Les Cahiers du GERAD ISSN: 0711–2440

GCC countries strategic options in a global transition to zero-net emissions

F. Babonneau, A. Badran, A. Haurie, M. Schenckery, M. Vielle

G–2022–18

April 2022

La publication de ces rapports de recherche est rendue possible grâce au soutien de HEC Montréal, Polytechnique Montréal, Université McGill, Université du Québec à Montréal, ainsi que du Fonds de recherche du Québec – Nature et technologies.

Dépôt légal – Bibliothèque et Archives nationales du Québec, 2022
– Bibliothèque et Archives Canada, 2022

The publication of these research reports is made possible thanks to the support of HEC Montréal, Polytechnique Montréal, McGill University, Université du Québec à Montréal, as well as the Fonds de recherche du Québec – Nature et technologies.

Legal deposit – Bibliothèque et Archives nationales du Québec, 2022
– Library and Archives Canada, 2022

GERAD HEC Montréal
3000, chemin de la Côte-Sainte-Catherine
Montréal (Québec) Canada H3T 2A7

Tél. : 514 340-6053
Téléc. : 514 340-5665
info@gerad.ca
www.gerad.ca

GCC countries strategic options in a global transition to zero-net emissions

Frédéric Babonneau [a, b]

Ahmed Badran [c]

Alain Haurie [b, d]

Maxime Schenckery [e]

Marc Vielle [f]

[a] *KEDGE Business School, Bordeaux, France and ORDECSYS, Switzerland*

[b] *ORDECSYS & University of Geneva, Switzerland*

[c] *Qatar University, Doha, Qatar*

[d] *GERAD, HEC Montréal, Montréal (Qc), Canada*

[e] *IFPEN, IFPSchool, Rueil-Malmaison, France*

[f] *École Polytechnique Fédérale de Lausanne, LEURE, Lausanne, Switzerland*

frederic.babonneau@kedgebs.com
a.badran@qu.edu.qa
ahaurie@gmail.com
maxime.schenckery@ifpen.fr
marc.vielle@epfl.ch

April 2022
Les Cahiers du GERAD
G–2022–18

Abstract : Using a multi-level perspective approach combined with top-down macroeconomic models, we analyse the situation of the GCC countries in the perspective of a global transition to zero-net emissions before the end of the century. Based on these analyses we propose strategic and political options for these oil and gas exporting countries. We show that it would be unwise for GCC member states to adopt an obstructionist strategy in international climate negotiations. On the contrary, these countries could be proactive in developing international emissions trading market and exploiting negative emissions obtained from CO_2 direct reduction technologies, in particular Direct Air Capture with CO_2 sequestration, and thus contribute to a global net-zero-emissions regime in which clean fossil fuels are still used.

Keywords : Net-zero emissions, multi-level perspective approach, macroeconomic modelling, GCC countries, carbon dioxide removal, financial compensation, energy policy

1 Introduction

The successive COPs [1] have encouraged a transition of the global energy system towards sustainability through deep decarbonisation and the active use of renewable energy sources. COP26, held in Glasgow UK in November 2021reaffirmed the goal to *secure global zero-net emissions (ZNE) by mid-century and to keep 1.5 °C within reach.* To deliver on these stretching targets, countries will need to accelerate the phase-out of coal, curtail deforestation, speed up the switch to electric vehicles and encourage massive investment in renewables. [2] This reaffirmation of the Paris agreement goals will not however convince everybody that such a transition will take place. In [47], Nordhaus claims that Paris agreement, like Kyoto accord, is a "dead-end" because of lack of penalties for countries that would do "free riding". In any case, the GCC [3] countries are hit by a "double whammy", with the necessity to adapt to an even warmer climate and the possible deep decline of fossil fuels worldwide. [4] Already in 2017 KAPSARK, a Saudi research centre on energy, has organised a workshop on the theme "Role of oil in the low carbon energy transition" [33]. Among key points put forth we can quote :

> *... Under a binding constraint, the energy transition would have an impact on demand for hydrocarbons, including oil, which would probably peak... Although Gulf Cooperation Council (GCC) oil producers are better placed to survive periods of greater price volatility that are expected as part of this transition than higher cost suppliers, they are still exposed to fiscal risks if they do not diversify from reliance on hydrocarbon revenues... The energy transition poses challenges for both companies and governments. Those institutions that assume that it is business as usual face a threat to their business models. For financial institutions, the uncertainty posed by this transition represents a major risk factor. ...*

In this paper, [6] we address the conundrum posed by climate change to GCC countries by proposing a Multi-Level Perspective (MLP) approach to provide a qualitative assessment of the challenges for GCC countries and policy choices that could be taken to mitigate the societal cost of a transition to ZNE before the end of the century. This qualitative analysis is complemented by quantitative scenario-building approaches that exploit top-down macroeconomic modeling to assess the welfare losses associated with different climate policies around the world.

The scenarios obtained from modelling the energy system at the GCC country level and the macroeconomic effects of deep decarbonisation on a global scale highlight the key role that emerging CO_2 direct reduction (CDR) technologies, and in particular Direct Air Capture (DAC) [17], coupled with carbon capture and sequestration (CCS) [55] or coupled with enhanced oil recovery (EOR) [63] will play in the future.

In reviewing the literature, we note that the topics in this paper have received considerable attention recently in GCC member states and around the world. The issue of climate change is now well recognized, as evidenced by the numerous articles that have appeared in the general and specialised press, see e.g. *the Economist* briefs. [7] The book *When Can Oil Economies Be Deemed Sustainable ?* [42] edited by Luciani and Moerenhout, is a recent presentation of the situation of GCC member countries in a global transition to sustainability. Two KAPSARC reports, *Understanding the energy transition* [34], and *Role of oil in the low carbon energy transition* [33], analyse the impact of energy transition on GCC member states. The limited level of cooperation among GCC countries is analysed by Rossi in [51]. The stranded asset risks is evaluated by IRENA [32] and the GCC states energy challenges associated with renewable energy is discussed by Al-Maamary et al. [2]. The impact of oil prices on

1. Conferences of the parties ; UNFCCC see https://ukcop26.org/uk-presidency/what-is-a-cop/.
2. Quated from https://ukcop26.org/cop26-goals/.
3. The Gulf Cooperation Council is a regional, intergovernmental political and economic union that consists of Bahrain, Kuwait, Oman, Qatar, KSA, and UAE.
4. see [5].
6. Based on the results of the research project "*Modelling and Assessing the Transition to Low Carbon/Smart Economy in Gulf Countries*", supported by QRNF.
7. https://www.economist.com/schools-brief/2020/05/16/damage-from-climate-change-will-be-widespread-and-sometimes-surprising.

GCC economies is discussed by Vohra in [62] and the need of diversification by Fassano and Iqbal [18] or Flamos et al. [19]. Strategies of oil exporters in a carbon-constrained world are discussed by Van de Graaf and Verbruggen [15] and Gross and Matsuo claim for pragmatic policies [26]. A comparison of alternative programs for climate policies is done by Atalla et al. in [4]. Carbon trading scheme [27] and willingness to pay for a climate backstop provided by direct CO_2 air capture was already considered by Nemet and Brandt in 2012 [46]. CCS : State of play, challenges and opportunities for the GCC countries was discussed in [59]. Policy lessons from China's CCS experience are derived by Yang et al. in a KAPSARC report [65]. The development of CO_2 direct reduction technologies in long-term climate strategies of the Gulf countries is proposed in [5] and [6]. The role of negative emission technologies in meeting Paris Agreement targets is discussed in an EASAC report [17]. CDR/DAC in EU is also envisaged by Gelden et al. in [22]. CCS technology was already described in the models developed by ETSAP [55]. Enhanced oil recovery and CO_2 storage potential outside north America is discussed by Ward et al. in a KAPSARC report [63].

The rest of the paper is presented as follows : Section 2 recalls how the multilevel perspective (MLP) approach can provide insight into the possible transition to sustainability for GCC economies; Section 3 focuses on the transition to a net-zero emissions regime at the global and GCC country level; Section 4 presents the results of two macroeconomic modeling exercises that were used to explore possible socio-technical regimes. possible techniques; Section 5 summarizes the results of this MLP analysis; Section 6 concludes.

2 Multi Level Perspective for GCC countries transition to sustainability

The multi-level perspective (MLP) has emerged as a promising framework for analysing socio-technical transitions to sustainability [23]. Figure 1 summarises on a diagram inspired from [23] and [24] how the MLP approach can be used to analyse the techno-economic transformation of the GCC economies in their possible transition to sustainability.

One distinguishes the "Landscape" level describing global environmental, political and societal developments, "Meso" level where new socio-technical regimes take place and "Micro" level where technological niches nurture emergent technologies. Figure 2, below is a presentation in the MLP structure of the topics that are more specifically addressed.

Landscape developments. Landscape developments concern the mounting awareness of climate change risks, the reaffirmation of Paris agreement goals, but also the evolution of oil and gas markets in a global geopolitics perspective. They are mainly dominated by the global climate change issue and the possible global drive toward ZNE worldwide. The challenge of anthropogenic climate change caused by emissions of GHGs is now common knowledge, as indicated by the many articles on this topic published in the economic and general press. In the academic, corporate or international agency circles, scenarios about the future of climate change have been assessed using integrated assessment models (IAMs); see [25, 47, 49, 53] for a small sample of recent IAMs. In most of these scenarios a ZNE regime is reached before the end of the century and some forms of negative emissions must be obtained to offset the remaining use of fossil fuels in economic production domains not compatible with renewable energy sources (see e.g. the IEA scenario [12] or Shell Sky scenario [54]). Currently, the economies of the GCC countries are among the most carbonised, resulting in some of the highest GHG emissions per unit of GDP in the world. However they are part of the Paris agreement and all the GCC member states must envision a transition to ZNE by 2070 or earlier. This has been recognised in several recent publications, e.g. [64] on policy pathways to meet KSA's contributions to the Paris agreement, [45] on the development of a GCC power market and [57] on macroeconomic pathways of the Saudi economy.

