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Power generation under post Copenhagen emission reduction pledges

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Abstract

The study relies on the ETSAP/TIAM-FR approach performing the optimization of the energy system in the long-term with explicit descriptions of the technologies used: it is based on an explicit formulation of the input-output relationships for each technology and minimises - over the chosen time horizon 2000-2050 and for a given final services demands - the total discounted cost. We assess for the period the evolution of energy consumptions (primary, electricity generation) global and regional emission levels, and global and regional costs of the climate policy.

We will address the ability of national energy system to curve the past trends in order to reach those targets, first relying on the actual technical structure of the energy production and consumption system. In this framework, we will assess how the energy system in general and the electricity generation in particular can evolve over time to follow different low carbon future policies? The results show a complex impact of the mitigation policies on the future electricity mix and technologies.

Keywords: Long term Planning. Linear programming. Power systems.

1. Introduction

Electricity is a very convenient way to deliver huge amounts of power in areas where demand is concentrated. Due to the predicted population densification, electricity consumption is set to significantly increase over the next decades. The International Energy Agency has estimated that US$ 10 trillion will be spent during the next thirty years on the generation, transmission and distribution of electrical power, in order to replace existing capacities in developed countries, or to accompany the development of energy markets, or to substitute energy vectors that are less clean or growing scarce [10]. In this context, two essential features challenge forthcoming changes in the power system: (i) the emergence of different paradigms for serving electricity than those for which the system was designed [5]; (ii) the will to improve the energy efficiency of electrical power transmission, given that the current system clearly lacks efficiency (e.g. electrical losses are twice as high as electricity consumption was in 1950 as pointed out in [6]).

Moreover, the world net generation of electricity increasingly relies on fossil fuels as shown in figure 1, which implies a higher impact on the environment due to the level of greenhouse gas emissions emitted by the electrical sector.

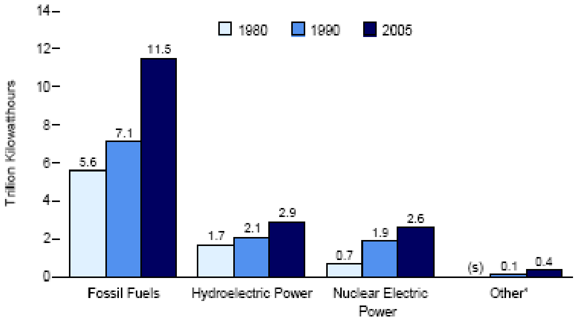

Figure 1: Net Generation by Type, 1980, 1990, and 2005 [6]

These issues stress the need for assessing future electrical power systems in a world where the global warming question remains on top of the energy agenda.

In the past couple of years the climate change debate has been marked not only by scientific evidences reported in the IPCC assessment reports, but also politically by a number of major events: the approval of the EU climate package by the EU parliament in December 2008, the transition in US with "green" positions expressed by the new administration, and the large participation of developed as well as developing countries in the Copenhagen Climate Change Conference (COP 15), in December 2009. The international agreement at COP 15 was the final step of the two-year negotiation process set by the Bali conference in 2007. On the one hand, COP15 discussions eventually failed to reach a global agreement on greenhouse gas emissions mitigation targets. On the other hand, countries wishing to associate themselves with the Copenhagen Accord were required to formally submit to the United Nations Framework Convention on Climate Change (UNFCCC) their emission reduction pledges before the end of January 2010.

The aim of this paper is to analyze the outcomes of different coordination schemes, derived from the submitted pledges, and associated to intermediate targets levels through models for energy planning which have proven useful to determine a plausible evolution of the energy sector in the mid -to long-term in the face of strong environmental pressures, such as carbon mitigation or fossil energy depletion.

Indeed issues such as pointing out the main drivers of the energy system at a given regional scale, anticipating changes in and impacts of energy prices, and estimating pollutant emissions, require models of substitution possibilities throughout the whole energy chain. The MARKAL (MARKet ALlocation) type of technology-rich models and its derived world version TIAM-FR provide a partial solution to this problem [3, 7, 1].

In section two, we present the TIAM-FR modeling approach for the electricity sector relying on an optimization paradigm. Section three attempts to clarify what results can be expected by integrating the pledges in different scenarios constraining the CCS and the renewable integration in the energy systems worlwide. Section four then provides a conclusive discussion, in which we will analyze the modelling results we brought about, under a specific demand scenarios and hypotheses. We will outline some of the environmental assertions which are not relevant with the electricity sector.

