From Nationally Determined Contributions to a World Carbon Market
The Road to Success for the Paris Agreement

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Abstract

Though adopted unanimously and with great enthusiasm by all parties to the COP 21 as well as by the civil society at large the Paris Agreement may stumble upon serious obstacles, the most important not being the hostile position taken by the new American administration. From the start it has been acknowledged that the total of commitments by countries for 2030 is far from what requires the fulfillment of the long term target of limiting global warming to 2°C, and a fortiori to 1.5°C, which is the aim asserted in the Agreement. The overshooting in the volume of GHG emissions is of about 35%, which means that in terms of abatement, compared to the Business as Usual projection, less than a third of the required path would be completed for this year, in the best circumstances.

It is then important :

- *on the one hand to explain the reasons of this gap, and to point to the responsibilities of the various countries. Not in order to blame those who appear to be far from committing to the same degree of ambition than others, but to assess how to induce them to increase their efforts ;*
- *on the other hand to devise a mechanism aiming at leveling the endeavors among countries, which is the condition of a concerted substantial increase of commitments, in line with the long term target.*

The vast majority of economists and analysts, joined by many national and local governments and by industry in its various components -including the sectors most involved in fossil energy production or consumption- consider that carbon pricing is a requirement in order to go beyond the bottom-up approach of the INDCs, which obviously favors free-riding behavior. It is the only way to clearly exhibit and assess the capacity by the various countries–and the associated economic burden- of their abating commitments.

Economists debate on the respective merits of the two contending systems, world uniform carbon price and cap and trade. If within a given country or jurisdiction a uniform carbon price appears the simplest and most efficient solution, in particular in the form of a carbon tax, this is not anymore the case at the international level. In terms of implementability (and in particular prevention of the risk of manipulation), subsidiarity, efficiency and equity, the system of cap and trade is superior. The main argument by the proponents of a uniform carbon tax is its alleged simplicity. Only one quantity, the price, is to be determined or agreed upon, instead of a vector, the allocation of permits. But what is at stake is a rule, insuring feasibility and incorporating equity concerns.

In a cap and trade system, it is the responsibility of each country to determine, freely and independently, its net demand for permits, together with the other aspects of its domestic environmental policy and in accordance with its fiscal policy (not forgetting shadow taxation for the provision of public goods) because all these aspects are obviously intertwined.

After a thorough investigation of the INDCs, operated through the GEMINI-E3 general equilibrium model and various assessments by academics, research centers, NGOs and international organizations, the paper presents several simulations of carbon tradable

[1] I am indebted to Marc Vielle of EPFL for various partial contributions to this work and for comments.

permits scenarios to various horizons and with different configurations, first limited to developed economies, then extended to other groups of countries, emerging and developing in particular.
In conclusion the paper proposes a progressive agenda, starting with the implementation as soon as 2020 of a market of tradable permits limited to developed countries. The results of the simulation show that the emerging carbon price is close to the ones cited or favored by economists and policy-makers.
The challenge is to enlarge the system to other countries, possibly as soon as 2030 and ideally even before. The bridge is to be based on transition scenarios, mixing the "desirable" and the "politically acceptable" for these countries i.e. their pledges eventually strengthened, which have been simulated and assessed.
However, contrarily to several proposals, the idea of implementing in the first stage a Border Adjustment Tax appears very ill-advised, apart from its sheer complexity. The subject is not to "punish" countries who don't participate to the market at its start –mainly because they are not ready to-, but to induce them to take the necessary steps in order to be able to join, as soon as possible, other participants.

Keywords
Climate change; Paris Agreement; Marginal Cost of Public Funds; Marginal Abatement Cost; Market of Tradable Permits

Contents

1. Introduction

Referring to the two French Imperators Napoléon Marx said “History repeats itself, first as tragedy, second as farce”. In modern History, and concerning the dramatic issue of climate change, it may be the opposite : first as farce, second as tragedy.

It is what suggests the long and never-ending negotiation under the auspices of United Nations and UNFCCC. Exactly 18 years separate the signature December 11, 1997 of the Kyoto Protocol from the signature, December 11, 2015 of the Paris Agreement. The former was rapidly disavowed by the U.S. and finally came into force after a delay of a little more than 7 years while the latter has been ratified by the U.S. and came into force in less than one year. The signature of the Paris Agreement was praised as a world success and its ratification by a qualified majority of countries hailed as the entry in a new era of an unanimous worldwide will to cooperate on the issue of climate change.

1.1.The Predicament of the Paris Agreement

Few days later, the election of Donald Trump and the prospect of U.S. retracting from the Agreement threw a chill on this unanimity. It is argued that the U.S. now only represents some 15% of GHG emissions and that its withdrawal will not affect the implementation of the Agreement and the future stages of the negotiation. Obviously the reality may be very different, inasmuch as even with U.S. participation the progress towards the COP 21 long term target already appears unwarranted.

In the present context, is it possible to save the Paris Agreement and convince the present U.S. Administration to fully cooperate ? In order to answer such a question, it is first necessary to understand what fundamentally may motivate the U.S. decision. What fundamentally was at the source of the rejection –at a near unanimity by the Congress !- of the Kyoto Protocol was the will to put the onus of GHG abatement on developed countries and to free developing countries of any duty, even offering them several advantages (in terms of scientific and industrial transfers, flexible market mechanisms…). This option was understandable and easy to justify : developed countries were the main GHG emitters, and were responsible of most of the stock of GHG in the atmosphere. However it was easily predictable that the balance would rapidly overturn and that emerging and developing countries would become the main emitters. Exonerating them of any obligation would be rapidly unsustainable, at least in the eyes of the American administration.

With the Paris Agreement, there is a similar suspicion of a difference of treatment between countries, not as obvious as in the Kyoto Protocol, but more subtle and subdued.

United Nations and their affiliates in charge of climate change negotiation, mainly UNFCCC and to a lesser extent UNEP, found clever to substitute to the top-down approach of the Kyoto Protocol, based on the objective–however imperfect- criterion of marginal abatement cost set forward by markets of tradable permits, the bottom-up approach of Intended Nationally Determined Contributions. As in the famous Spanish Inn, everyone would bring its stuff, its food more or less secretly cooked at home[2]. No comparison between countries of the intensity of their efforts was provided, not any such tool was implemented or contemplated, and even the plain idea to make comparisons seemed proscribed. The result was the one that could easily be expected : if some countries would play the game and set forth really voluntary commitments, others and probably the majority of them would not, with

[2] Or, according to the skating terminology, the INDC exercise asked to the Parties was more a “freestyle” than a “compulsory”- figure.

a total of commitments far from what would set the world economy on the path of the long term target of limiting temperature warming to 2°C (target reaffirmed in the Agreement and even "irresponsibly" raised to 1.5°C). It was a clear demonstration of the syndrome of the "free rider" that the INDC mechanism was purportedly aimed to prevent.

In its official documents and reports, UNFCCC never considered any possible split between countries, and didn't not even report any breakdown of INDCs in a clear and comparable form (in the same units and with the same definition and content –for instance all GHG emissions or energy-related CO_2 emissions, for the same year of 2030).

UNEP surreptitiously raises a corner of the veil, but in a well-hidden graph and without any comment. From this graph[3] as it will be shown, and the possible comparison of INDCs and BAU or Current Policy scenarios, the difference in ambition comes out clearly[4].

Though exhibiting more detailed data and estimates, the major regional/international organizations such as OECD/IEA and the World Bank are not much more talkative on the topic[5].

But several studies by think-tanks, NGOs and research centers belonging to world Universities or national administrations addressed the issue and all converge to the same conclusion, of a significant difference of ambition in INDCs, more in the favor of developed countries than of big emerging -and to a lesser extent- developing countries. But stressing such a statement is somehow a taboo and there is a sort of conspiracy of silence –of world institutions but also of countries or groups of countries such as the European Union apparently willing to appear very virtuous and generous- had been put on the talks in order to reach unanimity[6].

One must nevertheless be very cautious. Assessments on the ambition of INDCs rest on forecasts of BAU or Current Policy scenarios, which depend on data and mechanisms (as represented in models) that are, in particular concerning emerging and developing countries, very subject to uncertainty or even mere ignorance: The precise measure of effective present emissions (China for instance recently modified substantially its figures); the nature and the working of the tax system that play an important role in energy demand; the technical

[3] As we shall see below, assessing pledges and various scenarios requires the use of several, conceptual and technical tools. In the present case, the tool which is required is the good old ruler of our schoolchildren (and a photocopier in order to print the graphs !)

[4] Clearly lack of clarity was a condition of success of the approval by all countries who signed the agreement "a pig in a poke". But were abused only those who accepted and even wanted to be, because more precise assessments were performed and released by various Research Centers, Universities, Think Tanks and NGOs.

[5] UNFCCC issued as early as October 30, 2015 a synthesis report on the aggregate effect of the INDCs communicated by 147 Parties by 1 October, without disclosing the detail by country, and an update May 2, 2016 concerning 189 Parties, also in the same generality. A naive mind would wonder how it is possible to make a total without having at one's disposal the figures to be summed.

UNEP issued, also before the final adoption of the Paris agreement, the 2015 version of his regular "Emissions Gap Report" devoted to an assessment of INDCs which shed some light of the individual country figures and their comparison to a "Current Policy Trajectory", but only in graphical presentations and without any comment on the relative ambition of the commitments.

IEA issued in Spring 2015 and then long before the start of the negotiation, a "World Energy Outlook Special Report" estimating the INDCs for the main countries and for total World (how without the figures of other countries?) in terms of energy-related CO2 emissions. A "Special Briefing for COP 21" was issued weeks before the adoption of COP 21 but does not display detail by country.

As for OECD and the World Bank, if they have not been aware of comments and recommendations (in particular on the fundamental role of carbon pricing), they didn't indulge up to now in a detailed analysis of the INDCs (and precise proposals concerning the implementation of a world carbon price or a world carbon market)

[6] « Let's kiss together Folleville » of Labiche and Lefranc describes with irony this type of situation of seeming and false unanimity.

parameters such as the energy price-elasticities that affect the importance of emissions' abatement under various policy measures: all these data condition the possible forecasting of emissions' trends and then the comparison with INDCs.

In any case, whether the U.S. withdraws from the Paris Agreement or implements it with very limited zeal, contradictions will burst out when successive COPs will have to switch from the present "soft" and "unsaid" to the future "hard" and "explicit". This clearly requires that the global system of climate change control rest on objective mechanisms, economic in particular, and that carbon pricing and preferably market mechanisms can facilitate equal efforts from all Parties and then convergence towards the path of an energy-sober economy. It is a obviously a question of efficiency, but also an issue of equity because the effort by every stakeholder (country, and in each country each group of citizens) can thus be precisely measured and eventually compensated for by adequate transfers.

