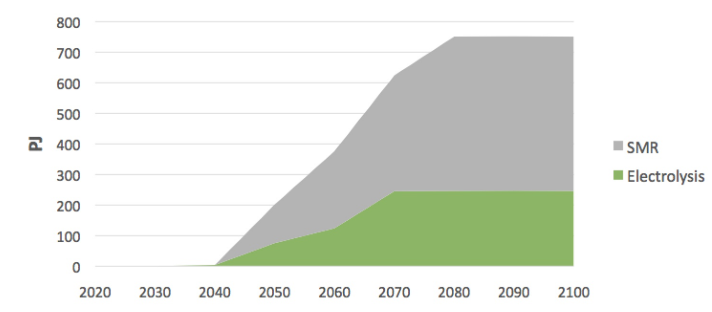

Figure 17: Hydrogen production by source (PJ)

In Figure 18 one sees that the storage of CO_2 in depleted oil and gas reservoirs develops strongly. Starting in 2050, DAC activity develops and reaches a high level at the end of the century (around 150 Mt of CO_2 captured and sequestered per year). This consumes 1000 PJ of gas each year.

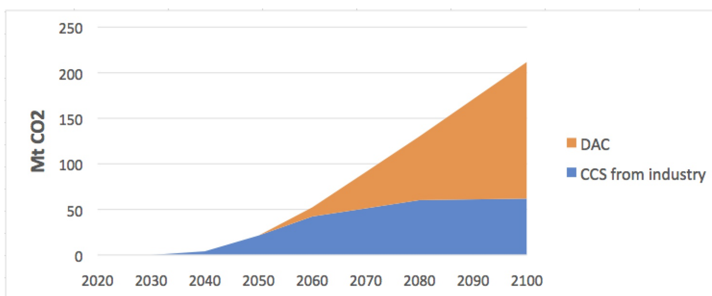

Figure 18: CO_2 storage (Mt CO_2)

5.6 ZNE scenario in a nutshell

To reach a ZNE regime by 2070 and exploit the resources offered by DAC technologies, this scenario proses Qatar to:

1. start immediately to foster the use hybrid and electric cars;
2. develop electricity generation from solar sources;
3. develop district cooling;

4. Develop hydrogen production with SMR (with CCS) or Electrolysis; starting in 2040;
5. introduce CCS in all industrial sector; starting in 2040;
6. Develop actively DAC with CCS, starting in 2040.

All these new technologies are close to maturity, and demonstration units are already available.

6 Which climate strategy for GCC states?

In [25] Jim Krane analysed the possible climate strategies for oil and gas production countries, taking the case of Saudi Arabia as a motivating example. He focused on three types of nearer-term climate strategies that he titled "Dig in," "Join in," and "Throw in."

- By "Digging in," states assume GHG accords like Paris agreement remain aspirational rather than binding, and act to to insulate the hydrocarbon sector against the aims of such accords;
- By "Joinning in," states engage in pursuing economically rational domestic energy policies that provide benefits in reducing GHG emissions;
- In "Throw in" strategy producer governments concede that climate change is inevitable and argue that damage caused by anthropogenic GHG emissions is preferable to costly GHG mitigation in line with Paris goals.[15]

Interestingly, J. Krane observes that Saudi Arabia, the largest economy among the GCC states has adopted a mixed strategy, which includes components of the three types above. In the past Saudi Arabia was a climate obstructionist, which joined UN-led climate treaty negotiations to thwart, delay or weaken a possible agreement (see J. Depledge [11]). Since the 2015 Paris agreement, Saudi Arabia has shifted its stance to one of support for climate action. With other GCC member states Saudi Arabia has declared nationally determined contributions (NDCs) to reduce emissions of GHGs. Domestically the kingdom has launched reforms of fossil fuel subsidies; internationally it promotes cleaner fossil fuel usage by supporting CCS, flaring

[15] quoted from [25].

reduction, and reduction of "alternate" GHGs, such as methane or Nitrous oxides. At COP22 the kingdom declared it sees CO_2 emissions as a "harmful effect" that can be mitigated with technological solutions[16]. And finally, Saudi Arabia is also supporting a "throw in" strategy that revolves around the idea that one will be better off by delaying strict mitigation because improved technology will emerge in the future to reduce GHG emissions without eliminating the fossil fuel industry.[17] A technical report from KAPSARC [19] uses the integrated assessment model DICE [35] to provide a cost-benefit analysis supporting this "pragmatic approach".