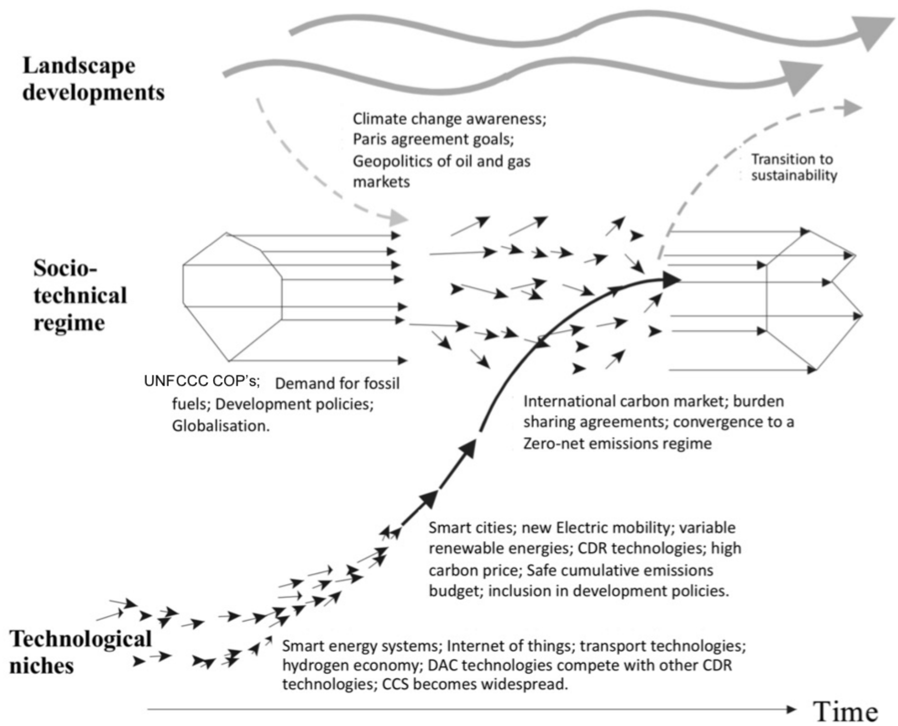


Figure 1 – MLP approach to GCC countries adaptation to a new climate regime

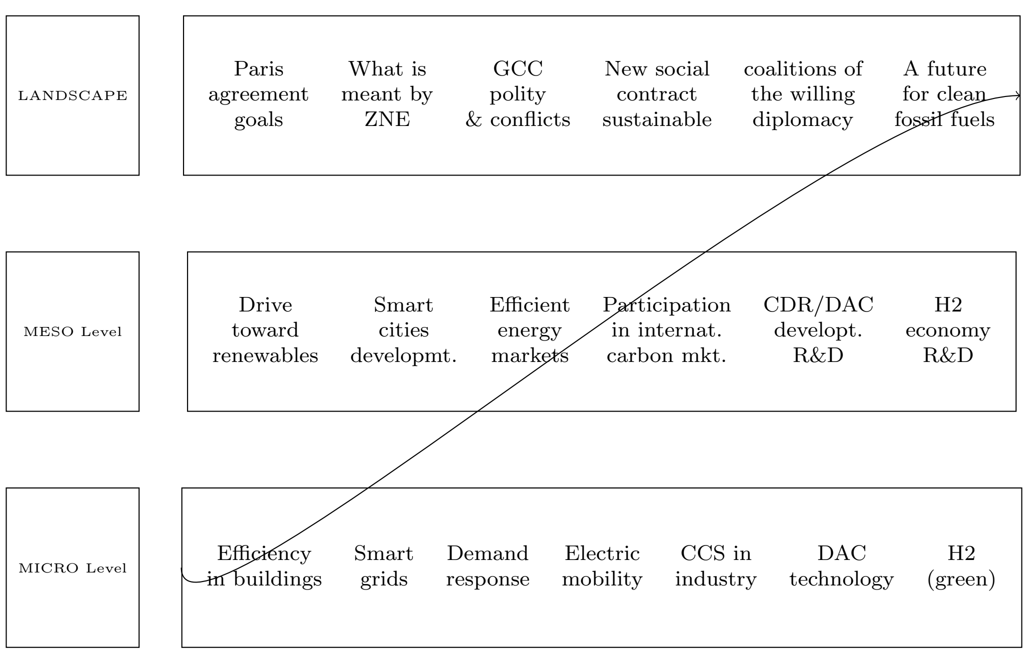


Figure 2 – Topics in MLP

Socio-technical regimes. The socio-technical regimes that develop in this landscape are negotiated at the UNFCCC COPs. These negotiations focus on the technological transformation of the world economy's energy systems needed to meet the ZNE target, the need to continue to supply fossil fuels to developing and emerging countries, the equitable sharing of costs and burdens between groups of nations, etc. The implementation of a global carbon pricing system, for example in the form of an international market for tradable emission rights, would facilitate the transition to ZNE in the foreseeable future. In GCC countries the socio-technical regimes are affected by five groups of factors corresponding to :

1. the geography of hydrocarbons deposits and CO2 storage capacities ;
2. the size and diversification of the economies that are in transition ;
3. the public/private structure of fossil fuel exporting economies and the possible dominance of the national oil company (NOC) ;
4. the willingness of political leaders to change ;
5. the balancing mechanism of the energy industry (market vs. public).

Technological niches. Finally, the technological niches regroup the development of smart energy systems, exploiting the Internet of Things (IOT) in Smart Grids (SG) that are delivering electricity to Smart Cities (SC), the development of an hydrogen economy and also the development of operational large scale negative emission technologies, like DAC coupled CCS.

The arrows in Figure 1 indicate the diffusion of new technologies permitting the establishment of new technological regimes that are motivated by the global climate change awareness effect and will ultimately permit a transition to sustainability. In this MLP framework, all the innovation is external. This is relevant for GCC countries, as new technologies are imported from the rest of the world through expatriate employees and foreign companies investments.

3 GCC and Net Zero Emissions : A policy perspective

Could ZNE be achieved in the Gulf region without undermining economic progress ? Changes in the field of climate change at the level of the Arab Gulf region always come from abroad. For a long time, the countries of the Arab Gulf region have not made real commitments to reduce their carbon emissions. Those countries contented themselves with hosting the international conferences of many organisations working in the field of environment without taking actual steps to reduce the carbon footprint of their economies that rely heavily on hydrocarbons. This situation has changed now, as these countries, like others, are required to take effective measures and develop policies to reduce their carbon emissions. Many countries in the Arab Gulf region tended to submit their commitments to reduce carbon emissions prior to the meeting held in Glasgow, United Kingdom, during the month of October of the year 2021. In this context, some Gulf countries, including the United Arab Emirates (UAE), Kingdom of Saudi Arabia (KSA) and Bahrain, announced their intention to reduce carbon emissions in accordance with the Paris Climate Agreement, which is trying to maintain the rise in the Earth's temperature at one and a half degrees Celsius.

3.1 Towards a zero net emissions regime for GCC countries

For a long time, Gulf states were reluctant to commit to absolute quantitative cuts in their carbon emissions. This is evident in the commitments made by these countries in the framework of the Paris climate agreement, which lacked any real commitment to reduce carbon emissions, but contained a lot of goodwill about the desire to tackle the problem of climate change. Instead of the Gulf countries presenting their commitments in the form of quantitative targets for the reductions they intend to make in the field of carbon emissions. The documents presented included flexible statements about the need to preserve the environment and expand investment in the field of clean energy. From this angle, many analysts in the field of environmental and energy policies concluded that the commitments made by the Gulf states under the Paris Climate Agreement are insufficient, and stressed the need to take more realistic steps and develop effective policies that include numerical targets to reduce carbon emissions. [8]

With the trend of many countries in the world to adopt the concept of ZNE, the Gulf countries found themselves compelled to keep pace with the development in this field. At the forefront of countries that announced their commitments in this regard was China, which set the year 2060 to achieve the climate neutrality goal. The USA and the European Union countries have also announced achieving the same goal by the year 2050. This global trend has created pressures on many Gulf countries to do something similar. In this context, in November 2020, Saudi King Salman bin Abdulaziz announced the launch of the National Program for the Circular Carbon Economy during KSA's presidency of the G20. As reported by the Ministry of energy, the program was approved by the G-20 as an integrated and comprehensive framework to address the challenges arising from greenhouse gas emissions and manage them with various available technologies. This approach represents an economically sustainable way to manage emissions using four strategies : reduction, reuse, rotation and removal. These four strategies are in line with the Kingdom's Vision 2030 through its programs aimed at achieving social transformation and more sustainable economic growth, by aligning and working with all development sectors in the Kingdom such as energy, industry, water, agriculture, tourism, and other sectors. [9]

Following the same lead, UAE announced that it is committed to achieving the goal of reducing carbon emissions to zero by 2050. Other countries in the Arab Gulf region, including KSA and Bahrain, have set the year 2060 as a target to achieve ZNE. The importance of this step comes from the fact that the three countries, UAE, KSA and Bahrain, are responsible for producing the equivalent of thirteen percent of the total oil production globally. Other countries have expressed some reservations about this matter, such as a country like the State of Qatar.

Perhaps one of the factors that attract the Gulf states to the concept of ZNE is the lack of emphasis by this term on the need to specify absolute quantitative reductions in the volume of carbon emissions. Instead, the ZNE concept focuses on the need to offset carbon emissions by adopting certain techniques to sequester carbon, convert it into sustainable carbon, and then reuse it again in industry. The most prominent example here is the building materials industry, in which carbon is widely used. From this point of view, the application of this concept will not affect the productive capacity of the Gulf states and will not disrupt their economic development plans as long as the amount of carbon in the atmosphere is compensated through other mechanisms.

3.2 What sectors and what technologies to reach ZNE ?

In order to reach the goal of reducing carbon emissions to the zero level, the energy sector comes at the top of the sectors targeted by the Gulf countries. To achieve that goal, the GCC countries are required to review the energy policies and systems currently used, which still depend to a large extent on generating energy from fossil fuels, especially petroleum and natural gas. In KSA, for example, there is the equivalent of 60% of the total energy generated using gas, while reliance on oil to produce the remaining percentage of energy to meet the country's need and meet the increasing domestic demand for energy. Looking at the case of UAE, it can be noted that natural gas represents the primary fuel for power generation operations. It is responsible for producing abour of 90% of the total energy generated within the country. The percentage of renewable resources in the process of power generation does not exceed 4% in 2020. But it is also noted here that KSA has announced its intention to increase the volume of investments and participation in terms of renewable energy sources to 50% by 2030. UAE has also set the year 2050 as a target to reach 50% of its total energy production from clean energy.