This is the target of the present analysis, and the main message it aims to convey. But such a message cannot be only supported by general considerations or purely theoretical arguments. It must be based on precise data and scenarios simulating carbon pricing and markets of tradable permits, in various global or regional configurations, according to the selected horizon and the possibility of enlarging participation from the various world countries.

Developed countries, for which a consistent and relatively reliable information is available, are at the core of such a system: alone and up to 2050 in order to assess its long-term stability and sustainability, then incorporating progressively other countries with different configurations from 2030, which is the reference horizon of the Paris Agreement.

Returning to the issue of carbon pricing and the lack of detailed provision in the Paris agreement –which is also the main topic of the present paper- we can say:

- first than this is not discarded, with a special article devoted to it (Article 6);
- secondly that the mere existence of commitments by the near-totality of countries can be the basis of such a tradable market of permits.

Then, whatever are the flaws of the INDCs process, signing the agreement by any country means two things:

- the first is of course that the given country is committed to its intended contribution;
- the second is that it considers intended contributions of all other countries as reasonable, acceptable in comparison to his own.

Thus the trade of "internationally transferred mitigation outcomes to achieve nationally determined contributions" is precisely the trade of permits based on an allocation among countries defined by these contributions. If the marginal cost in a country for implementing its commitment is (significantly) higher than in another country, such an exchange would be profitable to both of them. Gradually a genuine market of tradable permits would emerge, without intervention of a supra-national institution.

However this appears theoretical as long as such a market is not under control, which means that the amount of exchanges (and the associated financial transfers) is not too big, explosive in some sense. That is why a precise comparative assessment of INDCs is required beforehand, trade being possible –ethical in some sense- only between countries respecting the same rules[7]. Equity is another dimension in the issue, and it is not obvious that INDCs represent a fair allocation between countries. Anyway, if not immediately but rapidly, permits have to be allocated under objective criteria, taking into account feasibility (in particular

[7] Otherwise the system of INDCs would support the charge addressed by many economists that it is a mechanism favoring free-riding by countries, and then unable to target important abatements in the long run.

acceptability by all participants) and equity concerns. This is the approach followed in the present paper, which requires a prior assessment of the INDCs

Designing a market of tradable permits and simulating it, in various configurations, is not out of reach but needs method and use of the appropriate tolls, that exist or can be adapted from existing ones and more generally the economic literature. What is required is care and consistency because, similarly to war as theorized by Napoleon, economics is “an art simple and all of execution”

1.2.Plan of the paper

The topic of this paper is twofold. The first aim is to assess pledges globally –how far are they from the long term 2°C trajectory- and individually -how the main countries/regions are « situated », i.e. “responsible” of the gap. This can be answered only by reference to a detailed trajectory and a « rule » of allocation of emissions abatement, the simplest –though controversial- being the implementation of a uniform world carbon price. It obviously relies on simulations performed with a detailed computable general equilibrium model, and the one used is GEMINI-E3 which has more than 25 years experience, has been continuously implemented for governments (French, Swiss) world organizations (UNEP lately) and thoroughly assessed and compared to other models through academic work, in particular seminars and working groups such as IEW and EMF.

The second issue is precisely a simulation of what could be a world market of tradable permits, topic which is the great absent of COP 21. It is not that various groups and organizations have insufficiently buzzed and lobbied over the need to start as quickly as possible the implementation of such a mechanism in COP 21, but they have been unaware of promoting a feasible and efficient framework, ignoring or underestimating the difficulties of the task and the weight of constraints. Pricing carbon is not exactly pricing an ordinary commodity, it is a taxing issue, for at least two reasons : i) fossil energy consumption –and associated GHG emissions- is pervasive in the economy, the outcome of nearly each private or social activity of each economic agent, and ii) fossil energy is already taxed, with huge differences among countries -and even sometimes subsidized- in every country, and what we call a carbon price or tax is just and additional levy on existing taxation. Implementing a world carbon market is then a exercise in optimal taxation, which can be assessed and framed at a global (and world) level, with the tools and techniques of second-best analysis. It is not, as some seem to think, an exercise in partial equilibrium, that the best specialists and the most sophisticated tools in industrial organizations can resolve. General equilibrium models are the appropriated tools, under the condition that they are able to exhibit a reliable measure and detailed analysis of the welfare cost of climate change policy (and in particular the domestic part, the deadweight loss of taxation –the other part being the gains or losses from terms of trade) and then the marginal abatement cost, i.e. the pure welfare cost of a unitary increase in emissions abatement.

It also presupposes that the model has enough flexibility, concerning commodities’ and factors’ markets, but also aggregate markets and prices, such as the (real) interest rates and the (real) exchange rates. From the very beginning in 1990, GEMINI-E3 has been precisely designed on these principles and simulations of world markets of tradable permits –with the associated theoretical support- have been performed as far as the year 1999.

The paper ends with precise proposals on how to restore, as efficiently and equitably as possible, the 2030 pledges on the trajectory consistent with the long term target of 2°C, which inevitably implies increased commitments by developed, emerging and developing countries, and a proposal (with precise – though tentative- figures) on the implementation of a market of tradable permits amidst developed countries.

2. Assessing INDCs

Assessing INDCs can be performed to reference either on a given prospective situation, a Business as Usual Scenario (what would result if no decision is taken in the concerned area) or a "Current Policy Scenario" (what would result from existing or expected –i.e. announced- policy[8]), or a desirable long-term evolution of the economy, consistent with a specific aim. Concerning climate change, the benchmark is represented by the long term target of limiting average global warming to 2°C above pre-industrial levels[9]. This reference is also defined as a the limit of concentration of GHG in the atmosphere of 450 ppm.

This type of scenario has been overwhelmingly assessed, by all modeling teams around the world and in world and regional institutions such as the World Bank and OECD (jointly with IEA). Results have been synthesized by IPCC, in each Assessment Report and in particular in the most recent one, AR5.

Simulating both a BAU or CPS scenario and a 2°C or 450 ppm trajectory (at least up to 2050) is then a pre-requisite for assessing and comparing the INDCs, and exhibit their relative ambition. Designing and simulating what we can call a "Benchmark Pathway to Long Term Decarbonization" (BPLTD or Benchmark scenario for short) is the topic of the next section.

2.1. A Benchmark Pathway to Long Term Decarbonization

To be significant, the exercise must be sufficiently detailed in terms of regional groups, individualizing the main emitting countries and regions such as USA, China, India, European Union. Represented separately are the main energy and oil exporters, OPEC and Russia, and the remaining countries in to groups according to their level of development (Other Developed Countries and Other Developing Countries, the limit between them being a Gross National Income per capita of 12375 US$ in 2014).

2.1.1. Definition and underlying assumptions

Though a worldwide uniform carbon price faces serious flaws in its implementation and is not anymore a warrant of efficiency nor equity, it is convenient in a first approach for setting the required benchmark and allow, at least approximately, to compare the relative ambitions of INDCs.

This simulation parallels a previous exercise performed for UNEP and is based on exactly the same modeling in GEMINI-E3 and the same assumptions[10]. Differences are in the regional aggregation, which was previously more detailed and in particular split developing and low income countries into three groups instead of a single one[11]. One can then refer to these two reports for the methodology and the main assumptions of the simulation.

[8] The distinction between BAU and Current Policy Scenario is not always obvious. In fact it depends on the reference year.
[9] A 1.5°C warming above pre-industrial levels, retained as the target by the Paris agreement, has not yet been really assessed in the community of modelers and has not been considered up to now by IPCC, which announced that it will be the yardstick for the next Assessment Report.
[10] Re-thinking a Minimum Global Carbon Price, November 2015. This report was a follow-up of a previous report of 2013 for UNEP, Modeling the Impacts of a Minimum Global Carbon Price. In particular the BAU is calibrated on the Copenhagen pledges.
[11] And also individualized the group Canada and Australia among Other Developed Countries

“Benchmark Pathway” is a better denomination than “Minimum Global Carbon Price” because there is no warrant than such a scenario, based on an uniform carbon price, is the most efficient (we can even be sure that it is not, as will be developed in the third section).

Beside the spatial condition of uniform carbon price, the other main similar assumption is its temporal evolution or, equivalently, the evolution of the associated constraint of global abatement overtime. Modeling is restricted to energy-related CO_2 emissions, approach that is followed by most modeling teams and institutions (IEA in particular) who found their simulations on a carbon price[12].

The Benchmark Pathway is based on the average IPCC-AR5 scenario, and in particular on the same level of emissions decrease from the average of period 1990 to 2000 (related to the Kyoto Protocol) and the year 2050, i.e. 63.2%. This brings out a carbon price of 355 US$ of 2007.

From 2040 to 2050 is applied the rule of increase according to the (average international) interest rate of 5.7%. Applying the same rule from 2020 to 2040 would produce a too high carbon price in 2020 (which is only 3 years from now) and a too steep increase from 2020 to 2030, knowing that important technologies such as Carbon Capture and Storage won’t be commercially available at this horizon. Lower figures have been selected and their justification will appear below.

The resulting path of carbon price in the Benchmark scenario is given in the Table below in domestic money (the values for U.S. representing the international price).

Table 1: Evolution of the carbon price in domestic money in the Benchmark scenario

	2020	2030	2040	2050
USA	6	76	203	355
EUR	6	73	189	325
Other Developed Countries	6	72	190	329
RUS	6	86	251	480
CHI	8	110	300	531
IND	8	102	273	470
OPE	7	88	256	480
Other Developing Countries	7	88	245	447

2.1.2. Results of the BAU and Benchmark scenarios

As recalled in Box 1 presenting the GEMINI-E3 model, flexibility of the whole price system is essential in order to simulate accurately the world economy in the long run, and in particular to measure with reliability the welfare cost of policies.

Flexibility refers to the microeconomic –and domestic-prices of goods, services and production factors-, but also to “macroeconomic” prices represented by the rates of interest and the exchange rates. There is no rationale that these macroeconomic prices remain constant in the long run (notably in the BAU scenario) nor that they stay unchanged in any policy scenario, in particular with strong constraints on emissions abatement.

[12] Modeling the marginal abatement cost curves for non-CO_2 emissions is very imprecise and subject to high doubts, while for energy-related CO2 emissions they are narrowly linked to energy demand (and supply) and the corresponding price-elasticities which can be econometrically estimated.

This is important per se, but also and particularly in the present context, when measuring the Marginal Abatement Cost. We refer to the true one, not the underlying carbon price which in several –we can even say most- studies is labeled Marginal Abatement Cost.

Marginal Abatement Cost is the welfare loss for a unit additional abatement of GHG (or CO_2 emissions) and differs, sometimes very significantly, from the carbon price. This divergence (most often the MAC is higher than the carbon price, for reasons that are easy to understand) is at the root of the issue of carbon pricing in a world or regional framework, and this will be developed thoroughly in the second part of the paper.

a) Exchange rates and interest rates

The evolutions of exchange rates (with respect to US$) and of interest rates[13] over the period 2010-2050 are given in Tables 1 and 2. They are represented in appendix Figures 1 and 2.