2. TIMES and TIAM-FR

2.1. MARKAL/TIMES

MARKAL (Market Allocation) is an optimisation software program developed by the International Energy Agency (IEA) in the early 1980s to examine the mid- or long-term impact of production, transformation and demand technologies in the energy sector.

It has since become the subject of the IEA's development programme, ETSAP (Energy Technology Systems Analysis Programme). MARKAL is used by 77 institutes in 37 countries, including the USA, China, Japan, Canada and the Netherlands [7].

Since its creation, the model's basic methodology has been adapted to problems in the energy sector (e.g. trans-boundary exchanges, life-cycle analysis, assessment of demand, etc.), and today the MARKAL acronym in fact embraces a family of models consecrated to each issue (MATTER, TIMES, RMARKAL, MARKAL-MACRO, etc.) [4].

In the following, we will describe MARKAL. TIAM-FR model is based on TIMES which is the latest evolution of MARKAL. Thus, we will specify the differences between the two versions each time necessary. MARKAL, in its basic version, is a technical optimum model. It relies on an explicit formulation of the input-output relationships for each technology and minimises - over the chosen time horizon and for a given final outcome - the discounted global cost, with decisions depending on the choice of the activity level of the technologies and of capacity investments.

In the MARKAL model, the energy sector that we have chosen to analyse is seen as a chain of transformations that allow raw materials to meet final energy demand. In this portrayal, a technology is defined as an "energy vector" converter and is associated with each of the transformation stages. This reference system (RES) can be illustrated by Figure 2.

The highly coherent nature of this approach allows for the arbitrary disaggregation of energy exchanges and consequently of technologies. This is one of the principal characteristics of MARKAL.

Over the chosen horizon for MARKAL modelling (typically two to three decades), a group of time periods of equal length (TIMES allows more flexible periods) are defined. The characteristics of the technologies can evolve from one period to another. In this way, any technological progress can be taken into account (improved yield, diminished costs, etc.).

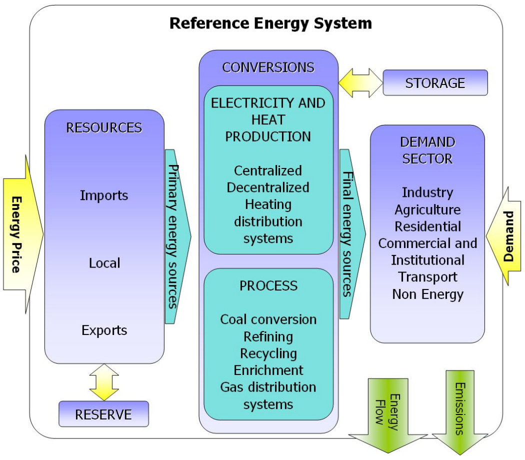

Figure 2: Reference Energy System

Once the technologies have been informed and connected together, it is possible to attain a group of linear equations for each period, linking the activities to each of the technologies. These are the system's energy equilibrium equations. Among them, we can distinguish those equations that bring demand (demand is exogenous in the majority of MARKAL versions). The latter equations, interpreted as "constraints through demand" render MARKAL "a partial equilibrium model piloted by demand" [2, 3].

2.2. The specific case of electricity

Electricity production has a particular position in MARKAL. In order to take into account production peaks and more generally the variations in the demand on power, each period is split up into six time slices (in TIMES there is no limit and TIAM-FR has twelve time slices) that correspond to the possible combinations between, on the one hand, day and night, and on the other hand, winter, summer and the intermediate seasons. Electric demand (of both sectors and technologies) is by default proportionally broken down into the duration of each of these time slices, or into a proportion decided by the user. The second alternative allows for a more subtle understanding of the distribution of demand over the year. Each means of electric production is affected by: a coefficient of annual or seasonal availability, a function indicator (e.g. imposed capacity production as for wind, base*, free, or stocking units†, etc.), and by a peak participation coefficient (essential for renewable energy sources). These coefficients, which are linked to obligatory capacity reserves for peak periods and to certain constraints defined by the user, make it possible to improve the representation of the generation system and to ensure that electric equilibrium is attained in each time slice.