8. See Climate Action Tracker, https://climateactiontracker.org/countries/.
9. https://www.moenergy.gov.sa.

In terms of technologies used to reduce carbon emissions, the GCC countries are using technologies that are related to CCS during industrial processes. These technologies are regarded as one of the alternatives available to public policy-makers in the field of energy. In this regard, these technologies can help the countries of the Arab Gulf region to achieve their goals and their commitments to reduce carbon emissions. For example, UAE uses CCS technologies and reuse carbon in many industrial sectors, including the steel industry.

3.3 Policies and actions to reach ZNE

On the operational level, many companies working in the field of oil extraction have adopted The Oil and Gas Climate Initiative. As part of this initiative, Saudi Aramco announced its intention to commit to reducing carbon emissions during exploration and extraction. [10] Despite this initiative, it is noticeable that at a time when governments, investors, asset managers and consumers in European countries are exerting great pressure on companies operating in the oil field in order to reduce emissions and achieve ZNE, these pressures are almost non-existent in the Arab Gulf countries. Hence, it is not expected that these companies will commit themselves to the restrictions imposed on them by similar pressures in European countries. For instance, The region's hydrocarbon sector continued to expand, with ADNOC (Abu Dhabi National Oil Company) announcing a five-year investment plan worth $122 billion (Saadi 2020).

4 Modelling scenarios for socio-technical regimes

To explore possible socio-technical regimes for GCC countries under a transition to ZNE, we developed scenarios using two top-down macroeconomic models. The first model is based on an optimal economic growth paradigm, while the second model is a game-theoretic approach to the burden-sharing issue, with an emphasis on measuring the economic impact on the GCC countries. In these macro models, some key elements of an MLP are retained at the landscape or technology niche level, but the socio-technical regimes that emerge are dictated by pure cost-benefit or cost-effectiveness considerations.

At the landscape level, we represent the advent of active global climate policy by : (i) the definition of a remaining safe emissions budget (SEB), which should not be exceeded for the entire future, as suggested in [3, 48] ; and (ii) the creation of an international emissions trading system, where different groups of countries will trade on their respective shares of the SEB.

At the technological niche level, we represent two important innovations : (a) the progress in efficiency and cost of renewable energy technologies ; and (b) the penetration of direct air capture technologies that generate negative emissions. DAC is an emergent technology that has been described and analysed in [36, 37] ; and more recently, in [28] and [35].

4.1 Optimal economic growth with DAC technologies

The potential role of DAC in climate stabilisation has been explored in [46], and then in [13], using the WITCH model [11] and in [43], which used the MERGE-ETL model [40]. Both models are based on an optimal economic growth paradigm. To assess the role of DAC technologies in establishing a global ZNE regime, we use a new compact optimal economic growth model, where the production of economic and energy goods as well as negative emissions are described by a set of CES functions [61]. The originality of our approach, compared to [13] and [43] lies in a consistent representation of useful and secondary energy production as well as negative emissions production across the DAC, by dedicated factors such as capital (factories), labour and primary fossil energy, source of GHG emissions. The model describes the economic and energy production functions for three regions of the world :

10. https://www.ogci.com/about-us/#advocacy.

OECD (industrialised countries), BRIC (emerging economies), [11] ROW (rest of the world, developing countries). Calibration of the CES production function for DAC technologies was made using the techno-economic analyses of [35] and [56].

We represent climate policy as the sharing a remaining safety emissions budget (SEB), as suggested in [3, 48]. In addition, the representation of an international emissions trading system is included in this new model. The global supply of emission rights (permits) will determine the price of the permit and the emission levels in each region, which will be such that the marginal cost of abatement is equal to the price. The structure of this model and the detail of the modelling approach, is presented in [8]. Below, we discuss the results obtained from three contrasted scenarios : (i) a BAU optimal growth scenario in which there are no global environmental constraints, (ii) a GREEN scenario where convergence to ZNE is achieved without using DAC technologies and, (iii) a MARKET scenario in which shares of the SEB are allocated to different groups of countries, which exploit their budget in the international carbon market and invest optimally in DAC technologies.

4.1.1 BAU optimal growth

Using this modelling of the economy/energy system in three regions of the world we have produced a base case scenario also called BAU. [12] This scenario provides guidance on the pace of implementation in a traditional framework where economic rationality drives the transition to lower dependence on fossil fuels. In the absence of public guidance, the cost of solar and wind technologies is the key driver of the pace of their diffusion. By our calculations, CO_2 emissions do not decline until after 2080. A socio-technological regime driven solely by technological economics will lead to catastrophic temperature increases in the long term.

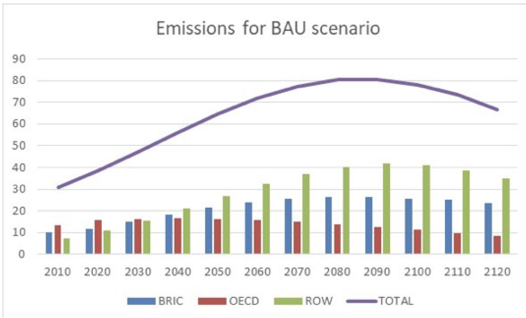
In this scenario the sum for the three regions of the discounted utilities derived from consumption is optimised over a 150 year horizon. To avoid the end-of-horizon effects we look only at the variable values between 2014 and 2120. In the BAU scenario, there is no need to use CDR or DAC since there are no global environmental constraints. The resulting global and regional emission profiles that are associated with optimal economic growth are shown in Table 1. Yearly emissions top at 80 Gt CO_2 in 2090 and decline afterwards. This is due to the increase in efficiency of renewable energy technologies. Cumulative emissions on the next 150 years reach more than 9'170 Gt CO_2. This is 8 times the nominal safety emissions budget [13] (SEB) compatible with a 2 °C increase. Note that according to most climate models, the temperature increase and resulting damage could be considerable. Per-capita consumption more than double for OECD countries, from 2020 to 2130, but it is multiplied by a factor 11 for BRIC and a factor 16 for ROW. In brief, in the BAU scenario OECD countries make a transition to a relatively decarbonised economy but BRIC and ROW achieve their development by still relying heavily on fossil energy sources. The considerable increase in fossil energy (K_1) and renewable energy (K_2) capital stocks is summarised in Table 2, in per-capita values.It is important to note that the resulting cumulative emissions budget should lead to a catastrophic temperature increase in the long term.

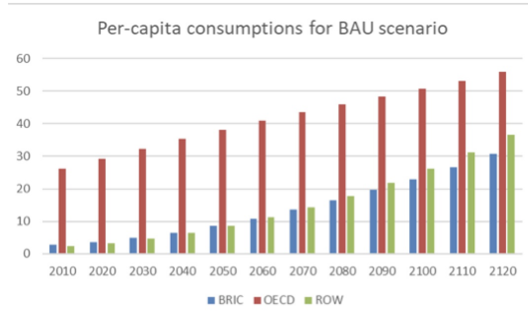
4.1.2 GREEN : Convergence to ZNE without CDR/DAC

Using this model we have also produced a scenario that is more in line with the policy advocated at the COP21 in Paris, where DAC technologies don't play an important role ; we call it GREEN scenario. In this scenario a global SEB of 1'170 Gt CO_2 is imposed (recall that this SEB is compatible with the 2° C goal). We suppose that the emissions of this budget are allocated in each region over a 150 year horizon, in a program that maximises the sum for the three regions of the discounted utilities derived from consumption. In the GREEN scenario, since there is no possibility to use DAC technologies, the only option to reduce emissions is to switch to renewable energy source. The resulting global and

11. namely, Brazil, Russia, India and China
12. Business as usual.
13. For a justification of this SEB we refer to the recent IPCC report [31].

Table 1 – BAU scenario : Emissions (in Gt CO_2 /Year) and consumption (in \$1000/Year)





Year	BRIC	OECD	ROW	TOTAL
2014	11.72	10.76	6.27	28.75
2090	29.60	11.02	39.96	80.58
2120	25.70	7.49	33.72	66.91

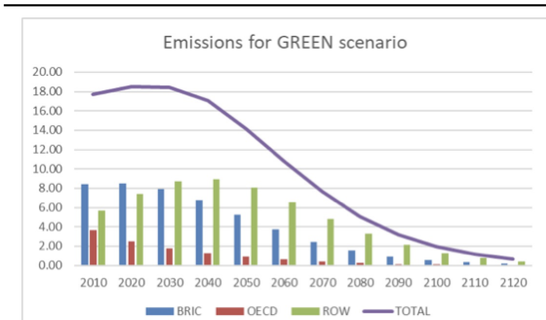
Year	BRIC	OECD	ROW
2014	2.72	26.26	2.26
2090	19.66	48.44	21.79
2120	30.70	56.02	36.41

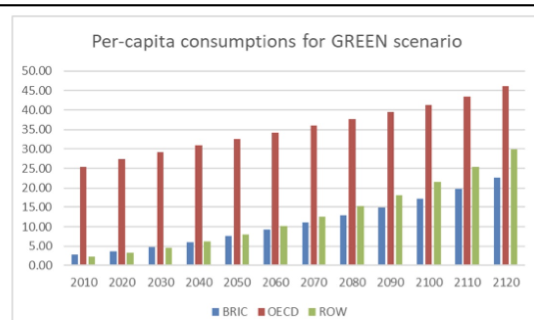
Table 2 – BAU scenario : K_1/L versus $K2/L$ (L refers to the population)

	K_1/L				K_2/L		
Year	BRIC	OECD	ROW	Year	BRIC	OECD	ROW
2014	1.56	3.82	0.89	2014	2.17	7.90	2.32
2120	21.52	28.94	22.00	2120	36.98	52.76	65.83

regional emission profiles that are associated with economic growth are shown in Table 3. ZNE is reached very late, because it is very costly to eliminate totally the use of fossil fuels. From 2020 to 2130, per-capita consumption is multiplied by a factor 1.8 for OECD countries, but it is multiplied by a factor 8 for BRIC and a factor 13 for ROW. The fossil energy capital stock collapses and renewable energy capital stock reaches much higher value as shown in Table 4. In short, this scenario shows how costly a complete exit from fossil fuel use will be for the BRIC and ROW countries.