The diverging evolution of the exchange rate across countries deserves an explanation. Countries experience over the period very different rates of economic growth, resulting in particular of different rates of growth of productivity and/or technical progress. A trade balance between them, without accumulation of commercial surpluses or deficits, requires than the difference in the rates of growth be compensated, partly at least, by adjustments through exchange rates. Appendix Figure 1b clearly shows the correlation across countries/regions represented in the model between exchange rates and growth rates over the whole 2010-2050 period. We can say that everything is like if rates of productivity measured in constant US$ (and not domestic money) were, if not equalized, at least brought closer.

b) CO_2 emissions by country/region

The results concerning the BAU and the Benchmark scenarios are given in the two tables below[14].

They are represented in appendix Figure 3. Benchmark scenario exhibits for all countries/regions a limited inflexion between 2010 and 2020, that is significantly sharpened after 2020 and leads to the aimed global reduction of 63% in 2050 compared to the average of the 1990-2000 period.

Table 2: CO_2 emissions in the BAU scenario (millions tons of CO_2)

	1990	2005	2010	2020	2030	2040	2050
USA	4869	5774	5538	4935	5612	5643	5881
EU28	4068	3988	3926	3459	3664	3875	4139
Other Developed Countries	2396	3333	3531	3282	3453	3633	3876
Russia	2179	1512	1593	1668	1902	2214	2613
China	2278	5444	6927	9027	11126	13226	15325
India	580	1191	1648	2487	3186	3779	4261
OPEC	732	1421	1729	2317	2951	3647	4580
Other Developing Countries	3251	3834	4475	4884	5877	7093	8596
WORLD	**20353**	**26498**	**29367**	**32059**	**37770**	**43110**	**49271**

[13] Of course they represent real values, real exchange rate and real interest rate as the model is (as most CGE models) in real terms.
[14] Let us recall that they are those related to the energy sector, production and demand

Table 3: CO_2 emissions in the Benchmark scenario (millions tons of CO_2)

	1990	2005	2010	2020	2030	2040	2050
USA	4869	5774	5479	4713	3514	2677	2068
EU28	4068	3988	3889	3271	2663	2181	1829
Other Developed Countries	2396	3333	3503	3214	2318	1803	1460
Russia	2179	1512	1575	1449	1038	693	468
China	2278	5444	6856	7782	5590	4133	3123
India	580	1191	1636	1993	1324	1110	942
OPEC	732	1421	1706	2108	1956	1569	1306
Other Developing Countries	3251	3834	4432	4693	4021	3397	2891
WORLD	**20353**	**26498**	**29075**	**29223**	**22423**	**17563**	**14086**

The BAU and Benchmark scenarios obtained with the GEMINI-E3 model can be compared to the corresponding trajectories referred to in IPCC Assessment Report 5, which concerns all GHG. Appendix Figure 4 shows the close parallelism of both trajectories, and this substantiates the assumptions retained on the profile of the carbon price.

On the basis of Year 2010, emissions reduction in 2050 are fairly similar, mainly in the range 40 to 60%. Lowest is for Russia (30%) then USA (38%), and highest for Other Developing Countries (65%) and OPEC(77%). Differences can be explained in part by differences in the carbon tax in domestic money and more significantly by differences in the marginal abatement cost, as will be shown below.

Differences in the carbon price in domestic money, which are shown in Figure 5, reflect the diverging evolutions of the exchange rates. Carbon prices are lower in developed countries, higher in emerging and developing countries as well as Russia and OPEC.

c) Possible biases in the simulations

The BAU and the Benchmark scenarios are based on data and parameters that are uncertain, in particular concerning some countries that play a major role in the global economic and environmental equilibrium, namely China and India.

On the one hand the measure of global emissions is subject to doubts, and in the case of China the figures have been recently modified, and substantially increased.

Another major parameter is the price elasticity of demand for energy, which directly affect the capacity of the given country to decrease consumption and abate CO_2 emissions. The results presented above exhibit for emerging and for most developing countries high levels of abatement in the Benchmark scenario, significantly higher than for developed countries –for the same (international) carbon price.

A simulation has been performed under the assumption of lower price-elasticities of energy demand, more precisely a division by 2. We can assume that in the concerned countries, which are building their development on energy and are not as energy-intensive than developed countries, the substitutability to other factors of production are lower.

The simulation has been operated for India and other Developing Countries and the results are given below.

Table 4: Change in emissions in the case of a lower of price-elasticity of energy[15]

	2020	2020	2030	2030	2040	2040	2050	2050
	BAU	Benchmark	BAU	Benchmark	BAU	Benchmark	BAU	Benchmark
India and Other Developing Countries	8.2%	1.5%	4.5%	7.3%	2.3%	8.2%	1.7%	12.7%
Total World	5.8%	1.5%	4.8%	2.0%	4.2%	2.3%	4.0%	3.4%

d) Welfare cost and components

Simulations with GEMINI-E3 of climate change policies, in the medium to long run, have from the start included a measure of the welfare cost in each country/region and its two components[16], Gains from the Terms of Trade (GTT) and Deadweight Loss (DWL).

Results for the Benchmark scenario are presented below:

Table 5: Gains from Terms of Trade in percentage of Households' Final Consumption

	2020	2030	2040	2050
USA	0.3%	0.5%	0.7%	0.8%
EUR	0.2%	0.7%	1.1%	1.3%
Other developed countries	0.2%	0.5%	0.9%	1.2%
CHI	1.3%	3.2%	5.0%	5.5%
IND	1.4%	3.0%	4.3%	5.1%
RUS	-2.9%	-6.7%	-10.1%	-12.2%
OPE	-5.3%	-12.4%	-20.1%	-23.8%
Developing countries	-0.3%	-0.9%	-1.3%	-1.3%
WORLD	0.0%	0.1%	0.1%	0.1%

Table 6: Deadweight Loss of Taxation in percentage of Households' Final Consumption

	2020	2030	2040	2050
USA	0.1%	-0.7%	-2.5%	-3.6%
EUR	-0.2%	-1.0%	-2.6%	-4.1%
Other developed countries	0.1%	-1.1%	-3.2%	-5.0%
CHI	-0.4%	-3.2%	-12.2%	-14.2%
IND	1.2%	0.4%	-2.5%	-4.2%
RUS	-1.2%	-5.4%	-14.8%	-17.1%
OPE	0.4%	-0.9%	-5.0%	-7.8%
Developing countries	-0.6%	-1.9%	-4.5%	-6.7%
WORLD	-0.1%	-1.3%	-4.2%	-6.1%

[15] Let us note that this change affects the Marginal Abatement Cost as it will be defined below
[16] There is a third component, in the case of trade of permits, which consists of the related receipts or payments .

Table 7: Welfare Cost in percentage of Households' Final Consumption

	2020	2030	2040	2050
USA	0.4%	-0.3%	-1.8%	-2.8%
EUR	0.1%	-0.3%	-1.5%	-2.7%
Other developed countries	0.3%	-0.5%	-2.3%	-3.8%
CHI	1.0%	0.1%	-7.2%	-8.7%
IND	2.6%	3.5%	1.8%	1.0%
RUS	-4.1%	-12.1%	-24.8%	-29.3%
OPE	-4.9%	-13.3%	-25.1%	-31.7%
Developing countries	-0.9%	-2.8%	-5.8%	-8.0%
WORLD	0.0%	-1.2%	-4.2%	-6.1%

The welfare cost is particularly heavy for Russia and OPEC and this can be easily understood: they cumulate high losses from terms of trade[17], resulting from their situation of fossil energy exporters, mainly oil and gas. The DWL is high not necessarily in the absolute, but in relative terms because fossil energy represents a high share in total economy.

On the opposite some countries benefit from high gains in the terms of trade, it is in particular the case of India and China. These results are important because they condition the measurement of the marginal abatement cost and then the possible development or implementation of a world or regional carbon market.

2.1.3. Comparison to other estimates

Results of the BAU and the Benchmark scenarios can be compared to other simulations. Detailed forecasts by country come mainly from administrations, such as the American Department of energy (EIA) and from international or regional organizations such as the International Energy Agency. Some major energy groups, such as EXXONMOBIL, also issue forecasts but their precise statute is not always very clear (Business as Usual or incorporation targets of emissions abatement).

Business as Usual or Current Policies scenarios

	IEA Current Policies Scenario (2013)				IEO 2016			
	2010	**2020**	**2030**	**2035**	**2010**	**2020**	**2030**	**2040**
United States	5340	5304	5201	5196	5458	5499	5514	5549
EU28	3609	3438	3340	3341				
China	7214	10251	11968	12727	7383	9861	10636	11051
India	1635	2579	3779	4654	1624	2143	2693	3732
Russia	1624	1795	1992	2119	1665	1814	1897	1864
Total World	30190	36281	41177	44090	30741	35631	39103	43217

Projections by IEA and EIA are fairly close, and also close to the BAU scenario calibrated with GEMINI-E3 and presented in Table 2.

[17] Note that GTT measures the pure price effect in international trade, and not any volume effect. As domestic markets are supposed totally flexible, a decrease in demand and then production in some sectors is compensated by an increase of production in some other sectors, in reason of the mobility of factors in the economy.

2°C or 450 ppm scenarios

	IEA 450 Scenario (2013)				Benchmark GEMINI-E3			
	2010	**2020**	**2030**	**2035**	**2010**	**2020**	**2030**	**2040**
United States	5340	4850	2876	2222	5479	4713	3514	2677
EU28	3609	2955	2105	1781	3889	3271	2663	2181
China	7214	8419	6205	4948	6856	7782	5590	4133
India	1635	2125	2113	2238	1636	1993	1324	1110
Russia	1624	1583	1273	1143	1575	1449	1038	693
Total World	30190	31449	24861	22055	29075	29223	22423	17563

Only up to our knowledge IEA issues detailed scenarios by country consistent with the long term target of limiting the temperature warming to 2°C (or GHG concentration to 450 ppm). As previously, the scenario yields figures which are globally close to the Benchmark scenario but with large differences by country, in particular Russia and India. This highlights the previous observation of a great uncertainty for these countries, in particular when a high carbon price is implemented.

Intermediate scenarios, from IEA and from EXXONMOBIL, as presented below, are interesting because it will be considered later transition scenarios, based on the assumption of commitments higher than INDCs, from both developed and developing countries.

Intermediate scenarios

	IEA New Policies Scenario (2013)				EXXONMOBIL			
	2010	**2020**	**2030**	**2035**	**2010**	**2020**	**2030**	**2040**
United States	5340	5178	4625	4328	5500	5221	4718	4200
EU28	3609	3259	2878	2717				
China	7214	9532	10108	10224	7400	9489	9891	9300
India	1635	2415	3247	3830	1700	2504	3201	3900
Russia	1624	1726	1816	1871				
Total World	30190	34560	36197	37037	30700	34461	36133	36400

On the whole, our results which are internally consistent are not in contradiction with other estimates though the latter are not based on a definite carbon price. They can then serve as a serious basis for the assessment of INDCs and further to the simulation of carbon markets in various configurations, either regional or global.