2.3. A techno-economic optimiser

Besides its model, each technology is linked to its programmed capacity at the start of the horizon, to its lifespan and, for each period, to three costs: an annual investment cost, a fixed cost (annual maintenance, taxes, etc.), and a variable cost (fuel, maintenance, taxes, etc.). The cost of a technology over a given period therefore appears as the sum of these three costs, respectively counterbalanced by the decision variables: programmed capacity, investment and activity. If we notice that the programmed capacity at a given moment is the sum, over the equipment's lifespan, of capacity investments made and of residual capacity, we can record the energy system's global cost as a linear combination of activities and investments over the whole horizon. Because of this, capacity investments for each technology appear as decision variables in the pursuit of an optimum.
The techno-economic optimum is reached as the solution to a classic problem of linear programming: the minimisation of the system's actualized global cost over the model's horizon, while respecting: the constraints of the problem, the model's inherent constraints (equilibrium of energy vectors, satisfaction of demand, peak capacity reserve, activity/capacity constraints, etc.), and possible constraints defined

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*The basic functionning of MARKAL is taken as uniform production, both night and day

†Pumping at night and restoration during the day

by the user (environmental constraints, regional specificities, etc.). As well as providing levels of activity and investment, and the cost of each technology at any time, MARKAL supplies the marginal associated cost for each constraint (i.e. the increased cost when a unity's constraint is relaxed, all things being equal elsewhere), and the reduced costs for unused technologies (i.e. a reduction in cost that allows an unselected technology to participate). [9]

The afore-mentioned developments show two things. On the one hand, the generality of the notion of "energy vector", which is MARKAL's strength and on the other hand, the importance of having an adequate technological database for handling the chosen technological and sectoral disaggregation.

2.4. TIAM-FR

The analysis carried out in this paper is based on TIAM-FR, the French version of the global multiregional TIMES Integrated Assessment Model. TIAM-FR is geographically integrated and offers a representation of the global energy system in 15 regions covering the entire world: Africa, Australia-New Zealand, Canada, China (includes Hong Kong, excludes Chinese Taipei), Central and South America, Eastern Europe, Former Soviet Union (includes the Baltic states), India, Japan, Mexico, Middle-East (includes Turkey), Other Developing Asia (includes Chineise Tapaei and Pacific Islands), South Korea, United States of America and Western Europe (EU-15, Iceland, Malta, Norway and Switzerland). TIAM-FR describes the entire energy system of each region with regard to several thousand current technologies. The regions are linked by energy, material and emission permit trading variables, if desired; actions taken in one region may affect all other regions.

End-use demands (i.e. energy services) are based on socio-economic assumptions which are specified exogenously by the user in appropriate units (number of houses, commercial area, industrial production, vehicles-kilometers, etc.) over the planning horizon (which could be until 2100). TIAM-FR acknowledges that demands are elastic to their own prices. This features insures the endogenous variation of the demands in constrained runs, thus capturing microéconomic feedback of the energy system. Thereby, the energy consumption in TIAM-FR is based on external projections of the growth of regional GDP as well as population and volume of various economic sectors (transport, residential, industry, etc.). The model assumes perfect markets and unlimited foresight for the calculation period, the economic sectors, and commodities. TIAM-FR tracks emissions of CO_2, CH_4 and N_2O from fuel combustion and processes. Emission reduction is brought about by endogenous demand reductions, technology and fuel substitutions (leading to efficiency improvments and process changes in all sectors), carbon sequestration (including CO_2 capture at the power plant and hydrogen plant level, sequestration by forests, and storage in oil/gas fields, oceans, aquifers, etc.).

3. What possible futures with the post Copenhagen pledges?

Even if negotiations during COP 15 failed to reach a global agreement on targets for reductions in greenhouse gas emissions to the post-Kyoto, the stakes are no less crucial, and in late January 2010, some countries pledged their commitment to the UNFCCC as part of the Copenhagen Agreement. Although this international agreement did not meet up to expectations, it includes a share of all major industrialized countries (and primarily the United States that had not ratified the Kyoto Protocol), and for the first time, the fastest developing countries whose economic activities and demographic prospects constitute real challenges for the coming decades. Indeed, it was imperative that such mitigation policies were promptly considered by these countries, primarily China and India. Their participation and the one of the United States was the major issue of this agreement.