"Dig in" and "Joining in" strategies are also developing in other GCC member states, in particular UAE. To decarbonise the production and use of oil and gas CCS is a valid option in Gulf countries; in UAE one envisions capturing CO_2 in natural gas fuelled power plants and sequestering it for EOR [47]. UAE government announced in 2018 a proactive CCS development[18]. At the regional level, GCC nations have both the drivers and environmental gains to adopt the CCS technologies[19]. CO_2 Direct capture (CDR) and in particular Direct Air Capture (DAC) with CCS, are also promising options for these countries, which can tap unlimited renewable solar energy source or huge natural gas reserve to power plants located in vast open desert space. DAC technologies are becoming mature; a commercial demo DAC plant opened in Switzerland in May 2017; since then several operational projects have taken root in Iceland and USA[21]. Another available strategy to preserve the economic value of fossil fuels in a decarbonising world is to separate them into hydrogen and CO_2 with CCS for the latter. This strategy makes sense in the perspective of the development of a hydrogen economy as discussed by the International Energy Agency (IEA)[21]. In summary, these strategies involve offering "clean fossil fuels" whose car-

[16]Ministry of Energy, industry & mineral resources of Saudi Arabia 2017.

[17]quoted from [25].

[18]Carbon capture projects need to scale up 100 times. Gulf News.com Aug. 16 2018.https://gulfnews.com/news/uae/environment/carbon-capture-projects-need-to-scale-up-100-times-1.2136967

[19]Some of the GCC countries are already engaged in R&D initiatives, for example, Saudi Arabia has KACST- Technology Innovation Center on Carbon Capture and Sequestration while Saudi Aramco have their own CCS R&D program for CCS. In Qatar there is the Qatar Carbonate and Carbon Storage Research Center while Bahrain has Sitra Carbon Capture System. Recently, Masdar and ADNOC launched Middle East first Joint Venture for carbon capture usage and storage. On a multilateral level, back to 2007, King Abdullah pledged $300 million to finance a research program on the future of energy, environment and climate change. In addition, a sum of $150 million from Qatar, Kuwait and UAE has been allocated to support CCS research[20].

[21]http://www.climeworks.com/

bon content is either captured and sequestered or offset by DAC with CCS. Indeed, the current price of carbon on the ETS market does not bode well for the competitiveness of these technologies; however, if the goals of Paris agreement have to be reached most of the scenarios predict a carbon price that should make these technologies competitive in 2050 or even before.

The scenarios produced in our research with two macro-economic models and a bottom-up technology rich model tend to show the following:

- The climate change issue is now recognised everywhere and there is no future for GCC member states in adopting an obstructionist strategy;
- The options offered by CCS, DAC and Hydrogen economy tend to strengthen a mix of the "Dig in" and "Join in" types of strategy. On one side one will work at preserving te economic value of fossil fuels, while on the other side on will decarbonise entirely the local economy and exploit the opportunities offered by the international carbon markets.
- CCS and CCD technologies are essential to achieving the ZNE regime globally and also locally. In the scenarios studied in our research, the cumulative emissions budget was not allowed to be exceeded. Therefore, there was no incentive to adopt a "Throw in" strategy.
- GCC countries have to be proactive in the coming negotiations. They should aim at defining a governance based on equalizing the relative welfare losses among groups or coalitions of countries.
- GCC countries should develop their programs of clean fossil fuels, in particular CCS and Hydrogen extraction.
- GCC countries must prepare to the change in oil and gas demand patterns caused by the advent of electric mobility and SCs.
- GCC countries should push forward their policies in favor of SCs and SESs.
- SCs and SESs will develop in GCC states only if a new energy polity, exploiting the opportunities offered by IoT, is put in place.
- All of these transitional policies will require an effort to diversify the economies of GCC member states and to change their political and social contracts.

7 Conclusion

1. GCC countries have to be proactive in the coming negotiations. They should aim at defining a governance based on equalizing the relative welfare losses among groups or coalitions of countries.

2. GCC countries should develop their programs of clean fossil fuels, in particular CCS and Hydrogen extraction.

3. GCC countries must prepare to the change in oil and gas demand patterns caused by the advent of electric mobility and SCs.

4. GCC countries should push forward their policies in favor of SCs and SESs.

5. SCs and SESs will develop in GCC states only if a new energy polity, exploiting the opportunities offered by IoT, is put in place.

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