2.2. Assessment of INDCs

The BAU and Benchmark scenarios set the stage for assessing the Intended Nationally Determined Contributions, and in particular their comparative ambition. The exercise has been performed, mostly partially, by world or regional bodies such as IEA, by research centers and academic institutions, and by think tanks and NGOs.

The issue is particularly frustrating because institutions in charge of the climate negotiation have done nothing or nearly nothing to shed light on the INDCs submitted by the near-totality of world countries. Estimates in terms of emissions, in various definitions and contents –all GHG, all CO_2 emissions, energy-related CO_2 emissions, resulting in 2030 from INDCs have apparently not been performed in detail, at least not issued. Only global figures, representing world total, have been issued by UNFCCC.

Estimates for some countries or group of countries have been performed by UNEP and IEA and issued through graphical representations that don't facilitate their utilization. In the same unwillingness to initiate a genuine debate, the related publications abstain to emit any judgment or to give clues for comparison of ambitions.

From a thorough study of the literature, it is possible to find more detailed assessments, which usually converge towards the same results and judgments. We will review the main publications and report their figures.

In particular an exhaustive assessment has been performed on the 189 countries which have submitted INDCs by a team in Ecole Polytechnique Fédérale de Lausanne (EPFL), led by Marc Vielle[18], It will serve as the base for the present assessment of INDCs, and to a more global comparison to other assessments mentioned above[19].

2.2.1 Global and detailed assessments from EPFL figures

Figures from EPFL have been aggregated according to the country/region nomenclature of the present work. They are presented in the Table below, for all GHG and for energy-related CO_2 emissions, the latter being compared to the BAU and Benchmark scenarios.

Table 8: Unconditional and conditional INDCs estimated by EPFL and comparison to BAU and Benchmark scenarios

	Unconditional GHG	Conditional GHG	Unconditional energy-related CO2	Conditional energy-related CO3	BAU scenario	Benchmark scenario
	(Millions tons of CO2eq)		(Millions tons of CO2)		(Millions tons of CO2)	
USA	3,918	3,794	3,604	3,490	5,612	3,514
EU28	3,230	3,230	2,414	2,414	3,664	2,663
Other Developed Countries	3,806	3,658	2,711	2,653	3,453	2,318
China	16,172	14,452	11,172	9,776	11,126	5,590
India	6,702	6,502	3,439	3,336	3,186	1,324
Russia	2,649	2,473	1,622	1,514	1,902	1,038
OPEC	3,830	3,453	2,420	2,300	2,951	1,956
Other Developing Countries	16,845	15,768	5,237	4,922	5,877	4,021
WORLD	57,154	53,330	32,621	30,404	37,770	22,423

At the world level estimates by EPFL show that INDCs, unconditional and conditional, are well below BAU scenario but significantly above Benchmark scenario. On

[18] Marc Vielle has been my co-author in the near totality of my work on climate change, through in particular the GEMINI-E3 model we built and continue to manage together. The paper on INDCs has not yet been published but Marc Vielle has been kind enough to communicate it to me.
[19] The value of INDC retained for the USA results from the interpolation between the 2025 figure committed to by the Government and the 2950 target recalled in the document (80% reduction compared to 2005).
The same assumption is taken by other analysts and research teams, in particular PBL

the whole, it appears that *implementation of INDCs in 2030 would perform at best half of the way to joining the long term 2°C trajectory*. This is consistent with nearly all other assessments, as it will be shown below.

By country or group of countries, estimates concerning energy-related CO_2 emissions are represented in the appendix Figure 5, and compared to past evolutions and BAU and Benchmark scenarios.

From Table 8 and Figure 5, it appears that for developed countries INDCs are much below BAU and close to Benchmark scenario. This is particularly the case of USA and EU28, not exactly for other developed countries for which there is a gap of around 15%.

Russia and OPEC are under BAU but above Benchmark scenario, and it is the same for Other Developing Countries.

The assessment is totally different for China and India, whose INDCs are close or above BAU scenario and significantly above Benchmark scenario. The combined excess of these two countries explains most of the world gap.

2.2.2 Other global assessments

The first official assessment was issued by UNFCCC, then reviewed in a second report issued May 2, 2016.

Table 9: UNFCCC estimates for total world (All GHG)
(second estimate issued May 2, 2016)

	Total range	Unconditional INDC	Conditional INDC	Current Policy Trajectory	Decrease from CPT	AR5 scenario	Gap wrt AR5
2030							
median	56.2	57.9	55.5	59.5	3.3	42.7	15.2
range	(52-59.3)	(54.4-59.3)	(52-57)		(0.3-8.3)	(38.3-43.6)	(10.1-21.1)
2025							
median	55	55.6	54.1	57.8	2.8	44.3	8.7
range	(51.4-57.3)	(53.1 57.3)	(51.4 55.8)		(0.0-6.0)	(38.2-46.6)	(4.5-13.3)

UNEP released its own estimate in the Gap Report 2015, reproduced below, and fairly close to the previous one.

2030 emissions gap assessment estimates				
Scenario	Global total emissions (range)	Emission reduction compared to baseline (range)	Emission reduction compared to current policy trajectory (range)	Remaining emission reduction to stay within 2°C limit (range)
	$GtCO_2e$	*$GtCO_2e$*	*$GtCO_2e$*	*$GtCO_2e$*
Baseline	65 (60-70)	n/a	n/a	23 (18-28)
Current policy trajectory	60 (58-62)	5 (3-7)	n/a	18 (16-20)
Unconditional INDCs	56 (54-59)	9 (6-11)	4 (1-6)	14 (12-17)
Conditional INDCs [a]	54 (52-57)	11 (8-13)	6 (3-8)	12 (10-15)
2°C pathways	42 (31-44)	23 (21-34)	18 (16-29)	0 (0)

[a] Assumes full implementation of both unconditional and conditional INDCs.

Estimates were also performed and issued by several research centers and think tanks. They are summarized in two publications: one by Partnership on Sustainable Low Carbon Transport (PSLCT) dated November 24, 2015; the other by Climate Policy Observer, dated January 6, 2016.

Table 10: Assessment of Mitigation Ambition INDCs by PSLCT

	Emissions Gap with 2°C	Decrease from BAU	Temperature increase by 2100
Rodney Boyd et al.	15-17 billion tons dy 2030		
PBL	15-16 billion tons dy 2030	3.5-4 billion tons dy 2030	2.7°C
Climate Action Tracker	11-13 billion tons dy 2030		2.7°C
UNFCCC	15 billion tons dy 2030		
UNEP	12 billion tons dy 2030		3-4°C
Climate Scoreboard	78 billion tons (in 2100)		3.5°C
JRC Policy Brief	about 10 billion tons dy 2030		
Danish energy Agency	12 billion tons dy 2030		

Table 11: Comparison of estimates of global emission gap and global temperature increase according to different assessments (Climate Policy Observer)

	UNFCCC	**UNEP**	**CAT**	**Climate Interactive**	IEA	**Average value**
Global emission gap wrt 2°C target by 2030 (average in CO2 eq)	15 Gt	14 Gt	16 Gt	14 Gt	N/A	14.75 Gt
Global temperature	N/A	3.5° C	2.7° C	3.5° C	2.6° C	3.1° C

On the whole, these various assessments of INDCs show that the world decrease of emissions from the baseline (BAU or Current Policy Scenario, with differences from the two) is fairly limited and represents a small share, from a third to a quarter and even less, of what is needed for reaching in 2030 the long term 2°C trajectory. This confirms the assessment obtained from EPFL estimates of INDCs.

These studies also give an estimate of the associated increase in long term global warming: from 2.6° (IEA) to 3.5° (UNEP and Climate Scoreboard) with an average value of 3.1°.

2.2.3 Other assessments for selected countries

The main were issued by UNEP in the GAP Report 2015, reporting the estimations of several institutes and research teams[20] (including the PBL Netherlands Environmental Assessment Agency) and by PBL in a separate and later publication.

The UNEP publication yields comparisons of INDCs to a baseline (Current Policy Scenario) but not to a 2°C trajectory, while the separate publication by PBL reports estimates (obtained with the model LIMITS). They are presented below.

[20] As mentioned previously, the figures from UNEP are not given « in clear » by the publication but appear on several graphs from which they can be (approximately) measured with a ruler. It is obviously an archaic way of publishing data but this is not totally innocent !

Table 12: Assessment of UNEP for selected countries[21]
(All GHG, in millions tons of CO_2 eq)

	Baseline	Current policy	Unconditional Pledges	Condditional Pledges	2°C limit	pm: 2020 Cancun Pledges
USA		6000	4500			5200
EUR		3700	2700			3600
CHI		14400	14500			13500
IND		4700	5400	4550		3700
RUS		2000	2400			1950
WORLD	65000	60000	56000	54000	42000	

Table 13: Assessment of PBL for selected countries[22]
(All GHG including LULUCF, in millions tons of CO_2 eq)

	Unconditional (or upper estimate)	Conditional (or lower estimate)	BAU	Current Policy Scenario	Least cost 2°C scenario Median	Least cost 2°C scenario Range
US	4121	3992	6447	5572	4000	(2200-4000)
EU28	3376	3376	4992	3992	3250	(2750-3600)
China	13957	13957	15914	14646	9000	(8000-11600)
India	4739	4168	5374	4739	3400	(2400-3800)
Russia	2523	2354	2342	2174		
World	56235	53990	65032	59339	42000	

These assessments converge with the one resulting from EPFL estimates of INDCs and BAU and Benchmark scenarios simulated with GEMINI-E3, i.e.:

- for developed countries (here only USA and EU28), the INDCs are in line with the long-term 2°C trajectory;
- this is not the case for China and India, which exhibit INDCs close to baseline or Current Policy scenario and then a huge gap with respect to the long term 2°C trajectory that can be expected from these countries;
- other countries/regions are in an intermediate situation.

2.2.4 An assessment through carbon prices

Assessments presented above refer to physical quantities, emissions committed to in INDCs compared to trend and emissions inscribing the world economy on a virtuous environmental path.

A comparative assessment can also be performed through carbon prices, i.e. the carbon prices underlying the INDCs, those which should be uniformly implemented in each country in order to reach the commitment.

[21] The unconditional pledge reported for EUR (EU28) is obviously wrong (a figure of 3100 would be more appropriate

[22] The US INDC target for 2025 is extrapolated to 2030 by assuming a linear pathway to the national long-term target (83% reduction below 2005 levels by 2050)

The task has been performed with GEMINI-E3, and by other teams and/or with other models, in particular RITE, WITCH, DNE21+, and Vandyck et al for the European Commission[23]. They are presented in the Table below.