3.1. Announced pledges by country and scenario specification

We defined scenarios according to the CO_2 mitigation targets expressed to UNFCCC for the Copenhagen Agreement in January 2010 by Western Europe, the United States of America, Australia, Canada, Japan, China and India. Table 1 presents these regional commitments. Note that for China and India, the commitment is not on the emission level but on the carbon intensity. This means that Indian and Chinese GDPs will continue to rise but their carbon emissions will have to increase at a lower rate due to greater energy efficiency and investment in greener technologies. Another important and well-known observation to note concerns the choice of reference year. Indeed, while Western Europe and Japan pledge for a CO_2 emission mitigation target up to 2020 compared to 1990 levels, other regions take 2005 (or

2000 for Australia) as the reference year. This naturally has a significant impact on targets.

Table 1: Post COP 15 commitments for 2020

Regions	Reference year	Level of commitment	Mitigation rate	Mitigation type
Western Europe (WEU)	1990	Pessimistic	20%	Emissions
		Optimistic	30%	
Japan (JPN)	1990	Fix	25%	Emissions
Australia-New Zealand (AUS)	2000	Pessimistic	5%	Emissions
		Optimistic	25%	
United States (USA)	2005	Fix	17%	Emissions
Canada (CAN)	2005	Fix	17%	Emissions
China (CHI)	2005	Pessimistic	40%	Carbon intensity
		Optimistic	45%	
India (IND)	2005	Pessimistic	20%	Carbon intensity
		Optimistic	25%	

The international community appears to converge on long-term objectives, namely a GHG mitigation of 60% to 80% by 2050. In this context, we investigate these scenarios according to this convergence for industrialized countries. An exception exists in the case of the USA and Canada who already pledged for the long-term targets to the UNFCCC. Thus, for these countries, we consider a CO_2 mitigation target of 30% by 2025, 42% by 2030 and 83% by 2050, like they have announced. Also, we specify particular assumptions for China and India following their context and, in a more ambitious target, we suppose that China and India pledge on emission level for 2050 and no on carbon intensity. The table 2 presents these assumptions taken in order to express the long-term targets of carbon mitigation.

Table 2: Assumptions for 2050

Regions	Reference year	Level of commitment	Mitigation rate	Mitigation type
EU and JPN	1990	Pessimistic	60%	Emissions
		Optimistic	80%	
AUS	2000	Pessimistic	60%	Emissions
		Optimistic	80%	
CHI	2005	Pessimistic	90%	Carbon intensity
		Optimistic	10%	Emissions
IND	2005	Pessimistic	60%	Carbon intensity
		Optimistic	10%	Emissions

We then create two scenarios to analyze different scheme of international coordination on climate policies over the period 2000-2050:
- **Optimistic:** This international scenario represents the fix and optimistic CO_2 mitigation targets of the COP 15 commitments expressed for 2020 and optimistic assumptions for 2050.
- **Pessimistic:** This international scenario represents the fix and pessimistic CO_2 mitigation targets of the COP 15 commitments expressed for 2020 and pessimistic assumptions for 2050.

A baseline business as usual (BAU) scenario without any emission constraints was first calculated. This reference scenario outlined some key patterns in the evolution of the energy system and allows us to investigate the changes induced by a strong environmental policy, assess the implications on the future development of the energy system and formulate policy recommendations.

3.2. Understanging the international CO_2 emission mitigation targets

Post Copenhagen emission reduction pledges and, de facto, assumptions for long-term targets base on different reference years and types of mitigation, that can confuse the issue. To a better understanding of the various targets, we translate these pledges to the same reference year and follow the same type of reduction, i.e. emission mitigation. The table 3 shows this conversion and interesting informations.

In the case of China, reducing carbon intensity by 40% by 2020 compared to 2005 (its pledge) is strictly mathematically equivalent to limit the increase of its CO_2 emissions by 295% in 2020 compared to 1990 and by 69% compared to 2005. For the optimistic scenario, in which China pledges to reduce its CO_2 emission levels by 10% by 2050 compared to 2005 levels, this limits the increase of its CO_2 emissions to 111% in 2050 compared to 1990 levels. These figures have to be interpreted carefuly and they show that we are not in the same context than already industrialized countries, whether for political, economic or technological reasons.