Table 3 – GREEN scenario : Emissions (in Gt CO_2 /Year) and consumption (in \$1000/Year)





Year	BRIC	OECD	ROW	TOTAL
2014	8.44	4.94	5.60	18.98
2120	0.20	0.06	0.34	0.60

Year	BRIC	OECD	ROW
2014	2.77	25.29	2.31
2120	22.72	46.12	29.85

4.1.3 MARKET : Optimal use of shares of SEB with carbon market and DAC available

In the MARKET scenario, an international carbon market is assumed to exist. Each coalition receives a share of the SEB and can capture CO_2 through DAC activity with some limits on sequestra-

Table 4 – GREEN scenario : K_1/L versus $K2/L$

K_1/L				K_2/L			
Year	BRIC	OECD	ROW	Year	BRIC	OECD	ROW
2014	1.56	3.82	0.89	2014	2.17	7.90	2.32
2120	0.39	0.55	0.51	2120	50.10	80.25	76.28

tion or storage, as shown on Table 5. In the model, negative emissions produced by DAC activity are represented through a CES production function properly calibrated to reflect the cost and efficiency of the technology.

The MARKET scenario leads to a ZNE regime reached by 2070, as shown on Figure 3. DAC activity begins in 2060 with a rapid increase until 2090 when it reaches a steady-state at 23 Gt CO_2 captured each year, as shown on Figure 4. After this date, all GHG emissions must be offset by some DAC activity in the world. The resulting global and regional emission and consumption [14] profiles that are associated with economic growth are shown in Table 6. From 2020 to 2130, per-capita consumption net of revenue from permit trading is multiplied by a factor 2 for OECD countries, but it is multiplied by a factor 9.6 for BRIC and a factor 14.4 for ROW. The emissions decline until 17 Gt/Y in 2070 and reach a steady state at 21.4 Gt/Y thereafter.

Table 5 – SEB shares and sequestration bounds

Budget shares $\theta(\cdot)$			DAC-CCS Bounds (Gt CO_2/Y)		
BRIC	OECD	ROW	BRIC	OECD	ROW
0.4	0.1	0.5	8	5	10

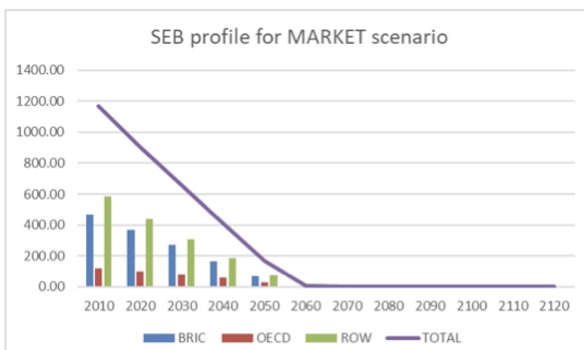


Figure 3 – Budget Profiles (Gt of CO_2)

Table 7 shows per capita consumption adjusted by revenues or expenditures associated with emissions trading.

Carbon price starts at $ 241 in 2020 and reaches $ 828 in 2130 (See Table 8). BRIC and ROW are permit sellers and OECD is a permit buyer, as indicated on Table 8. Table 9 shows the evolution of fossil and renewable capital stocks, expressed in per-capita values.

This MARKET ZNE regime allows complying with the Paris agreement in the proposed timeframe. It also permits continued use of oil and gas. Policies dictate massive investment in CCS and DAC technologies.

14. not counting the trading.

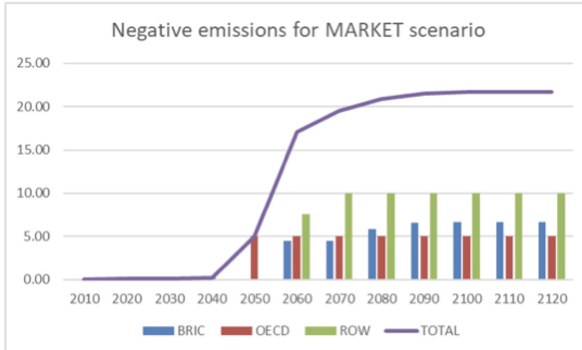
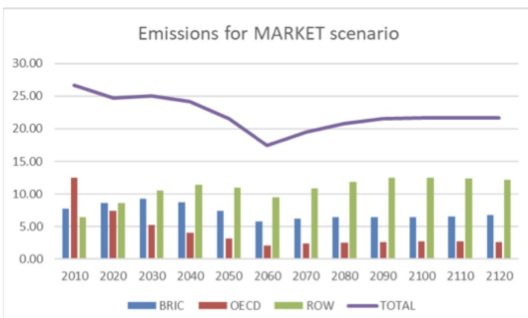
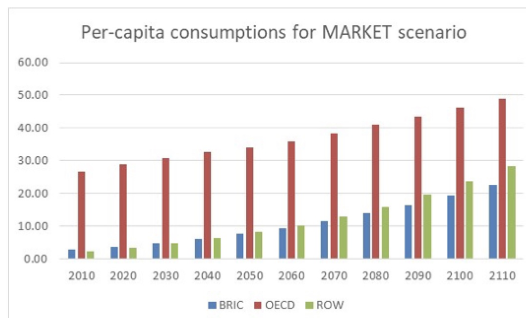


Figure 4 – DAC activity (in Gt CO_2 /Year)

Table 6 – DAC/MARKET scenario : Emissions (in Gt CO_2 /Year) and consumption (in \$1000/Year)



Year	BRIC	OECD	ROW	TOTAL
2014	7.75	12.47	6.40	26.63
2120	6.69	2.67	12.08	21.44



Year	BRIC	OECD	ROW
2014	2.94	24.54	2.97
2120	26.53	53.54	33.26

Table 7 – Per capita consumptions (\$1000/Year)

Year	BRIC	OECD	ROW
2014	2.77	25.74	2.30
2120	26.60	53.89	33.20

Table 8 – MARKET scenario : Carbon price and permits trading

Price (\$)		Trading (per-capita)			Negative emissions (Gt CO_2)		
Year	BRIC	BRIC	OECD	ROW	BRIC	OECD	ROW
2014	241	0.20	-2.03	0.66	0.00	0.00	0.00
2070	761	-0.40	1.44	-0.12	4.52	5.00	10.00
2120	828	-0.07	1.43	-0.26	6.44	5.00	10.00

Table 9 – MARKET scenario : K_1/L versus $K2/L$

	K_1/L				K_2/L		
Year	BRIC	OECD	ROW	Year	BRIC	OECD	ROW
2014	1.56	3.82	0.89	2014	2.17	7.90	2.32
2120	8.11	10.87	9.82	2120	39.81	60.88	67.18

4.1.4 Comparing welfare

We use the discounted sum of per-capita consumption as a welfare criterion. Table 10 shows the welfare losses with respect to the BAU scenario. From these figures it appears that introducing DAC technologies mitigates the welfare losses w.r.t. BAU scenario. We indicate also the welfare losses for a scenario OPT where the SEB is used optimally, without implementation of a carbon market, in order to optimise the total discounted sum of the utilities derived from consumption (we do not give the details of the run due to the lack of space). It is clear that the MARKET scenario is sub-optimal but very close to the optimal one. The variations in the welfare losses seem to indicate that giving 10 % of the SEB to OECD may be too generous and 50 % of the SEB to ROW is not sufficient.

Table 10 – Welfare criteria (in $1000)

Welfare	MARKET	OPT	BAU	GREEN
BRIC	231	231	254	220
OECD	1094	1087	1156	1029
ROW	248	248	262	238
Welfare Loss	MARKET	OPT	BAU	GREEN
BRIC	9%	9%	0%	13%
OECD	5%	6%	0%	11%
ROW	6%	5%	0%	9%

In this analysis, we have only considered economic variables that affect welfare. Indeed, in the BAU scenario the considerable emission budget would create enormous economic damage. Similarly, the risk of stranded assets, which exists in a GREEN scenario where fossil energy almost completely disappears, should also be taken into account and included in a policy analysis. These aspects will be discussed using a more detailed model where the macroeconomy of the GCC countries is represented more accurately.

4.2 Socio-technical ZNE regime : How DAC reduces GCC countries exposure to stranded asset risks

As discussed above, in a ZNE trajectory, energy exporting countries could be strongly negatively impacted by the decrease of fossil energy consumption combined with the drop in international energy prices. For example, the International Energy Agency shows that, in a ZNE scenario [30] the final global consumption of oil and natural gas drops to 42.1 EJ and 19.8 EJ, respectively in 2050 ; this represents a decrease of nearly 71% of current consumption. At the same time, the crude oil price falls to 24 US$ per barrel in 2050. However, a massive development of DAC activity could alleviate the stranded asset risk for GCC countries.

Using a computable general equilibrium model [10] we obtained scenarios confirming that oil and gas producing countries, and in particular the GCC countries, face a significant risk of welfare loss, due to "unburnable oil," if a global climate regime as recommended by the Paris Agreement is put in place. In some scenarios we see that the development of CDR technologies, in particular DAC alleviates somewhat this risk and offers these countries a new opportunity for exploiting their gas reserves and the carbon storage capacity offered by depleted oil and gas reservoirs. This was reported in [5] and [6]. Below we summarise some of these simulation results.

4.2.1 A metagame model with DAC options

To assess the opportunities offered by the development of DAC activities in GCC countries we have designed a model of competition on an international carbon market, when a global SEB is set at 1170 Gt CO_2. The modelling approach has been described in [6] and [7].

In brief, the model describes 10 coalitions of countries, including a grouping of GCC countries : European Union (28 countries), United States of America, China, India, GCC, Russia, Other Asian countries, Other energy exporting countries, Latin America, and the Rest of the World, which are competing for the supply of emission permits in an international cap-and-trade system designed to satisfy a cumulative global security emissions budget. A ZNE regime has to be reached at the end of this period. To summarise the climate negotiations on the issue of burden sharing, we consider different possible allocations of a cumulative global SEB among different coalitions. Once each coalition's share of the emissions budget is decided, the coalitions are assumed to play a non-cooperative game for the supply of emissions permits on the international carbon market. Depending on their respective reduction policies, coalitions can be net buyers or sellers of permits. This generates payment transfers that can lead to a fair distribution of burdens. The gains (payoffs) in the game theoretic model are obtained from a statistical emulation of GEMINI-E3, a well-established computable general equilibrium (CGE) model [10] that is built on the GTAP 9 database [1], with reference year 2011.