Table 14: various estimates of the carbon price underlying INDCs

	GEMINI-E3	WITCH (moyenne 2025-2030)	DNE21+	RITE	RFF	European Commission (Vandyck et al)	
USA	76.7	96	92	85	64	53	(reached in 2025)
EUR	92.6	118	149	210	166	53	(aver. ETS & non-ETS)
Other Developed Countries	56.9						
CHI	7.6	20	1	0	5	29	
IND	-6.3	0	0	0		0	
RUS	14.2		3	4	3	0	
OPE	48.5						
Other Developing Countries	40.4						

Once again, the high values obtained for developed countries and the low (even null or negative) for China and India show the difference in ambition of the INDCs. OPEC and Other Developing Countries exhibit intermediate values, which show a lesser ambition than developed countries but a significantly higher one than China and India.

That INDCs in their present level are not consistent –and from far- with the long term target of limiting temperature warming to 2°C (and a fortiori for “well under 2°C”) set in the Paris Agreement is overwhelmingly acknowledged (the precise gap varying from one assessment to the other). More ambitious commitments have to be taken, by developed countries but as we will see the margin is fairly thin for them, mostly then by emerging countries such as China and India because they play a crucial and appear to have still substantial flexibility in mastering the growth of their emissions.

2.2.5 Summing up: towards a transition 2030 scenario

The Paris Agreement –which is now ratified by a qualified majority of Parties and then enforced- clearly is in its present form inapt to drive the world economy close to the long term virtuous trajectory allowing to fight climate change. It is not very responsible to expect most –even some- countries to significantly increase their commitments in the near to medium term because there is strictly no incentive for each of them to do that, i.e. to renounce to the comfort of free-riding. Near-unanimity, sought and obtained by UNFCCC through the refusal to point in detail to the reality of commitments to abate by the various countries and their respective ambition, cannot go on this way. Responsibilities must be clearly pointed at and addressed. This would result from a world carbon market mechanism, prompting all countries to engage in similar endeavor.

The need for China, India and some other developing countries to engage in more drastic abatement appears in this crude fact that, *even if developed countries reach zero net abatement in 2030, the total of INDCs of other countries would this year surpass (in the case of unconditional pledges) and equal (in the case of conditional pledges) the level corresponding to the 2°C scenario*. China of course, with its emissions forecast in 2030, plays the major role in this disruption and it is not possible to contemplate a favorable evolution

[23] For the latter, the results deviate from other estimates and the methodology unclear (see “A global Stocktake of the Paris Pledge, 2016”

without a significantly higher contribution from this country (and in a lesser extent, from India).

That convergence to the long term path as soon as 2030 seem now totally out of reach needs to consider transition scenarios, somehow intermediate between present INDCs and the desired figure. Such a scenario would imply that China and India reach the peak of their emissions between 2020 and 2030, i.e. that they don't surpass in 2030 their 2020 level.

An alternative scenario would be an accompanying effort of developed countries, increasing their commitments of let's say 15%. The result would be globally close to the "transition scenario" presented by IEA, though on very different foundations. In the prospect of carbon pricing, involving as many countries as possible (eventually all), these commitments could constitute the base for allocating tradable permits between countries. This scheme will be simulated in the next section.

3. Designing a world carbon price mechanism from the Paris Agreement

Considering the large heterogeneity in the INDCs and their ambition, and in particular the very limited –not to say the lack of- commitment by major emitters like China and India, designing a carbon price mechanism appears as a true challenge. Moreover among proponents of this kind of mechanism, economists in particular but also the industry at large and world and regional institution such as the World Bank and OECD, there is a debate between defenders of a uniform carbon price that would be imposed on –or agreed upon by- all or a limited group of voluntary countries and advocates of a cap and trade system.

The debate is now more than 20 years old, starting with the Kyoto Protocol negotiation, and up to now no precise –and simulated and/or quantified- as been proposed. It would be fastidious to list all the "lobbies" that formed in defense of this proposal, the academic publications and seminars devoted to the topic and the claims of support from various institutions and VIPs. We can mock this sterile stir similarly as De Gaulle said about the proposal of a federal Europe: "Of *course*, one *can jump* on one's *chair like* a young goat, and repeat *Carbon price*! *Carbon price*! *Carbon price*! *But* this leads to nowhere and signifies *nothing* "

3.1. The Issue and Debates of Carbon Pricing

If the idea of taxing an externality is sensible and as old as its awareness by economists (Pigou in particular), in particular concerning a local pollution, with climate change and the need to tame GHG emissions we enter in a new and very different framework.

On the one hand the pollution is worldwide and pervasive in all human activities, either production or consumption. On the second hand, and this is more challenging, what we designate as a carbon price is in fact a new- explicit or implicit- tax that comes on top of already and sometimes very heavy taxes on fossil energy and possibly other GHG. *Then the effective carbon price is the sum of existing taxes and the new levy*[24].

This has long been acknowledged by economists. David Victor writes in his analysis of the Kyoto Protocol: "The third objection, however, may be fatal to the carbon tax approach. Monitoring and enforcement are extremely difficult…In practice, it would be

[24] In fact the issue is much more complex because the existing taxation on other commodities and/or factors of production weight –positively or negatively- on the effective global levy on fossil fuels. For instance subsidizing capital in coal or oil industry would alleviate the effective levy on the fuels.

extremely difficult to estimate the practical effect of the tax, which is what matters. For example, countries could offset a tax on emissions with less visible compensatory policies that offer loopholes for energy-intensive and export-oriented firms that would be most adversely affected by the new carbon tax. The resulting goulash of prior distortions, new taxes, and political patches could harm the economy and also undermine the goal of making countries internalize the full cost of their greenhouse gas emissions[25]".

William Nordhaus and Richard Cooper argue that the monitory issue can be overcome. The latter writes: "Monitoring the imposition of a common carbon tax would be easy. The tax's enforcement would be more difficult to monitor, but all important countries except Cuba and North Korea hold annual consultations with the International Monetary Fund on their macroeconomic policies, including the overall level and composition of their tax revenues. The IMF could provide reports to the monitoring agent of the treaty governing greenhouse gas emissions. Such reports could be supplemented by international inspection both of the major taxpayers, such as electric utilities, and the tax agencies of participating countries.[26]

William Nordhaus, in his communication "After Kyoto" presented to the International Economic Workshop in 2001 supports this view and performs a calculation on the differential between Europe and the Unites States: "An important issue involves the question of how to count initial carbon taxes. Some countries — particularly those in Europe — would claim that they already have high carbon taxes because of high taxes on gasoline. They would argue for taking existing taxes into account before requiring them to undergo further obligations. While this looks like a subterfuge, it is actually correct and easily seen to be so in the price framework. Therefore, the first step, and one absent from analysis of the Kyoto Protocol, would be a calculation of existing equivalent carbon taxes and subsidies. Our data suggest that, even without its CO_2 taxes, Europe is taxing carbon at a rate of approximately $100 per ton carbon more than the United States.[27] Given that disparity, it would make no economic sense to ask Europe to add, say, another $20 on top of its existing taxes with an equivalent expectation for the U.S. Moreover, the fact that Europe might be overtaxing carbon today would never come up in the quantity-type approach. So perhaps on reconsideration this turns from disadvantage to advantage!"

But of course what can be contemplated for a limited group of developed countries, which have at their disposal sophisticated economic and fiscal statistics and clever economists is out of reach for most other countries[28].

Then the idea of a world uniform carbon price, even with some adjustments, is far from warranting a leveled playing field among countries and a way of allocating efficiently abatements among countries.

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[25] David Victor, *The Collapse of the Kyoto Protocol, op. cit.*, p. 86.

[26] Richard Cooper, "*Toward a Real Treaty on Global Warming*", Foreign Affairs, vol. 77, no. 2, 1998, pp. 66-79

[27] See William Nordhaus and Joseph Boyer, *Warming the World: Economic Models of Global Warming*, MIT Press, 2000, and the associated data sheets.

[28] A recent report of OECD, mobilizing a vast cohort of skilled economists and analysts, focuses on what is labeled "Effective Carbon Price" (ECP) that summs all the taxes bearing on fossil energy: emission permit price, carbon tax and other specific taxes on energy use. It does not include the spill-over effect of other taxes (or subsidies) affecting the production cost or the user cost or energy. It is difficult to think that the resulting estimates –as interesting as they are-, can set the basis on an international agreement on the implementation of a carbon market.

It allows to avoid the implementation of a new world market with the associated transfer payments between countries as does a cap and trade system but does not resolve the problem of equity. Transfers are not visible but nevertheless behind the scene because what is the equity between countries that will support a relatively low welfare cost (mostly rich countries) and those supporting a high burden (mostly poor countries)?

In the recent and still pending debate between carbon price and cap and trade, Jean Tirole[29] clearly makes the choice of the latter in reason of its easier straightforwardness (measure country' emissions instead of assess the whole tax system) and proposes to:

- Fix a strategy on emissions that scientists deem consistent with the 2°C objective, and agree on the principle of this worldwide objective;
- Agree that the permits will be allocated to participating countries in line with the aggregate cap;
- Agree on a trading mechanism in which countries will have to match pollution and permits at the end of the year to avoid creating unfulfilled climactic debt.

In fact the main criticism against cap and trade is the way permits of pollution rights are allocated among countries: it would be arbitrary and a complex multi-dimension problem while a uniform carbon price is a one-dimension problem. But there are two answers:

- what is looked for in allocating pollution rights is not a set of figures decided in a bureau of the United Nations but a rule, *based on equity in the long run and possibility of implementation in the short to medium run*;
- in the short run, allocation of permits can be based on INDCs because there is a universal agreement on them (in signing and then ratifying each country commits to his intended contribution and consider that contributions by other countries are acceptable and "fair" by exhibiting approximately the same degree of ambition).

As we have seen in the previous section, this is not the case and anyway new NDCs expected from countries have to be significantly raised in ambition if the target of limiting long term temperature warming to 2°C is taken seriously.

3.2. What the theory says

Carbon pricing is obviously an issue of taxation, of "optimal taxation" is one wants to determine the best solutions, and then clearly resorts to second best analysis and methodology.

Second best analysis, at it was initiated and developed by Marcel Boiteux in his seminal paper on monopolies constrained to a balanced budget, has been applied in the framework of a closed economy[30]. The present issue is that of open countries, exchanging goods and services, and each faced with a constraint on carbon emissions. It presents an interest –and a challenge- if the countries can also trade emissions allowances, and then exchange in a new market in parallel to traditional markets.

Concerning emissions, each country has two decisions to take: implement a domestic policy, supposedly based on a domestic carbon price, and take a position in the carbon market, i.e. decide of the quantity of permits to buy or to sale. Globally, the country must

[29] In « Carbon Pricing for a Climate Coalition », TSE and IAST, June 10, 2016
[30] See Box 2 for an historical review of second-best analysis

satisfy its global carbon emissions constraint, that domestic emissions net of purchases be equal to its allowances or commitment.