Table 3: Understanding the targets

Region	On 1990 scale (pessimistic/optimistic)		On 2005 scale (pessimistic/optimistic)	
	2020	2050	2020	2050
WEU	-20% / -30%	-60% / -80%	-45% / -52%	-72.5% / -86%
JPN	-25%	-60% / -80%	-32.4%	-64% / -82%
AUS	+8% / -14.5%	-54% / -72%	-14% / -32%	-64% / -82%
USA	-0.30%	-79.6%	-17%	-83%
CAN	+3.2%	-78.9%	-17%	-83%
CHI	+295% / +262%	+195% / +111%	+69% / +54.5%	+26% / -10%
IND	+423% / +390%	+1318% / +86%	+154% / +138%	+588% / -10%

For the United States, a 17% reduction in its CO_2 emission levels by 2020 and a 83% by 2050 compared to 2005 levels, is equivalent to a 0.3% reduction by 2020 and a 79.6% by 2050 compared to 1990 levels. In the long-term, CO_2 emission mitigation in 2050 compared to 2005 is more comparable than optimistic targets of industrialized countries by 2050 compared to 1990. This is coherent with the fact that, even if for the long-term, a noticeable convergence existed between the views expressed by European Union and the Obama-Biden new energy plan for America, the deal on medium-term targets was far from being sealed during COP 15. For all that, in their commitment to the Copenhagen Agreement, the USA have already pledged to the 2050 target, indicating intermediate targets (for 2025 and 2030) to guide the CO_2 mitigation pathway of their policy up to this long-term target. The USA is constrained by political barriers, which limit medium-term possibilities for the new government, despite its greener position. This pledge could be a way of expressing its ambition to act against climate change and to position the USA at the forefront of this global combat.

3.3. Main scenario results

Firstly, the pathway of global carbon emissions consistent with achieving the regional CO_2 emissions mitigation targets lead to an atmospheric CO_2 concentrations for all scenarios below 450 parts per million (ppm) in 2050, and we recall here that this is only for the energy related emissions (thus it would be inapropriate to compare directly these figures with those given in the Intergovernmental Panel on Climate Change [8]) . If we compare the two scenarios, CO_2 concentrations are closer until 2030. The targets variations don't impact in a large measure the medium-term level of CO_2 concentration. But differences widen on the long-run, as we can see in the figure 3.

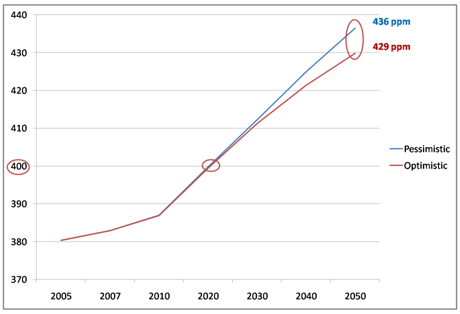

Figure 3: CO_2 concentration (ppm)

The figure 4 expresses the impact of these climate policies in terms of global and regional emissions levels. In 2050, carbon constraints involve a decrease in emissions of more or less 15 Gt CO_2 (following optimistic or pessimistic targets for that year) in comparison with BAU. In 2020, the level of global CO_2 emissions decreases by about 5 Gt in 2020 in comparison with the BAU scenario. Furthermore, the effect of the climate policies developed regarding COP 15 pledges are for the most part expected in the long-term, even for pessimistic targets. In the medium-term, the carbon constraint leads to a less noticeable decrease in CO_2 emissions. An interesting medium- and long-term result is that the level of pledges do not reverse the growing trend of emissions, despite the significant reductions achieved compared to the BAU.

While environmental stakes involve global action, measures and impacts remain regional. Indeed, the level of ambition of CO_2 mitigation from developed countries (especially the USA) and developing countries (particularly fast developing countries like China and India) is a determining factor in the post-Kyoto international agreement to establish a course of action for climate change.

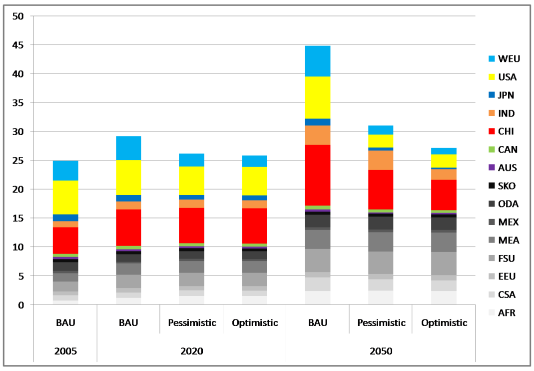

Figure 4: Regional CO_2 emissions (Gt CO_2)

By 2020, Western Europe, together with Japan, has pledged the biggest effort in tackling climate change. This graph highlights how strong the European targets are for the medium- and long-term, for all carbon constraints scenarios. The European Union, which before COP 15 was alone in committing to a Post-Kyoto international agreement, has pledged a 20% reduction in CO_2 emissions by 2020 compared to 1990 levels, and is prepared to commit to additional efforts in case of international agreements, i.e. to increase its pledge from 20% to 30%. The USA's commitment and its implication are far from ambitious and satisfying in the medium-term. Conversely, the impact of USA policy is clearly more noticeable in the long-term.