4.2.2 The impact of developing CDR/DAC activities

Cost of DAC has been discussed in recent publications. For instance, in [35], a full cost analysis is presented for a process fully powered by natural gas ; it obtains a levelised cost of 232 \$ per ton of CO_2 captured ; an American Physical Society study [58] arrived at a levelised cost of 550 \$/t-CO_2 ; another study [28] determined the cost for powering a gas-fired DAC plant with CCS at 396 \$/t-CO_2 avoided ; and the extra energy cost of DAC was estimated around 232 \$/t-CO_2 captured in [41] and [20, 21]. Storage costs were evaluated in [52] to be in the range of 6 to 13 \$/t-CO_2 stored. The total levelised cost in our model is set at \$300/t-CO_2 captured and stored, for all regions except the USA and EUR. These latter are priced at \$350/t-CO_2 captured and stored, assuming higher logistical costs.

BECCS technology consists of producing electricity from biomass while capturing and injecting CO_2 into geological formations. We use a unique levelised cost of 60\$/t-CO_2 for the whole world, consistent with the IEA estimates [38]. BECCS potentials are estimated from the global and regional assessments [38], which take biomass supply chains and processing into account, and also include deployment issues due to policy and regulatory barriers. [15] Using the IEA estimates, we have derived a global bound on GHG captured through BECCS equal to 10.2 Gt CO_2, based on technical potentials by 2050. These figures are derived from technical and economic assumptions from the World Energy Outlook [30]. Finally, BECCS penetration is related to electricity generation levels and composition by year 2050.

The main information obtained from simulations performed with the meta-game model, on the importance of developing CDR/DAC is given in Table 11. This is based on scenarios corresponding to a worldwide optimisation, for the 10 groups of countries on the time horizon 2015-2100. In terms of global welfare, we observe a reduction of the welfare loss, which passes from 3.8% of discounted GDP to 2.8%. The shares of the SEB budget given to each coalition have been calculated in order to equalise the welfare loss (or cost) expressed in % of GDP (a Rawlsian rule solution). Therefore each coalition has a welfare cost equal to 2.8 %. In Table 12, we detail the Rawlsian rule outcome.

Table 11 – CO_2 price in 2030 and welfare cost in the period 2018-2100 assuming a safety budget of 1170 Gt CO_2 and a 3% discount factor

DAC & BECCS	Without	With
Discounted CO_2 price (ref. 2030) in $\$_{2010}$	775	480
Discounted World cost in % of discounted GDP	3.8%	2.8%

In this fair burden sharing solution, the GCC coalition receives 8.8 % of the SEB. This is significant and represents the main source of welfare cost mitigation for these countries, which are heavily affected by changes in the terms of trade (representing changes in the price and trade of fossil fuels). Table 11

15. see e.g. Potential for carbon-negative bioenergy in US [9]. For BECCS see [14].

gives two indicators of the role of CDR/DAC in reaching a feasible ZNE regime. The carbon price in 230 would be at $\$_{2010}$ 775 without CDR/DAC instead of $\$_{2010}$ 480, when these technologies are available. The welfare loss, worldwide, increases by 30% over the rest of the century.

Table 12 – Burden-sharing and welfare cost with Rawlsian rule in percentage difference from the reference scenario

	Budget share	Welfare cost[a]	Components of welfare cost[a]				
			Abatement	DAC	BECCS	GTT	Emissions trading[b]
USA	9.07%	2.84%	1.78%	0.17%	0.32%	-0.02%	0.58%
EUR	4.31%	2.84%	0.82%	0.33%	0.24%	-0.41%	1.87%
CHI	19.93%	2.84%	3.72%	0.20%	0.15%	-0.63%	-0.61%
IND	6.53%	2.84%	3.49%	0.29%	0.57%	-1.33%	-0.18%
RUS	7.01%	2.84%	3.16%	6.22%	1.29%	1.89%	-9.70%
GCC	8.81%	2.84%	3.30%	5.38%	0.02%	5.55%	-11.39%
OEE	15.57%	2.84%	1.68%	0.19%	0.14%	0.99%	-0.16%
ASI	9.45%	2.84%	1.45%	0.28%	0.23%	-0.69%	1.56%
LAT	3.00%	2.84%	1.83%	1.56%	1.22%	0.11%	-1.88%
ROW	16.31%	2.84%	2.53%	0.27%	0.19%	0.32%	-0.47%
World	100.00%	2.84%	2.04%	0.54%	0.29%	0.00%	0.00%

[a] Discounted welfare cost in % of discounted GDP
[b] Negative (positive) values are for net sellers (buyers)

Figure 5 shows variation in global welfare loss for the different scenarios corresponding to different SEB targets, always assuming that CDR/DAC options are available. The diagram shows that the 1.5°C objective appears to be very challenging [44, 50], with a cost multiplied by 5. This indicates that the 1.5°C scenario has a very high cost, which make it quite unlikely. Figure 6 shows the evolution of carbon price when CDR/DAC is an available option or not. This graph gives a clue on the importance of implementing negative emissions to keep the economy on a feasible path.

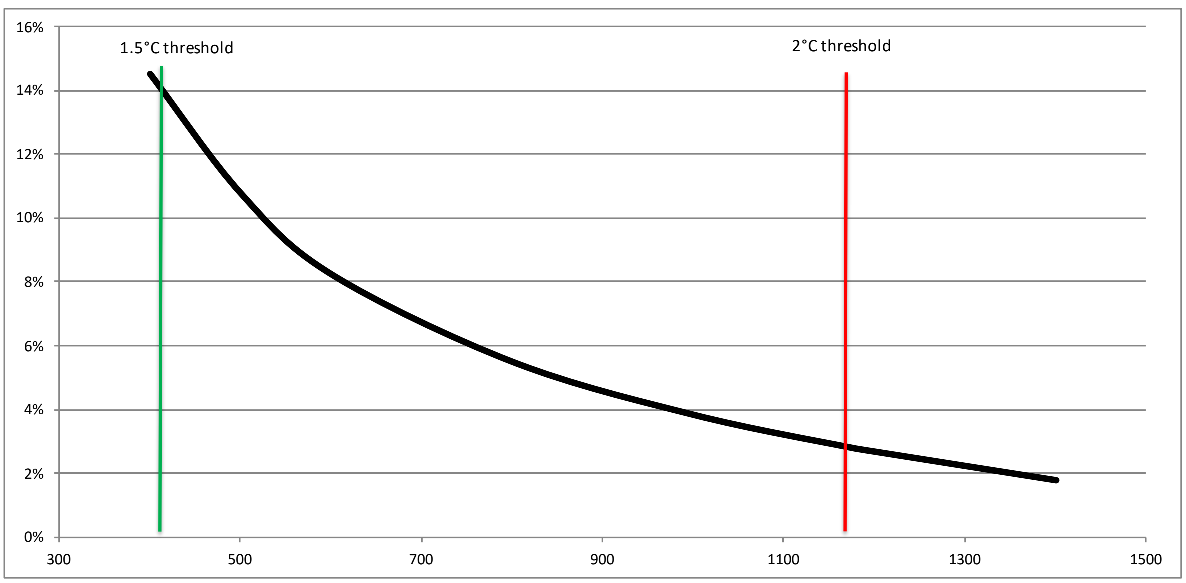


Figure 5 – Discounted global welfare cost in % of discounted GDP with respect to carbon budget in Gt CO_2

Figure 7 shows the relative importance of abatements and negative emissions in reaching the environmental goal. We can see that the abatement effort remains considerable in the scenario with CDR/DAC. However, allowing negative emissions leads to a policy that avoids the most costly emissions reductions in sectors of the economy where there are virtually no substitutes for fossil fuels.

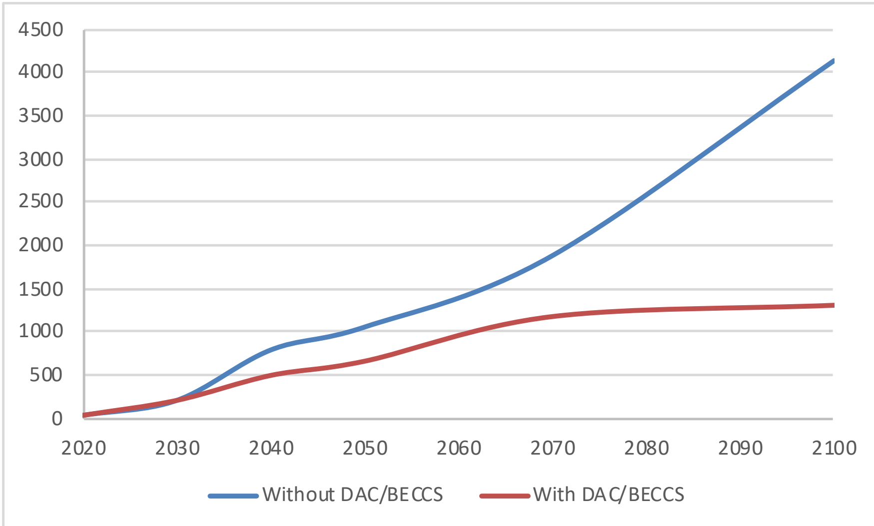


Figure 6 – CO2 prices

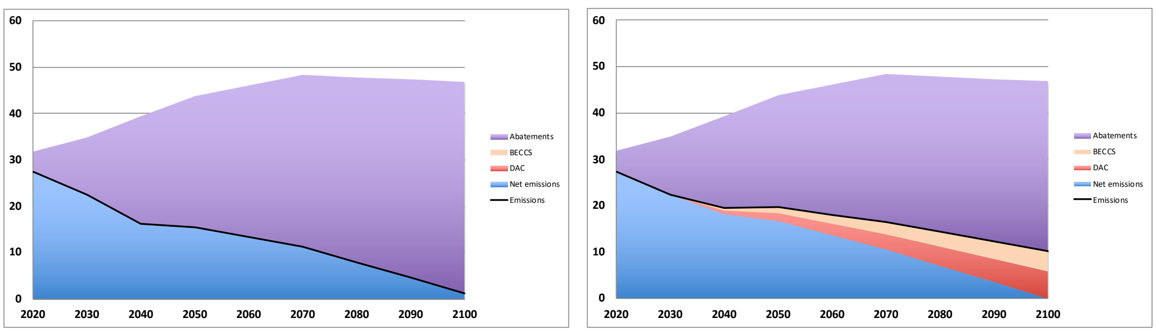


Figure 7 – Net emissions, DAC, BECCS and abatement profiles without (left) and with (right) DAC/BECCS (in Gt CO_2)

4.3 Clues provided by the macroeconomic scenarios

Through these scenario-building exercises, using macroeconomic models, we can derive several useful insights for the MLP applied to the ZNE transition. We list them below

— The technical progress of renewable energies will make them dominant in the energy landscape, even in the absence of a strict climate policy ; however, this will not make it possible to achieve the goal of climate stabilisation before the end of the century.