At the theoretical level and also technically, the issue is to design and characterize the equilibrium between second-best economies, i.e. economies governed –mainly in their fiscal policy- under the principles of second-best management. This problem has been addressed and simulations have been implemented on the Kyoto Protocol in two papers presented at the International Energy Workshop held in Paris in 1999.

As it can be expected, the result depends heavily on the fiscal policies and more precisely on the constraints existing or put on the fiscal system. A simple case is absence of any a priori constraint on the fiscal system, and in particular the possibility of taxing profits of private firms at any rate. It is the model developed by Diamond & Mirrlees in their seminal papers of 1971.

In this case, the results concerning the working of a market of tradable permits are identical to the first best situation, and this arises from the property of production efficiency (and correlatively a unitary value of the marginal cost of public funds). In particular all countries implement domestically the same carbon price which is the price of the world market.

Obviously the reality is far from this scheme and there are constraints on the tax system. The tax rate on private profits is not equal to 100%, level at which it accrues in the D&M model. Then the property of production efficiency does not hold anymore and the marginal cost of public fund is different from 1, most of the times higher.

Two questions are raised in this framework: how to determine the demand for international permits, i.e. what is its shadow price and is such an equilibrium Pareto-efficient.

To the first question, the answer is that each country must adjust its marginal abatement cost to the world market price of permits. Marginal abatement cost must be understood as the welfare loss of an additional abatement divided by the marginal cost of public funds (MCPF).

This can be easily understood: a purchase of permits is profitable to the country if the price does not exceed its domestic “cost”, measured in terms of welfare. The deflation by the MCPF results from the fact that taxes and levies are “public money” while marginal abatement cost (the loss for consumers) is “private money”.

Pareto efficiency is not generally warranted, only in special cases (for instance when the production function of the economy is separable with respect to labor and pollution). In a second-best world, where often counter-intuitive results are obtained- it could not be expected to get more general results.

But the issue is a practical one, i.e. whether a market of tradable permits increase the welfare of each country. We can have doubts though we can expect that there is a gain in aggregate welfare and that it would be possible to compensate (effectively) losers in order to make all countries winners. And this can be checked on simulations of a real situation.

3.3. Estimation of Marginal Abatement Costs

This has been performed along the Benchmark scenario. There are three steps in the task.

The first is to estimate the welfare cost of an additional abatement for each country and each period. Was is directly measured is the welfare loss, which is the sum of the marginal gain of terms of trade and the marginal Deadweight Loss of Taxation, which represents the searched quantity. The second step is to estimate the Marginal Cost of Public Funds. The approach is the same: difference between the welfare loss of a unit increase in global taxation and the associated change in the terms of trade. The last step, in order to make MAC comparable and the basis for permits trading is to deflate then from the exchange rate.

The table below gives the (average on the total period) values of the Marginal Cost of Public Funds by country/region.

Table 15: Marginal Cost of Public Funds by country/region (average 2010-2050)

USA	EUR	Other Developed Countries	CHI	IND	RUS	OPE	Other Developing Countries
1.066	1.216	1.130	1.031	1.019	1.202	1.161	1.101

They differ significantly and there is two possible explanations of the differences. The first is the efficiency of the fiscal system, but this is not easily quantifiable. The second is the weight of taxes on the economy, its share on the total GDP. Part of the taxes correspond to redistribution between economic agents, households in particular and should not weight on the effective (or net) fiscal pressure. Public outlays, and in particular public consumption, appears to have more leverage on the MCPF. Appendix Figure 7, which represents the correlation among countries between MCPF and share of public outlays in GDP corroborates this conjecture.

Resulting estimates of the Marginal Abatement Cost in constant US$ are given in the Table below.

Table 16: Marginal Abatement Cost by country/region and by year in constant US$

	2020	2030	2040	2050
USA	6	89	359	411
EUR	14	154	454	567
Other Developed Countries	10	112	391	476
CHI	7	75	441	653
IND	8	83	464	511
RUS	10	76	378	379
OPE	0	50	182	270
Other Developing Countries	7	80	259	340

The Figure clearly shows that:

- except OPEC, all countries have a MAC higher than the carbon price (which, in the Benchmark scenario, is uniform);
- there are also large differences between countries.

This reflects the effect of other existing taxes which weigh, together with the carbon tax, on the “effective carbon price”. In a very recently released report, OECD publish estimates of this quantity, more representative of the fiscal charge on energy, mainly fossil energies[31]. The results are presented below and it can be easily checked that there is in 2030 a

[31] The OECD report does not take into account the incidence of other taxes (and subsidies), in particular on capital, which also weight on the effective carbon price.

correlation between these measured effective carbon taxes and the estimated marginal abatement costs (low for USA, OPEC and Russia, rather high for European countries, intermediate for China and India).

Table 17: Average effective carbon rates (Year 2012 to 2014 according to countries, in EUR/tCO_2 and including emissions from biomass

	Including CO2 emissions from biomass	
	All non-road energy	Road energy
USA	0.8	18.4
France	9.7	179.9
Germany	23.4	219.5
UK	14.3	280.6
Italy	20.4	242.7
Netherlands	54.6	224.8
China	1.6	42.0
India	1.0	29.1
Russia	0	0.1
Mexico	0.2	8.1

3.4. Which mechanism for trading emissions rights and which allocation of permits

Theory as well as numerical assessments, such as the one presented above, totally discredits any mechanism based on a uniform carbon price that would be "imposed" or even agreed upon by participating countries, all world countries or a limited set constituting a club.

Because: on the one hand there would be large differences in the effective carbon price, due to other taxes weighting on energy and then it would not be a warrant of efficient allocation of abatements; on the other hand it would be easy for countries to cheat and alleviate the effect of the (new) carbon tax by decreasing other taxes and/or increasing subsidies (phenomenon known as "cushioning").

Measuring the "effective carbon price" as is performed by OECD would not really be an answer to the problem and would imply a bureaucratic solution, an office in the United Nations instructing each country which carbon price to implement for itself.

Only a decentralized solution can be acceptable to all countries, each of them being given the incentive to determine its own "effective carbon price" in the form of its marginal abatement cost. Theory, as developed and presented above, clearly shows that it is the self-interest of each of them to determine this cost (along the lines defined above) and to base on it its demand or supply of permits. Such a market of tradable permits would then exhibit an international carbon price to which each country would adjust, then equalizing all marginal abatement costs across countries (but of course not the domestic carbon price, that would vary from one country to another, due to the differences in other energy taxes).

It is possible to go a step further in decentralization. In the Paris agreement –and more generally in the climate change negotiation-, it is countries who take commitments and are held responsible of respecting them. However it would facilitate the trade, at least be helpful, if firms and maybe some important economic agents could operate directly in the market. But there is the obstacle of the gap between the domestic and the international carbon price. It could nevertheless be overcome by setting a corrective tax-or a restitution- to concerned operators, as will be shown below in the case of a market limited to developed countries.

Any market can only work if the rights are clearly defined[32]. In the present case, the rights are the emissions allowances allocated to each country, and consistent with the global target for the given year.

This is of course the big issue of a cap and trade system, and the reason why it is discarded by several economists and may also be rejected by some countries.

An easy answer, evocated previously, is to take as allowances the commitments of countries, as defined by their INDCs. But this wouldn't allow to go very far in the analysis, because at it was developed in the first part of the paper:

- the sum of commitments is very far from was would be requested to join the 2°C trajectory (and a fortiori a 1.5°C trajectory presented as the long term target in the Paris agreement);
- the degree of ambition is very different from one country to the other, close to zero for some countries like China and India that are big emitters and the prospective major world emitters.

On the contrary developed countries, USA, European Union and Other Developed Countries exhibit the right (and similar from one to the other) level of ambition and designing a tradable carbon market for such a club would be sensible. The underlying idea is even that such a market could start as soon as 2020, allow to check its relevance, and yield factual –not simulated- information on the effective behavior of countries, and their net demand of permits (and then their level of abatement).

The simulation is performed on the whole period 2020-2050 in order to check the stability of the mechanism (in particular that it does not skid into unmanageable levels of traded permits and correlatively financial transfers). Over such a period, the allocation of allowances cannot be based on INDCs but on an objective rule that could later be extended to other countries.

3.5. A market of tradable permits limited to developed countries

As it is a partial market, we have to determine the total allowance of permits. The obvious assumption is take the total of emissions for these countries in the Benchmark scenario (cf Table 3).

As for the allocation between countries/regions there are several "objective" rules, and in particular grand-fathering and proportionality to population, which have each their worth.

Grand-fathering allows to depart minimally from the existing situation. Its merit is to limit the potential volume of trade between. It has no other virtue, and in particular on equity concerns.

On the opposite, proportionality to population is the archetype of equity, treating all humans as equals and endowed of the same rights on the environment[33]. But proportionality applied in the short run may be disruptive in generating a too important volume of trade and then too high financial transfers. The rationality is then to apply this rule on the long term.

Several combinations between the two rules have been assessed, and the one which appears the most reasonable is to share the total allowance with a split 95%-5% in 2020 linearly converging towards 20%-80% in 2050 (i.e. complete proportionality to population

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[32] For an usual commodity, it is the right to bring to the market the totality or a part of the production of a given country or a producer, and the right to purchase the totality or a part of the quantity brought to the market.

[33] It does not compensate from unequal situations due to exposure to climate warming, and the cost of adaptation. But the solidarity in this aspect rest on special mechanisms, independent of the carbon trade system.

around 2060). The reference year for levels of population and of effective emissions is taken as 2010.

The system is then represented by a same allowance per capita and a same proportion of 2010 emissions allocated to the countries, as given in the Table 18 below:

Table 18: allowances per capita and proportional to 2010 emissions

	2020	2030	2040	2050
Ton per 2010 inhabitant	0.49	2.22	3.20	3.74
Percent of 2010 emissions	81.9%	45.8%	23.1%	8.2%

Applying the above-defined rule leads to the allocation of allowances presented in Table 19 below:

Table 19: Allowances in the carbon market of developed countries

	2020	2030	2040	2050
Share "population"				
USA	152	690	992	1160
EUR28	247	1123	1615	1889
Other developed Countries	161	735	1057	1236
Share "grandfathering"				
USA	4534	2534	1278	457
EUR28	3214	1796	906	324
Other developed Countries	2890	1615	814	291
Total allowances				
USA	4685	3224	2270	1617
EUR28	3461	2920	2521	2212
Other developed Countries	3052	2350	1871	1527
Total Developed Countries	11198	8494	6662	5356

Simulating the carbon market of developed countries yields the following results concerning the market equilibrium and the domestic carbon prices:

Table 20: market equilibrium and domestic carbon prices (in constant US$)

	2020	2030	2040	2050
Developed world market carbon price	9.8	110	393	472
Domestic carbon prices				
USA	9.8	95	222	407
EUR	4	55	176	296
Other Developed Countries	6	76	206	356

They are graphically represented in appendix Figure 7, while Figure 8 shows the restitutions that would be implemented for private operators in the international market. These restitutions are relatively important in reason of the difference between international and domestic carbon prices but tend to decrease in the long run.