Results for China and India could appear as telltale signs of the effort that the Chinese and Indian governments are willing to make in the climate change context. Indeed, when their CO_2 mitigation target on carbon intensity are translated in cap targets, it seems that they make a very weak effort. Actually, this has to be understood in their specific economic context, where they need to preserve a fast GDP growth.

The impacts on emissions levels then are that, for China, in 2020, CO_2 emissions represent 6.3 Gt in the BAU scenario and around 6.1 Gt in the climate scenario. For India, in 2020, CO_2 emissions represent 1.4 Gt in the BAU scenario and are at the same level in the climate scenario. The weak impact of Chinese and the Indian climate commitments emerges clearly in the medium-term. But for 2050, where there is no official position on their ambitions, 10% of mitigation based on the level of CO_2 emissions involves not only an effective impact, but also ambitious and concrete participation in the fight against climate change. One question could be: At what cost?

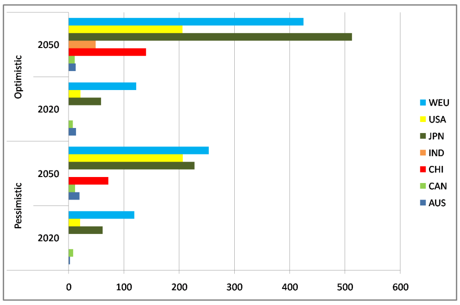

Figure 5: Regional carbon marginal costs ($/t$CO_2$)

The regional carbon marginal cost according to the various scenarios is given in the Figure 5. It appear high for Japan and Western Europe with respectively \$160/tCO_2 and \$128/tCO_2 in 2020 and \$512/tCO_2 and \$425/tCO_2 in 2050 for the optimistic scenario. For the United States, the marginal cost in 2020 is only \$21/tCO_2 and \$206/tCO_2. As discussed above the mitigation pressure for China appears only in

2050. This is linked to the fact that the BAU already supposes rational choices. In 2050, the carbon target imposed on China sharply increases carbon marginal costs for this region, particularly in the optimistic scenario, where it reaches $\$140/\text{tCO}_2$ ($\$71/\text{tCO}_2$ in the pessimistic scenario). This factor raises the question of the extent to which China (or other country) is capable of supporting more ambitious targets.

Additional constraints imposed on the energy system involve variations in energy and technology choices. Here, climate policy with carbon emission mitigation influences the structure of the energy mix, however, impact is weak on the total volume of primary energy consumption which decreases respectively to 1.55% and 0.6% on average in 2020 and 2050 by comparison with BAU levels. Figure 6 highlights the evolution of the primary energy supply and table 4 presents the impact of climate policies on the energy mix.

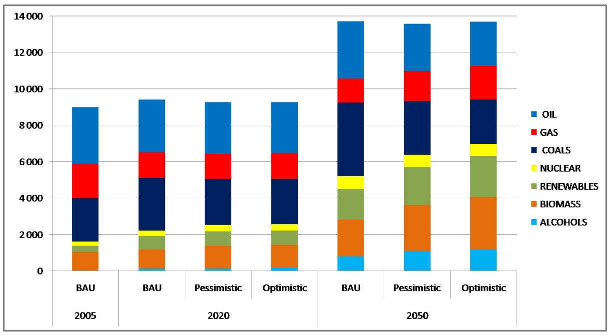

Figure 6: Total Primary Energy Supply

If we compare the BAU and climate scenarios in 2020, carbon constraints lead to an increase of other renewables and biomass and to a lesser extent, nuclear. Gas is not really influenced by CO_2 mitigation actions, and the impact of climate policy on oil consumption is low. Also, environmental targets lead to reduced coal supplies compared with the reference scenario. Moreover, coal supplies in carbon constraint scenarios in 2020 are only slightly greater than the 2005 level.