— Making a full transition to renewables in order to stabilise the temperature change at 2°C would generate a large welfare cost, in terms of lost consumption, in particular for emerging and developing countries.

— The availability of DAC technology at scale can mitigate the welfare losses and stranded asset costs of a global climate policy consistent with a 2°C target.

— The Gulf countries appear to have a comparative advantage in deploying DAC activities due to their easy access to natural gas as a primary energy source and depleted oil and gas reservoirs as storage facilities.

— An effective international carbon market will be an essential part of the DAC development strategy. It would allow the sale and purchase of negative emissions to offset remaining GHG emissions in different parts of the world.

5 MLP exploration of ZNE regime in GCC countries

In this section, we integrate the policy perspective of Section 3 and the macroeconomic scenarios of Section 4 into an MLP analysis of a global transition to ZNE and its possible impact on GCC countries, as outlined in Section 2 and sketched in Figures 1 and 2.

5.1 An overview

The recognition of the need to engage in climate policy on a global scale is a major landscape development. Sociotechnical regimes interweave policy with societal acceptance and industrial organisation. They will help create the negotiating arena (burden-sharing agreements) and economic tools (emissions trading markets) needed to meet the goals of the Paris Agreement. Technology niches involve a hoist of new technologies for renewable generation (solar, wind), zero-emission fuels (green hydrogen, clean fossil fuels) supported by CDR/DAC with CCS.

The "zero-net" equation involves balancing the sources and sinks of GHG emissions, i.e., reducing CO_2 emissions and removing CO_2 from the atmosphere. The variables in the "The "zero-net" equation are not fully defined and are constantly changing. While the focus is on man-made emissions, there are many natural sources and sinks of GHG emissions, from methane leaks to vegetation respiration. Similarly, many competing solutions coexist to decarbonise the economy and offset emissions. There are geographical limits to the implementation of renewable generation solutions, such as solar and wind or DAC with CCS, by region. A stranded asset risk exists in capital intensive energy sectors, etc.

We will organise the rest of our analysis around three key elements framing the transition to ZNE : (i) energy geography ; (ii) economic and societal adjustment costs ; and (iii) new governance, institutions and commitment.

5.2 Energy geography

5.2.1 Appropriate mix of technologies to reach ZNE

GCC countries have a competitive advantage in CCS and DAC. CCS development is still in the pilot stage, with some large projects (eg, in UAE or Qatar) already being implemented for enhanced oil recovery and storage. In 2020, the IEA [30] indicated that 40 mt were stored underground worldwide, but announced a need to capture and store 4 to 10 Gt/y by 2050, if a ZNE regime is to be reached. This is consistent with the results of the macroeconomic scenario presented in Section 4. In these scenarios the total of negative emissions generated by DAC and CCS could reach 23 Gt/y of CO_2 in 2080. However, as for today, only small DAC pilot projects are underway. [16] The cost of capturing and storing a ton of CO_2 was over \$800 per ton in 2019. A review of the literature for economic models in Section 3 indicates that a lower cost, on the order of \$300/t, can be achieved after 2030. Macroeconomic models indicate that at this cost level, DAC technologies break even in 2040.

There is a window of opportunity for such a techno-economic regime, but what are the conditions to enable it in GCC countries ? GCC countries should develop CCS projects in order to have access to the most recent data and to test the most promising pathways according to the specifics of the Gulf countries. National oil companies should be among the key players in this area as DAC could permit them to continue with a similar business model as nowadays. GCC countries could create industry-wide technology roadmaps to reduce uncertainty and align R&D investments in key technologies using "clean" hydrocarbons.

In each GCC country, emissions from petrochemicals, electricity generation, hydrogen production, and mobility could be reduced or offset by DAC where it is particularly costly to reduce them. These new forms of carbon management are a good hedging strategy and potential revenue diversification

16. Climeworks https://climeworks.com/roadmap/orca.

for GCC countries. As our scenario shows, they could significantly reduce the cost of transitioning to a ZNE regime and leverage the hydrocarbon resources of GCC countries.

If policy signals are driven by the public opinion in most OECD countries, in the GCC countries it is more the threat to future hydrocarbon demand, and hence revenues, that drives the political impetus. As a result, GCC countries are in a difficult balancing act between reducing oil rents and investing in clean energy and carbon-free economic activities.

For GCC countries, the consequences vary depending on the conditions that frame the trajectory towards the ZNE regime, such as natural gas endowment, the maturity of the oil sector, the cleanliness of the exploration and production processes (methane leaks and flaring) ; and the level of industrial activities associated with the transformation of oil and gas into steel, other energy intensive goods and petrochemical products. This raises questions about the national resilience of each GCC country : which sectors and geographic areas are particularly exposed and what mitigation measures (insurance, storage capacity, etc.) should be implemented. Thus, the creation of its own ZNE regime should be high on the agenda of each GCC country. Qatar, which has a large amount of natural resources and a small population, could opt for a ZNE regime based on neutral ammonia-hydrogen with CCS as well as neutral petrochemicals leveraging ADC solutions. Dubai could optimize carbon trading to enable carbon neutral real estate, tourism and financial services. Saudi Arabia, given its large population and land mass, may want to implement a different ZNE regime, in which solar power generation, carbon storage, and DAC could allow a hydrocarbon-based monarchy to survive on the cheapest oil reserves.

With uncertainty still very high, one of the avenues to be explored and experimented with by the GCC countries is to create forecasts and roadmaps for the entire value chain at the scale of technology development needed, to set consistent goals for all players in the sector, and to support coordination and collaboration between different stakeholders. The Lusail smart city in Qatar, the MASDAR experiment in the United Arab Emirates, or the Saudi NEOM city aiming for a ZNE environment in which energy is produced from decarbonized sources or renewables are needed to provide a large enough data set to make the right decision. These large investment programs, worth billions of U.S. dollars, encourage collaboration across supply chains and ecosystems to increase production by connecting providers of new technologies with providers of capital and secure buyers of those technologies.

5.2.2 Availability of natural resources

In the previous cycle, fossil fuels are key assets to power economies and supply chains. In the coming energy transition, metals become the key materials. Geopolitical power is beginning to be wielded over countries like China, Australia, Congo, Chile, ... that produce the copper, cobalt, lithium and rare earths needed to make batteries, solar panels, wind turbines, electric vehicles and the entire electrical grid. In this context, GCC countries will need to recycle fossil fuel revenues to access these new materials and build their new infrastructure to take advantage of solar and wind resources, but also to implement hydrocarbon neutrality. Clean water will become a scarce resource. Switching to seawater for the many uses of the energy industry (from fracking to water electrolysis for hydrogen) will become a necessity.

5.3 Economic and societal adjustment costs

5.3.1 Capital allocation and financing

As noted above, capital investments are needed across all sectors, geographies, and the full range of technologies deployed for the transition to ZNE. GCC countries need to determine, based on risk/return profiles, payback periods, and broader capital investment characteristics, what capital expenditures are needed over time for renewable energy, neutral hydrocarbon construction, and growth in the negative emissions business segment (e.g., public capital, public debt, private capital, project finance, and public guarantees). If public support is truly needed to launch new technologies and effectively demonstrate their potential, the role of private and public financing, including that of huge sovereign wealth funds, must be assessed and mapped.

In addition, financial innovations and new market structures such as carbon markets could support the transition from brown to green for carbon-intensive companies and countries. Compliance markets should be created to facilitate the necessary allocation of capital. For example, as in Norway, voluntary carbon markets could facilitate the reallocation of capital between investments in carbon removal, avoidance or reduction assets. While such a solution is currently being prototyped in Norway, such markets need to be adapted to the GCC and their integrity, liquidity, and depth guaranteed through appropriate mechanisms.

Similarly, from a financial perspective, many oil and gas assets are at risk of being abandoned, as well as energy-intensive industries or energy-inefficient buildings in all sectors and regions of the world. The associated risks must be managed proactively. This means creating financial incentives for the retirement and decarbonisation of carbon-intensive assets, rather than simply waiting for divestment. This may involve creating indicators based on life cycle analysis to assess the roadmap for green capital investment and brown one divestment.

Capital allocation decisions are often best made when there is transparency and robust information about transition risks. The development of new products and financial structures could help GCC states and companies to liquidate old assets and develop new low-emission assets. Fiscal solutions to delineate greenhouse gas emitting assets and retire them in line with a ZNE trajectory should be tested, as well as long-term purchase agreements for renewable energy plants to replace high-emitting generation assets. GCC sovereign wealth funds could help manage the gradual reduction of GHG emitting assets and reduce the value-at-risk of abandoned assets by providing guarantees if necessary.

5.3.2 Compensating mechanisms for socioeconomic impacts

The impact of the various transition paths on overall economic activity in the GCC will be very significant. This means job losses or gains, by sector, country, and region. The burden on household in each country and region in these transitions must be assessed Governments should address and manage the negative consequences with programs to support worker retraining and subsidies for lost consumption while maximising the positive effects, including job transitions to new and growing sectors. They must identify the skills that will be in greater or lesser demand under different transitions and establish appropriate retraining programs for those workers most at risk, both in the public and private and social sectors. These training programs will require social assistance and compensatory measures, including income support measures such as unemployment protection and public employment programs.

In this regard, the technological trajectories, based on gas-powered DAC with CCS, as modelled in the macroeconomic scenarios of Section 3, could permit GCC countries. to continue along their usual socio-economic paradigm. While creating huge investment needs, they do not require major changes in the economies and policy framework of the GCC countries.

5.4 Governance and the role of market in ZNE regime

5.4.1 Governing standards, tracking for market mechanisms

A key question for the GCC is whether existing institutions can cope with the change in governance involved in supporting the energy and environmental transition. Which institutions need to be rethought at the national and Gulf levels ? In what areas are new institutions needed ? GCC member states should explore solutions and test ideas from the perspective of what might not have happened in 2030, 2050, and 2070 to achieve the ZNE transition, and ask whether new institutions could prevent such failures, ensure collective success, create new industry collaborations to collectively make commitments, invest in new technologies, build capacity, and share best practices.