As for the associated emissions by country they are given in the Table 21 below (in millions tons of CO_2)

Table 21: market equilibrium emissions by countries (in millions tons of CO_2)

	2020	2030	2040	2050
USA	4626	3131	2438	1598
EUR	3346	2983	2426	2256
Other Developed Countries	3227	2380	1798	1503
Total emissions by developed countries	11198	8494	6662	5356

Allowances and emissions are represented in appendix Figure 9. Differences between the two quantities yields the net sales of permits. In particular it appears that in 2020 the USA and European Union would be net sellers, but for very limited amounts. In 2050, trade between developed countries would be close to zero (taking into account the great uncertainty pertaining this type of simulations). What the simulation over a long period -though limited to developed countries- shows is the relevance of the rule of allocation of permits, moving progressively from grand-fathering to proportionality to population.

In this scenario a year plays a major role because if allowances are to be compared to effective emissions, they must also be compared to INDCs. Table 22 below presents this comparison.

Table 22: Allowances and emissions compared to INDCs

	BAU 2030	Emissions	Unconditional pledges	Conditional pledges	Allowances	Purchases of permits	Financial transfers
USA	5612	3131	3604	3490	3224	-93	10.2
EUR28	3664	2983	2414	2414	2920	63	-7.0
Other Developed Countries	3453	2380	2711	2653	2350	30	-3.3
Total	12729	8494	8729	8557	8494	**0**	**0**

The comparison is more relevant for conditional pledges because their total is close to total emissions and allowances. USA and Other Developed Countries exhibit INDCs higher than allowances and market equilibrium emissions, contrarily to European Union. USA and Other Developed Countries (taken here together) can be considered as lacking ambition, while European Union appears “zealous”, and even “examplar”, and this is important in the present world political context.

The carbon market as defined in the present scenario has also the merit to confirm the assessment of INDCs in the previous section[34].

3.6. A world market of tradable permits in 2030

It is interesting to simulate, for the year 2030, a total world market of tradable permits on the same assumptions than in the previous scenario, with total world emissions equal to the Benchmark scenario and the same rule of allocation of allowances (70% grand-fathering and 30% proportionality to population).

[34] It was based on the Benchmark scenario, on the assumption of an uniform carbon tax among countries. The present one is based on the assumption of a uniform marginal abatement cost among developed countries, which is consistent with a tradable market mechanism while the previous one was not.

The resulting world market carbon price would be lower than in the previous scenario (80 US$ instead of 110) with domestic carbon prices as presented below:

Table 23: domestic carbon prices in a world market of tradable permits (in constant US$, year 2030)

USA	EUR	Other Developed countries	CHI	IND	RUS	OPE	Other Developing countries
73	42	58	86	78	85	130	82

and effective emissions, compared to allowances and INDCs, in the following Table:

Table 24: effective emissions and allowances in a world market of tradable permits (in millions tons of CO_2, year 2030)

	BAU 2030	Emissions	Abatement	Quotas (Basis 2010)	Purchases of permits	Financial transfers
USA	5612	3716	1896	3264	451	-36.3
EUR	3664	3143	521	2593	550	-44.2
Other Developed countries	3453	2633	820	2211	422	-33.9
CHI	11126	5209	5918	5024	185	-14.9
IND	3186	1386	1799	2081	-695	55.9
RUS	1902	994	908	992	3	-0.2
OPE	2951	1348	1603	1347	1	-0.1
Other Developing countries	5877	3994	1883	4911	-917	73.8
WORLD	37770	22423	15347	22423	**0**	**0**

If the quotas were allocated according to the situation (population and emissions, as they can be forecasted), the situation would be much more favorable to emerging and developed countries, then the volume of trade and associated financial transfers would be significantly higher.

Table 25: effective emissions and allowances in a world market of tradable permits (quotas allocated on the basis of year 2020)

	Quotas (Basis 2010)	Purchases of permits	Financial transfers
USA	2714	1002	-80.6
EUR	2149	995	-80.0
Other Developed countries	1911	722	-58.0
CHI	5651	-443	35.6
IND	2441	-1055	84.9
RUS	941	53	-4.3
OPE	1598	-250	20.1
Other Developing countries	5018	-1024	82.4
WORLD	22423	**0**	**0**

An important result is the amount of net sales of permits, and the associated financial transfers. They benefit India and Other Developing Countries, but China only in the case of the allocation of permits on the basis of the year 2020.

But this is “balanced” by a very high level of abatement, which may be not taken at face-value. As stressed in section 2, main data and parameters concerning these countries are very inaccurate, if not subject to doubt. It obviously affects the assessment of their capacity – and the related cost- of abating their emissions in large quantities.

3.7. Intermediate scenarios

The previous world scenario of tradable permits exhibits for Emerging and Developing countries rates of emissions abatement that are very high and significantly higher than for developed countries. As it has been quoted before, it is possible and even very likely that the difference comes from data and parameters (in particular the price-elasticity of demand for energy) that may be not very reliable and can be debated. Then the participation of these countries in a world market of tradable permits must be progressive and based on scenarios that are based on limited commitments for them.

The first one is based on the INDCs as they have been proposed and agreed upon in the 2015 Paris Conference. As it has been shown before, the commitments of most of these countries, in particular China and India, are very limited, close to BAU or current policy scenarios. By participating to the market, they are induced–though not committed to- to abate more in order to registering a welfare gain by selling to developed countries permits at a price higher than the effective cost for their economies.

Other transitional scenarios have been previously contemplated. In these scenarios, the INDCs of China, India and Other Developing Countries are supposed to capped to the 2020 BAU emissions. This is the case for the scenario labelled Transition 1.

Concerning the scenario labeled Transition 2, it is assumed that Developed Countries increase their commitments of 15% (INDCs lowered of this percentage).

In these scenarios, the quotas are allocated according to the same rule, which for the considered year mix grand-fathering (up to 70%) and proportionality to population (up to 30%)

The results of these three scenarios are given in the Tables below.

Table 26: Conditional INDCS’ Scenario

World Carbon Price : 22.1

	BAU 2030	Emissions	Abatement	Quotas	Purchases of permits	Financial transfers
USA	5612	4702	910	3490	1212	-27
EUR	3664	3414	250	2414	1000	-22
Other Developed	3453	3060	394	2653	407	-9
CHI	11126	8286	2840	9776	-1489	33
IND	3186	2322	864	3336	-1014	22
RUS	1902	1466	436	1514	-48	1
OPE	2951	2182	769	2300	-118	3
Other Developing	5877	4974	904	4922	52	-1
WORLD	37770	30404	7366	30404	**0**	**0**

Table 27: Scenario of Transition 1

World Carbon Price : 28.3

	BAU 2030	Emissions	Abatement	Quotas (Basis 2010)	Purchases of permits	Financial transfers
USA	5612	4499	1112	3490	1010	-29
EUR	3664	3358	305	2414	944	-27
Other Developed	3453	2972	481	2653	319	-9
CHI	11126	7656	3471	9027	-1371	39
IND	3186	2130	1055	2487	-357	10
RUS	1902	1369	532	1514	-145	4
OPE	2951	2011	940	2300	-289	8
Other Developing	5877	4773	1104	4884	-111	3
WORLD	37770	28769	9002	28769	**0**	**0**

Table 28: Scenario of Transition 2

World Carbon Price : 34.6

	BAU 2030	Emissions	Abatement	Quotas	Purchases of permits	Financial transfers
USA	5612	4341	1271	2966	1375	-48
EUR	3664	3315	349	2052	1263	-44
Other Developed	3453	2903	550	2255	649	-22
CHI	11126	7161	3966	9027	-1866	65
IND	3186	1980	1206	2487	-507	18
RUS	1902	1293	608	1514	-221	8
OPE	2951	1877	1074	2300	-423	15
Other Developing	5877	4615	1262	4884	-269	9
WORLD	37770	27485	10285	27485	**0**	**0**

As it could have been expected, in all three scenarios the carbon price is much smaller than in the global world trade market based on the Benchmark scenario. Abatement by emerging and developing countries are relatively important, significantly higher than in developed countries. Sales of permits give off important receipts and financial transfers.

3.8. Comparison of scenarios

Tables below, and appendix Figures 10 and 11, give a synthetic comparison for the year 2030 of all assessed scenarios of international or regional market of tradable permits. Clearly there is a big divide between scenarios that are on the long term path of decarbonization consistent with the long-term target of limiting warming to 2°C and scenarios based on or close to INDCs: in terms of emissions, in terms of carbon price, in terms of trade of permits.

Table 29: Comparison of pricing scenarios: emissions abatement (with Conditional INDCs for non participants)

	Developed countries market	Club1 market Basis 2010	Club1 market Basis 2020	World market Basis 2010	World market Basis 2020	Scenario conditional INDCs	Scenario transition 1	Scenario transition 2
USA	2480	1998	1998	1896	1896	910	1112	1271
EUR	681	549	549	521	521	250	305	349
Other Developed	1073	864	864	820	820	394	481	550
CHI		6234	6234	5918	5918	2840	3471	3966
IND		1896	1896	1799	1799	864	1055	1206
RUS		956	956	908	908	436	532	608
OPE				1603	1603	769	940	1074
Other Developing				1883	1883	904	1104	1262
WORLD	10047	14169	14169	15347	15347	7366	9002	10285

Table 30: Comparison of pricing scenarios: quotas of emission rights

	Developed countries market	Club1 market Basis 2010	Club1 market Basis 2020	World market Basis 2010	World market Basis 2020	Scenario conditional INDCs	Scenario transition 1	Scenario transition 2
USA	3224	3149	2689	3264	2714	3490	3490	2966
EUR	2920	2597	2219	2593	2149	2414	2414	2052
Other Developed	2350	2177	1933	2211	1911	2653	2653	2255
CHI		5166	5852	5024	5651	9776	9027	9027
IND		2383	2812	2081	2441	3336	2487	2487
RUS		974	941	992	941	1514	1514	1514
OPE				1347	1598	2300	2300	2300
Other Developing				4911	5018	4922	4884	4884
WORLD				22423	22423	30404	28769	27485

Table 31: Comparison of pricing scenarios: purchases of permits

	Developed countries market	Club1 market Basis 2010	Club1 market Basis 2020	World market Basis 2010	World market Basis 2020	Scenario conditional INDCs	Scenario transition 1	Scenario transition 2
USA	-93	465	925	451	1002	1212	1010	1375
EUR	63	519	896	550	995	1000	944	1263
Other Developed	30	412	656	422	722	407	319	649
CHI		-274	-959	185	-443	-1489	-1371	-1866
IND		-1093	-1522	-695	-1055	-1014	-357	-507
RUS		-29	4	3	53	-48	-145	-221
OPE				1	-250	-118	-289	-423
Other Developing				-917	-1024	52	-111	-269
WORLD				**0**	**0**	**0**	**0**	**0**
Total market	*93*	*1396*	*2481*	*1612*	*2771*	*2670*	*2273*	*3286*

Table 32: Comparison of pricing scenarios: financial transfers

	Developed countries market	Club1 market Basis 2010	Club1 market Basis 2020	World market Basis 2010	World market Basis 2020	Scenario conditional INDCs	Scenario transition 1	Scenario transition 2
USA	10	-37	-73	-36	-81	-27	-29	-48
EUR	-7	-41	-71	-44	-80	-22	-27	-44
Other Developed	-3	-33	-52	-34	-58	-9	-9	-22
CHI		22	76	-15	36	33	39	65
IND		87	121	56	85	22	10	18
RUS		2	-0.3	-0.2	-4	1	4	8
OPE				-0.1	20	3	8	15
Other Developing				74	82	-1	3	9
WORLD				**0**	**0**	**0**	**0**	**0**
Total market	*10*	*111*	*197*	*130*	*223*	*59*	*64*	*114*

This divide if the challenge for designing a market of tradable permits, which can start as early as 2020 for developed countries and must incorporate progressively, latest in 2030, all other countries without abating long-term ambition.