Table 4: Fuel shares in the energy mix (%)

Year	Scenario	Oil	Gas	Coals	Nuclear	RNW	Bio	Alcohols
2005	BAU	34.7	20.9	26.6	2.4	3.9	11.5	0.03
2020	BAU	30.7	15.1	30.8	3.2	7.9	10.9	1.4
	Pessimistic	30.6	15.2	27.0	3.7	8.5	13.5	1.4
	Optimistic	30.2	15.3	26.9	3.7	8.5	13.4	2.0
2050	BAU	23.0	9.6	29.6	4.9	12.4	14.6	5.9
	Pessimistic	19.1	12.2	21.8	5.0	15.3	18.8	7.9
	Optimistic	17.8	13.5	17.7	5.0	16.3	21.2	8.6

In 2050, we note a further decline of the oil share and an increase of renewables to shares of 41.2% and 46.2%, depending on more or less ambitious scenarios (with an marked increase essentially for biomass). Nuclear progresses, but not to a great extent, and is not really impacted by climate constraints. Interestingly, despite the large progression of renewables reaching 46% in the more ambitious scenario, fossil fuels still represent the major share of the energy mix (49%), and particularly, the share of coal remains high, despite carbon constraints.

4. Power sector Results

In the power sector, the impact of the climate policy is weak in 2020 with an electricity mix relatively similar whatever the scenario. What we can note is an increase of electricity production by renewables (+460 TWh, in optimistic scenario) and nuclear (+520 TWh, *id.*) and the investment in CCS technologies (+530 TWh, *id.*) as a response of international measures pledged in the Copenhagen Agreement. This deployment is particularly marked in 2050 where between 8.2 and 10.55 Gt of CO_2 should be sequestrated to reach the carbon emission mitigation target, depending on the stringency of the climate target. The figure 7 presents the electricity production and the sequestrated CO_2.

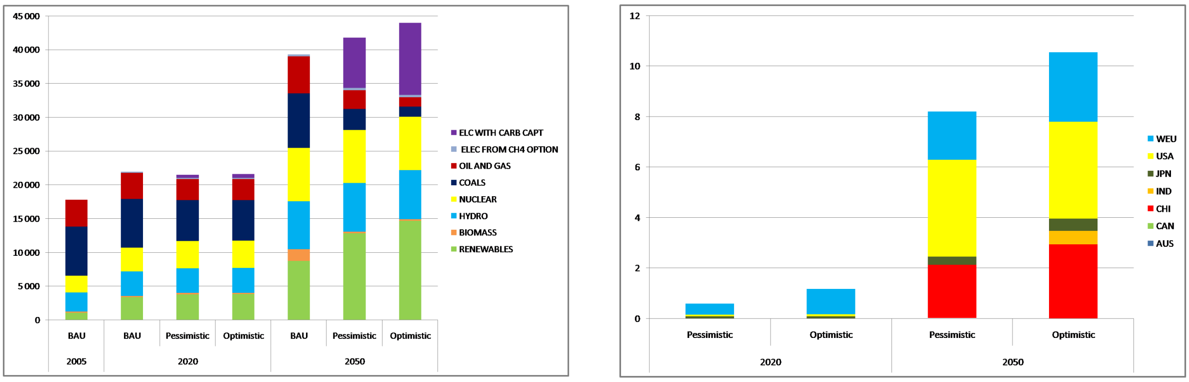

Figure 7: Electricity production by technology (TWh) and the regional CO_2 storage (Gt)

For the long-term, electricity production from renewables reaches more than 30% in the climate scenarios and fossils fuels less than 7% in favor of carbone capture technologies whose investments represent between 18 and 24% of the electricity mix according to pessimistic or optimistic scenario. For addressing the problem of global climate change, CCS technologies are expected to be deployed. However, are the 10 685 TWh based on CCS technologies needed to avoid around 10 Gt of CO_2 emissions feasible?

4.1. The deployment of CCS technologies

In order to face stringent carbon constraints, CCS technologies need to be installed on an industrial scale but their development rate remain uncertain. So we investigated new scenarios with limited CCS technologies expressing pessimistic views of their future development. The figure 8 presents the level of CCS deployment we constrain and the impact on the electricity production.