The ZNE regime leveraging DAC and CCS will need to establish standardisation and certification institutions for common carbon accounting principles across sectors and corporate disclosures for public and private companies to ensure appropriate levels of emissions traceability. Improved measurement of emissions at the source through digital tracking technologies to measure fugitive emissions or the use of satellite imagery data to map global carbon and methane emissions are needed to enable international carbon trading. Establishing governance mechanisms to ensure the quality and integrity of carbon credits is a key element in the development of a well-functioning carbon market and thus of a ZNE regime for GCC countries.

5.4.2 Collaboration among public, private and social sector

Beyond goals and roadmaps, mechanisms and coordination between private and public investments must be established. This means that the usual structure where a national oil companies is dominating the full economic activity spectrum might be changed to enable more market based incentives. GCC countries leaders must continue to reinforce and support the belief that change is necessary and must happen now within the window of opportunity created by large revenues from oil and gas sales enabling investment in the DAC and CCS technologies to support a ZNE regime. GCC leaders must take the long view and avoid short-term, free-rider climate strategies. If an electricity-based ZNE regime is adopted worldwide, will it still be room for a hydrocarbon-based ZNE regime ?

5.4.3 Support from citizen and consumers

In centrally controlled countries, such as in the GCC organisation, where is citizen participation most needed, and what changes might meet the most resistance ? The narratives and social dynamics around the transition to ZNE consumption in specific communities, sectors, societies, and countries need to be heard and addressed in order to cultivate broad support and encourage long-term thinking. The sovereign fund policy for investment could provide guidance for GCC economies and companies. Consumers must change their preferences and behaviors : what are the best incentives to implement these changes ? The collective impacts of increasing physical risks and the need for a ZNE transition must be communicated to build awareness, will, unity, and conviction.

5.5 An agenda for GCC leaders

The MLP suggests that GCC countries leaders must commit to several actions in order to implement a viable roadmap for survival in a ZNE environment.

Understand and commit. GCC leaders need to formulate an oil and gas revenue diversification program within the framework of representative global organizations, such as OPEC and GCC, in order to support their views and interests in the COP discussions as well as in other global institutions (G20, UN, etc.). Our various studies on ZNE show that implementing these regimes will have a significant cost (2.8% of discounted sum of GDP in the best case for GCC countries). To minimise this cost and achieve this goal, GCC countries must push for the appropriate international framework for carbon trading and support R&D in negative emission technologies such as DAC.

Foster emissions reduction technologies, CO_2 credits, and higher energy prices. Within the framework of their own economic processes and operations, the GCC countries need to improve energy efficiency, reducing wasteful energy use in the industrial, commercial and individual sectors. This means establishing a market price for energy to balance different energy production technologies and reduce energy use, coupled with a carbon market to value emission reduction technologies. This represents a significant shift in the GCC. For example, KSA has used regulated prices for domestic energy for decades. Energy subsidies in KSA are implicit because they are based on revenue foregone by the government. KSA has begun reforming energy prices, resulting in sharp increases in gasoline and residential electricity prices in 2018. In a recent article [34], it was shown that energy price reform in KSA has significant economic and environmental benefits. Similar policy should be pursued and extended to all GCC countries.

To achieve a global ZNE regime, an international emissions trading system is a necessity. The MLP analysis and the macroeconomic scenarios discussed above show that the GCC countries could benefit greatly from the organization of such a carbon market, which will allow them to exploit a new extractive resource, negative emissions. Investing in R&D to develop emission reduction technologies, negative emission technologies, and CO2 storage capabilities will provide new revenue streams for GCC countries. The sale of CO2 emission credits could be a significant business opportunity after 2050. The roadmap for realising this business opportunity must be developed by political leaders.

6 Conclusion

In 2020, the coronavirus pandemic dealt a heavy blow to global climate diplomacy, which was already suffering from the absence of strong leadership. It has paralysed all multilateral climate negotiations, banning face-to-face meetings and marginalising the issue of climate change in many other international discussions. In this context, "Green Recovery", which has become the new climate agenda in various parts of the world, has been absent from policy discourse in the Gulf. KSA's production of crude oil during the year 2020 reached a record level of 12.1 million barrels, according to the report submitted by Saudi Aramco. In 2022, the Ukrainian crisis gives the oil and gas of the GCC countries a major boost in value. Production and revenue will still increase. However climate change is a long-term issue, which will remain in the landscape for the rest of the century.

The challenge is clear for the GCC countries with regard to reducing their carbon footprint, given their high per capita emissions rate. It is noticeable that some of these countries, led by UAE and KSA, come at the top of the list of countries with a high carbon footprint, compared to many developed countries as well as developing economies around the world. In addition, these economies depend intensively on energy consumption. Moreover, air-conditioning systems, as well as the expansion of infrastructure projects and new urban construction, have in turn led to a significant increase of emissions. Domestic energy subsidies, implemented to lower fuel prices, represent one of the challenges facing the ability of these countries to achieve their emissions reduction commitments. The energy subsidy policies applied in the GCC states, as part of the social contract, lead to lower fuel prices in the Arab Gulf region compared to their counterparts in developed countries. Indeed, these policies encourage residents and citizens of the Gulf countries to consume more fuel, that in turn leads to an increase of carbon emissions.

Some energy policy analysts believe that the commitment of the GCC countries to reduce carbon emissions will not affect their ability to produce oil and natural gas. The reason is that the way carbon emissions are calculated depends mainly on the place in which these hydrocarbon are consumed. In other words, the oil producing and exporting countries are not responsible for emissions in the importing countries. Therefore, the increase in carbon emissions in those countries will not negatively affect the ability of the Gulf countries to increase production and will not affect their commitments. As a consequence, some Arab Gulf states (UAE and KSA) announced their intention to increase their oil production during the coming stages. Here the question arises about the extent of the seriousness of these countries with regard to their environmental obligations. The contradiction appears between their local ZNE pledges and the fact that these countries are exporting emissions globally.

So, which climate strategy for GCC states ? In [39] Jim Krane analysed the possible climate strategies for oil and gas production countries, taking the case of KSA 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 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 [39].

Interestingly, J. Krane observes that KSA, the largest economy among the GCC states has adopted a mixed strategy, which includes components of the three types above. In the past KSA was a climate obstructionist, which joined UN-led climate treaty negotiations to thwart, delay or weaken a possible agreement (see J. Depledge [16]). Since the 2015 Paris agreement, KSA has shifted its stance to one of support for climate action. With other GCC member states KSA 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 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. [17] And finally, KSA 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 [39]. "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 [60]. 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] CDR and in particular 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. [20] 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 [29]. In summary, these strategies involve offering "clean fossil fuels" whose carbon 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. In brief, the scenarios produced in our research with two macro-economic models and the MLP analysis developed 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 contribute to foster a mix of the "Dig in" and "Join in" types of strategy. On one side one will work at preserving the economic value of fossil fuels, while on the other side one will decarbonise entirely the local economy and exploit the opportunities offered by the international carbon markets.

17. Ministry of Energy, industry & mineral resources of Saudi Arabia 2017.

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, KSA has KACST- Technology Innovation Center on CCS 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 (CCS : Prospects in GCC — EcoMENA, 4/16/2018 https://www.ecomena.org/carbon-capture-storage/).

20. http://www.climeworks.com/.

— CCS and CCS 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 could be more proactive in the coming negotiations, and aim at defining a governance based on equalizing the relative welfare losses among groups or coalitions of countries.

— GCC countries could 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 smart energy systems.

— All of these transitional policies will require an effort to diversify the economies of GCC member states and to change their polity and social contracts.

Références

[1] A. Aguiar, B. Narayanan, and R. McDougall. An Overview of the GTAP 9 Data Base. Journal of Global Economic Analysis, 1(1) :181–208, 2016.

[2] Hilal M. S. Al-Maamary, Hussein A. Kazem, and Miqdam T. Chaichan. Renewable energy and GCC states energy challenges in the 21st century : A review. International Journal of Computation and Applied Sciences IJOCAAS, 2(1) :11–18, 2017.

[3] Myles Allen. Climate 2020, chapter The scientific case for a cumulative carbon budget, pages 118–120. Witan Media, London, 2015.

[4] T. Atalla, S. Bigerna, and C.A. Bollino. A comparison of alternative programs for climate policies. Technical Report 48, King Abdullah Petroleum Studies and Research Center, 2018.

[5] F. Babonneau, A. Badran, M. Benlahrech, A. Haurie, M. Schenckery, and M. Vielle. How a climate agreement creating an international carbon market could reduce stranded asset risk in gcc countries and qatar in particular. IAAE Energy Forum, pages 13–15, 2019.

[6] F. Babonneau, A. Badran, M. Benlahrech, A. Haurie, M. Schenckery, and M. Vielle. Economic assessment of the development of CO_2 direct reduction technologies in long-term climate strategies of the gulf countries. Climatic Change, 165(3) :1–18, 2021.

[7] F. Babonneau, O. Bahn, A. Haurie, and M. Vielle. An oligopoly game of CDR strategy deployment in a steady-state net-zero emission climate regime. Environmental Modelling and Assessment, Online first article, October 2020.

[8] F. Babonneau, A. Haurie, and M. Vielle. Reaching Paris agreement goal through CDR/DAC development : A compact OR model. Technical Report G–2021–71, Cahiers du GERAD, HEC Montreal, Canada, December 2021.

[9] E. Baik, D. Sanchez, P. Turner, K. Mach, C. Field, and S. Benson. Geospatial analysis of near-term potential for carbon-negative bioenergy in the united states. PNAS, 115(13) :3290–3295, March 27, 2018.

[10] A. Bernard and M. Vielle. GEMINI-E3, a General Equilibrium Model of International National Interactions between Economy, Energy and the Environment. Computational Management Science, 5(3) :173–206, May 2008.

[11] V. Bosetti, C. Carraro, M. Galeotti, E. Massetti, and M. Tavoni. WITCH : a world induced technical change hybrid model. Energy Journal, 27 :13–37, 2006.

[12] S. Bouckaert and et al. Net Zero by 2050 : a Roadmap for the Global Energy Sector. International Energy Agency, 2021.

[13] C. Chen and M. Tavoni. Direct air capture of CO_2 and climate stabilization : a model based assessment. Climatic Change, 118 :59–72, 2013.

[14] C. Consoli. Bioenergy and carbon capture and storage. Technical report, Global CCS Institute, 2019.

[15] Thijs Van de Graaf and Aviel Verbruggen. The oil endgame : Strategies of oil exporters in a carbon-constrained world. Environmental Science & Policy, 54 :456–462, 2015.

[16] J. Depledge. Striving for No : Saudi Arabia in the climate change regime. Global Environmental Politics, 8(4) :9–35, 2008.

[17] EASAC policy report. Negative emission technologies : What role in meeting Paris Agreement targets ? Isbn : 978-3-8047-3841-6, European Academies' Science Advisory Council, This report can be found at www.easac.eu, February 2018.

[18] Ugo Fasano and Zubair Iqbal. GCC countries : From oil dependence to diversification. IMF, International Monetary Fund, Publication Services 700 19th Street, N.W.,Washington, D.C.20431, U.S.A., 2003.

[19] A. Flamos, Ch. V. Roupas, and J. Psarras. GCC economies diversification : Still a myth ? Energy Sources, Part B : Economics, Planning, and Policy, 8(4) :360–368, 2013.

[20] S.A. Gardarsdottir, F. Normann, K. Andersson, and F. Johnsson. Process evaluation of CO_2 capture in three industrial case studies. Energy Procedia, 63 :6565–6575, 2014.

[21] S.A. Gardarsdottir, F. Normann, K. Andersson, and F. Johnsson. Investment costs and CO_2 reduction potential of carbon capture from industrial plants - a Swedish case study. Int J Green Gas Control, 76 :111–124, 2018.

[22] Oliver Geden, Glen P. Peters, and Vivian Scott. Targeting carbon dioxide removal in the European Union. Climate Policy, 19(4) :487–494, 2019.

[23] Frank W. Geels. The multi-level perspective on sustainability transitions : Responses to seven criticisms. Environmental Innovation and Societal Transitions, 1(1) :24–40, 2011.

[24] F.W. Geels. Understanding Industrial Transformation : Views from Different Disciplines, Xander Olshoorn and Anna J. Wieczorek (eds.), chapter 9. Multi-level perspective on system innovation : relevance for industrial transformation, pages 163–186. Springer. Printed in the Netherlands, 2006.

[25] Kenneth Gillingham, William Nordhaus, David Anthoff, Valentina Bosetti, Haewon McJeon, Geoffrey Blanford, Peter Christensen, John Reilly, and Paul Sztorc. Modeling uncertainty in climate change : A multi-model comparison. Technical Report 13, Nota di Lavoro, 2016.

[26] Samantha Gross and Yuhji Matsuo. Towards more pragmatic global climate goals and policies. Technical Report 20, King Abdullah Petroleum Studies and Research Center, 2017.

[27] Fakhri J. Hasanov, Brantley Liddle, and Jeyhun I. Mikayilov. The impact of international trade on CO_2 emissions in oil exporting countries : Territory vs consumption emissions accounting. Energy Economics, 74 :343–350, 2018.

[28] K.Z. House, A.C. Baclig, M. Ranjan, E.A. Nierop, J. Wilcoxx, and H.J. Herzog. Economic and energetic analysis of capturing CO_2 from ambient air. PNAS Early Edition, pages 1–6, 2011.

[29] IEA. The future of hydrogen : seizing today's opportunitie. Technical report, International Energy Agency, Paris, 2019.

[30] International Energy Agency. World Energy Outlook 2021. Paris, 2021.

[31] IPCC. Summary for Policymakers. In : Climate Change 2021 : The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [M. in[MassonDelmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press, 2021.

[32] IRENA. Stranded assets and renewables : how the energy transition affects the value of energy reserves, buildings and capital stock. Technical report, International Renewable Energy Agency, Abu Dhabi, 2017.

[33] KAPSARC. Role of oil in the low carbon energy transition. Technical Report WB10, KAPSARK, 2017.

[34] KAPSARC. Understanding the energy transition. Report WB16, KAPSARC, April 2018.

[35] D. W. Keith, G. Holmes, D. St. Angelo, and K. Heidel. A process for capturing CO_2 from the atmosphere. Joule, 2 :1573–1594, August 2018.

[36] David W. Keith. Why capture CO_2 from the atmosphere ? Science, 325(5948) :1654–1655, Sept. 2009.

[37] D.W. Keith, M. Ha-Duong M, and J. Stolaroff. Climate strategy with CO_2 capture from the air. Climatic Change, 74(1–3) :17–45, 2006.

[38] J. Koornneef, P. can Breevoort, C. Hendricks, M. Hoogwijk, and K. Koops. Potential for biomass and carbon dioxide capture and storage. Technical report, International Energy Agency, 2011.

[39] J. Krane. Climate strategy for producer countries : The case of Saudi Arabia. In G. Luciani and T. Moerenhout (eds.), editors, When can oil economies be deemed sustainable ?. The political economy of the Middle East., chapter 12. Palgrave Macmillan, 2021.

[40] S. Kypreos. A merge model with endogenous technological change and the cost of carbon stabilization. Energy Policy, 35 :5327–5336, 2007.

[41] K. Lackner. Capture of carbon dioxide from ambient air. Eur Phys J Spec Top, 176 :93–106, 2009.

[42] Giacomo Luciani and Tom Moerenhout (eds). When Can Oil Economies Be Deemed Sustainable ? The Political Economy of the Middle East. Palgrave macmillan, 2020.

[43] A. Marcucci, V. Panos, and S. Kypreos. The road to achieving the long-term Paris targets : energy transition and the role of direct air capture. Climatic Change, 2017.

[44] Daniel Mitchell, Rachel James, Piers M. Forster, Richard A. Betts, Hideo Shiogama, and Myles Allen. Realizing the impacts of a 1.5°C warmer world. Nature Clim. Change, advance online publication :–, 2016.

[45] Paul Mollet, Imtenan Al-Mubarak, Brian Efird, Saleh Al Muhanna, and Omar Al-Ubaydli. Assessment of the political feasibility of developing a GCC power market. Technical Report 39, King Abdullah Petroleum Studies and Research Center, 2018.

[46] G. F. Nemet and A. R. Brandt. Willingness to pay for a climate backstop : Liquid fuel producers and direct CO_2 air capture. The Energy Journal, 33(1) :53–81, 2012.

[47] William Nordhaus. Projections and uncertainties about climate change in an era of minimal climate policies. American Economic Journal : Economic Policy, 10(3) :333–360, 2018.

[48] Markus Ohndorf, Julia Blasch, and Renate Schubert. Emission budget approaches for burden sharing : some thoughts from an environmental economics point of view. Climatic Change, 133(3) :385–395, 2015.

[49] Sergey Paltsev, Andrei Sokolov, Martin Haigh, David Hone, and Jennifer Morris. Changing the global energy system : Temperature implications of the different storylines in the 2021 Shell energy transformation scenarios. Technical Report 348, MIT Joint Program Report on the Science and Policy of Global Change, February 2021.

[50] Joeri Rogelj, Gunnar Luderer, Robert C. Pietzcker, Elmar Kriegler, Michiel Schaeffer, Volker Krey, and Keywan Riahi. Energy system transformations for limiting end-of-century warming to below 1.5°C. Nature Clim. Change, 5(6) :519–527, 2015.

[51] Christopher R. Rossi. Game of thrones : the Qatar crisis, forced expulsions on the Arabian peninsula. Penn State Journal of Law & International Affairs, 7(1–52), 2019.

[52] E.S. Rubin, J.E. Davison, and H.J. Herzog. The cost of CO_2 capture and storage. International Journal of Greenhouse Gas Control, 40 :378–400, 2015.

[53] Sandrine Selosse and Nadia Maïzi. The decarbonized pathways of post-Paris climate policy. In 66th annual Congress of the French Economic Association (AFSE), hal-01735072. Association Française de Science Economique, Jun 2017, Nice, France, 2017.

[54] Shell-Corp. Shell scenarios Sky : Meeting the goals of the Paris agreement. Technical report, Royal Dutch Shell, 2018.

[55] Giorgio Simbolotti. CO_2 Capture and Storage. Technology Brief E14, ETSAP, 2010.

[56] Robert Socolow, Michael Desmond, Roger Aines, Jason Blackstock, Olav Bolland, Tina Kaarsberg, Nathan Lewis, Marco Mazzotti, Allen Pfeffer, Karma Sawyer, Jeffrey Siirola, Berend Smit, and Jennifer Wilcox. Direct Air Capture of CO_2 with Chemicals : A Technology Assessment for the APS Panel on Public Affairs. 01 2011.

[57] S. Soummane, F. Ghersi, and J. Lefèvre. Macroeconomic pathways of the Saudi economy : The challenge of global mitigation action versus the opportunity of national energy reforms. Energy Policy, 130 :263–282, 2019.

[58] The American Physical Society. Direct air capture of CO_2 and climate stabilization : a model based assessment with chemicals : A technology assessment for the APS panel on public affairs. Technical report, April 15 2011.

[59] Vijo Varkey Theeyattuparampil, Othman Adnan Zarzour, Nikolaos Koukouzas, Georgeta Vidican, Yasser Al-Saleh, and Ismini Katsimpardi. Carbon capture and storage : State of play, challenges and opportunities for the GCC countries. International Journal of Energy Sector Management, 7(2) :223–242, 2013.

[60] Iman Ustadi, Toufic Mezher, and Mohammad R.M. Abu-Zahra. The effect of the carbon capture and storage (CCS) technology deployment on the natural gas market in the united arab emirates. Energy Procedia, 114 :6366–6376, 2017.

[61] H Uzawa. Production functions with constant elasticities of substitution. Review of Economic Studies, 29(4) :291–299, 1962.

[62] Rubina Vohra. The impact of oil prices on GCC economies. International Journal of Business and Social Science, 8(2) :7–14, 2017.

[63] Colin Ward, Wolfgang Heidug, and Nils-Henrik Bjurstrøm. Enhanced oil recovery and CO_2 storage potential outside north america : An economic assessment enhanced oil recovery and CO_2 storage potential

outside north america : An economic assessment. Technical Report 27, King Abdullah Petroleum Studies and Research Center, 2018.

[64] David Wogan, Elizabeth Carey, and Douglas Cooke. Policy pathways to meet Saudi Arabia's contributions to the Paris agreement. Technical Report 49, King Abdullah Petroleum Studies and Research Center.

[65] Xiaoliang Yang, Wolfgang Heidug, and Douglas Cooke. Policy lessons from China's CCS experience. Technical Report 37, King Abdullah Petroleum Studies and Research Center, 2018.