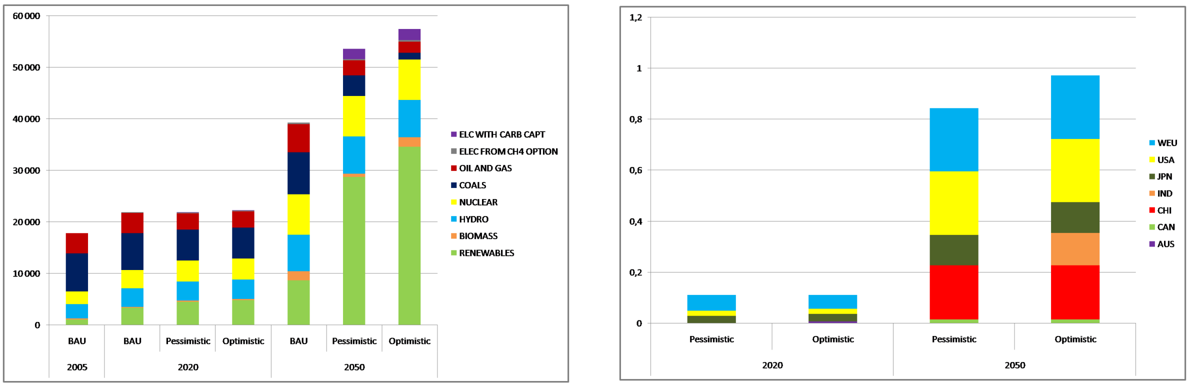

Figure 8: Electricity production by technology (TWh) and the regional CO_2 storage (Gt) with added constraint on CCS deployment

In 2020 as 2050, the impact of the CCS deployment limitation is the large progression of renewables in the power system which reach until 60%. While electricity production with carbone capture represents in this context 2 200 TWh (3.85% in the electricity mix in the optimistic scenario), 28 700 TWh based on renewables are needed to avoid targeted CO_2 emissions.

4.2. Renewables

The electric production by renewable technologies in 2020 is essentially marked by the deployement of geothermy and tidal wathever the climate scenario (with or without the added CCS constraint) in the detriment of wind which progresses a little on volume but knows a large decrease of its share. We also can note that the added CCS limit involve a higher investment on solar technologies. Figure 9 present the renewables electricity production according to the different scenario investigated. In 2050, the solar deployment yet results to the CCS limit. Indeed, 27 200 TWh are producted from solar technologies in the optimistic scenario with CCS limit against 7 300 TWh in the optimistic scenario without CCS limit.

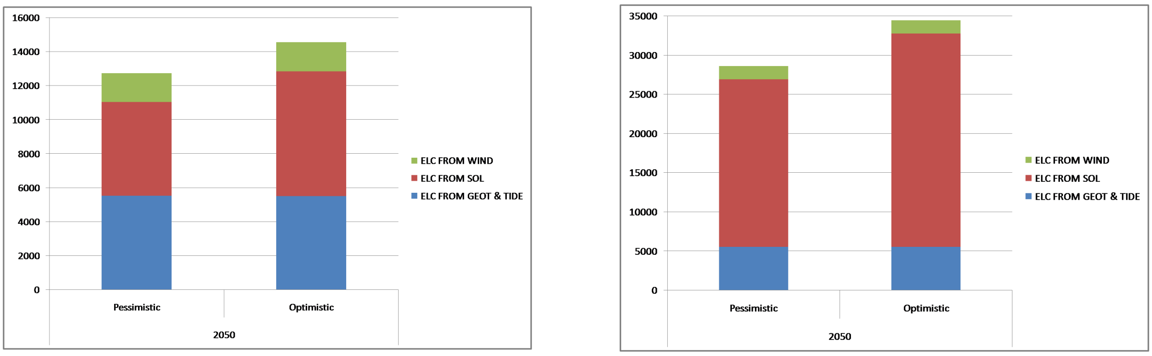

Figure 9: Electricity production by renewable technology without and with added constraint on CCS deployment (TWh)

Geothermal, tidal and wind technologies don't vary in volume but of course their share strongly decreases.

5. Conclusion

A key feature of the Copenhagen agreement is the participation of the United States and non-Annex I countries, especially China, as they represent a large share of the global CO_2 emissions. This analysis shows on the one hand that the impact of American and Chinese targets is weak by 2020 and essentially marked on long-term and on the other hand that the carbon marginal cost varies strongly according to countries.

The question of technological plausibility is also a critical factor for post Copenhagen international climate policy as regard CCS and renewables deployment. Could the potential use of these technologies, which is uncertain, be enough to satisfay the need? Concerning renewables, could they reach a competitive position and could they answer the stability need of the power system? In the case of intermittent renewables power and them variablility, can a given power system take up to 60% renewables without any changes whatsoever? Network stability should also be ensured. At what cost? Network will need to be reinforced and managed in other manner, which should be taken into account in further analyses.

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