4. An Agenda for Setting a World Carbon Market

As it has been stressed by the vast majority of economists, research centers, NGOs, think tanks, international organizations, and industry at large, and as it has been clearly shown in this paper, the Paris Agreement may only become really operational if it is sustained by a mechanism of world carbon pricing. It is the only way to exhibit the capacity –and the cost- of countries to abate and to level all of them on a same standard of ambition. It is thus the only way to exit from the free-riding behavior that has plagued COP 21 and there is no chance that by itself the bottom-up system of Nationally Determined Commitments give the incentive to countries to significantly upgrade their pledges.

4.1. Principles

If at the domestic level the rational system is a uniform carbon price –preferably in the form of an uniform carbon tax[35]- such a mechanism is not at all convenient at the world level. Only a cap and trade system can work and be accepted by all countries[36].

Effectively, contrary to a uniform carbon price that would be imposed –even agreed upon- by all countries-, this system is:

- not manipulable (countries can compensate by subsidies or other fiscal devices);
- decentralized (consistent with subsidiarity), each country determining freely and independently his net demand of permits, according to the equilibrium price;
- efficient because if induces all countries to equalize their marginal abatement cost to the world market price, then equalize them;
- equitable because it can be based on a rule of allocation proportional to the population (in the long run, in the short run implementability and acceptance impose some grand-fathering rule, in order to limit the volume of trade).

An argument stressed by proponents of a world carbon tax is that it is simpler because there is only one quantity to determine, and then agree upon by participation countries. This is not convincing because with a cap and trade system there is only a rule to determine –and agree upon- and this allows to incorporate equity considerations (which are non-explicit –and rather anti-distributive-in the carbon price system). Moreover, if we know –and there is at the international level a large consensus– what is the long term desirable path of emissions, it is not easy to translate it to precise values of carbon tax. In other terms, emissions –and correlatively desired abatements- must determine by market mechanism the associated carbon price, not the other way round.

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[35] Which implies, for reasons of efficiency, that all subsidies to fossil fuels and existing sectoral regulations are discarded, as suggested by Felstein and others

[36] See in particular the position of Jean Tirole already referred to (TSE and IAST, June 10, 2016)
In this contribution there are nevertheless missing links : one is conceptual, i.e. how to allocate permits among countries. Another is more technical, how to concretely determine such a cap and trade equilibrium.

Each country has then to determine its net demand for permits, together with other aspects of its fiscal policy: effective taxation but also shadow pricing, i.e. dual prices for public investment[37]. Effectively environmental taxation depends on and affects other fiscal tools and the whole fiscal system –effective and shadow- must be determined simultaneously and then consistently, as shown in the previous developments.

It then results from this approach that the domestic carbon tax differs from the international one, usually is smaller. This would imply that only the countries bid on the market of tradable permits. However it would be possible to economic agents, firms in particular, to operate in the market. In this case, they would be liable of the difference of the two prices, pay if they sell at a price higher than the domestic one. Then decentralization is wholesome, as are all international markets of goods and services.

Then contrary to what suggests the recently created Climate Leadership Council, there is strictly –apart for political reasons aiming at acceptance by citizens- to devote the receipts of environmental taxation to a uniform lump-sum transfer. There are probably better uses, from the efficiency viewpoint (correcting fiscal or economic distortions, according to the famous "double-dividend" theory) or equity (a uniform lump-sum transfer is not a priori the most equitable allocation).

Contrarily too to several proposals, the idea of implementing in a first stage of implementation of tradable permits starting with developed countries a Border Adjustment Tax appears very ill-advised, apart from its sheer complexity. The subject is not to "punish" countries who don't participate to the market at its start –mainly because they are not ready to-, but to induce them to take the necessary steps in order to be able to join, as soon as possible, other participants.

4.2. Implementation

In the short run, due to reliability of information, only developed countries can engage in a system of international carbon pricing. Such a mechanism can be implemented as soon as 2020, with an adequate -as defined above- rule of allocation of permits and a global level of abatement consistent to the long term 2°C target but still fairly small. According to our simulations and estimations, the resulting international carbon price would be in 2020 around 10 $ by ton of CO_2, increasing to 32 $ in 2022 and 63 $ in 2025. It would increase up to 110 $ in 2030.

These figures are perfectly in line with was is indicated in various studies, assessments and proposals (see in particular appendix Figure 21)

The main challenge is how to incorporate in the system new applicants, emerging and developing, and in particular China and India that are the biggest emitters in the group.

It has been designed and assessed intermediate scenarios and in particular a Transition 2 scenario which could be implemented in 2030. for developed countries this would imply a significant drop in abatement and carbon price, and the integration of other countries should be anticipated by them as soon as 2025.

After 2030 (for instance starting in 2035), the Transition 2 scenario must leave room to the world tradable permit market consistent with the global level of abatement with the

[37] Let us recall, because it now seems to be « forgotten » (involuntary but most likely voluntary) that shadow pricing was the issue addressed by Marcel Boiteux, who designed the methodology and the technical tools of second best theory and then optimal fiscal policy –following contributions being mainly more or less clever adaptations toi special issues).

long term 2°C target. This would imply a rapid growth in the international price of permits, around 200$ in 2040 and 350 $ in 2050.

All these estimations and assessments are consistent with the present forecast of technical progress, and in particular the cost of renewable energy. A substantial gain would allow to reduce these figures.

But whatever are the long run uncertainties, there is no reason not to rapidly start the implementation of an international market of tradable permits, limited to developed countries at the beginning, but conceived in order to incorporate progressively all other countries.

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Box 1 – The GEMINI-E3 Model

GEMINI-E3 is a General Equilibrium Model applied to climate change in the purest sense: all prices are flexible and all markets are competitively balanced. In the price systems there are the prices of commodities, exchanged in the domestic or in the international markets. But there are also macroeconomic prices such as the (real) rate of interest and the (real) exchange rates that are endogenous. These prices occur in the balancing of investment and savings (domestic or imported) one the one hand, imports and exports on the other hand. The GEMINI-E3 model is now built on a comprehensive energy-economy dataset, the GTAP-8 database. This database incorporates a consistent representation of energy markets in physical units, social accounting matrices for each individualized country/region, and the whole set of bilateral trade flows. Additional statistical information accrues from OECD national accounts, IEA energy balances and energy prices/taxes and IMF Statistics. We use an aggregated version of GEMINI-E3 that described 11 sectors/goods and 8 regions.

Regional aggregation

The 8 regional aggregates individualize large countries/regions (China, India, European Union, United States of America), major fossil fuel exporters (OPEC, Russia). The remaining countries are shared in two groups, according to their Gross National Income per capita: Other Developed Countries for the 15 countries which have an average GNI of more than $12,736 in 2014 (according to World Bank data and classification); Other Developing Countries for the countries under this limit.

The US, EUR28 and Other Developed Countries form the homogeneous group of Developed Countries who are the more likely to participate in the near future to a global market of tradable permits.

Sectoral aggregation

Sectors of the model are aggregated by fossil fuels, electricity, agriculture, land/sea/air transport, energy intensive industries and other goods and services, as in the following Table.

Model sector aggregates

Sector	Description
S01	Coal
S02	Crude Oil
S03	Natural Gas
S04	Petroleum products
S05	Electricity
S06	Agriculture
S07	Energy intensive industry
S08	Other goods and services
S09	Land transport
S10	Sea transport
S11	Air transport

Electricity generation

In this version of GEMINI-E3, electricity production is represented by a nested CES function including fossil fuels, nuclear and renewable plants. Power generation is separated from the other activities (transmission and distribution) that appear through their factors of production at the top of the nesting structure. Power generation involves only two factors of production, capital and fuel (only capital for renewables). With this nesting structure it is possible to better take into account the power generation portfolio and to represent interfuel substitutability as well as substitutability between fossil and renewable power generation. We distinguish 5 types of power plants:

- Nuclear power plant;
- Coal power plant;
- Natural gas power plant;
- Oil power plant;
- Renewable power plant (that includes hydro, wind, solar and other renewables).

The model has the possibility to use Carbon Capture and Sequestration (CCS) technology only for coal fired power plant. When the total cost of CCS technology is lower than the carbon price we suppose that all investments in power plants using coal is done with CCS. Concerning carbon capture and storage, the simulation is based on a cost of 100 US $ by ton of CO_2.

Configuring the model for assessing structural scenarios

Four sectors are concerned and have been particularly scrutinized, housing, industry (sectors S07 and S08) and transportation. For housing and transportation the reason is that the capital is important relatively to the services that are produced, and has a very long service life that prevent a rapid adaptation to the change in the price of energy for users. Concomitant to a long service life is heterogeneity which, in the case of Housing, is coped with through a detailed sub-model.

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Box 2 - Pure Economics of Tradable Permits

As always, economists indulge in models and in particular assumptions, however unrealistic as they can be, to obtain simple results. This is overwhelmingly the case in issues such as aggregation, industrial organization (with abuse of partial equilibrium, most of the times linear models) and second-best analysis. The aim is to demonstrate theorems and exhibit simple results, « rule of thumb » laws. Unfortunately the reality –and « stubborn facts » is far from these naive assumptions and easy-modeling and only a thorough examination and a numerical assessment can provide a reliable answer. But this needs to gather the wholesome and relevant information, and to assess the issue numerically.

An historical review on second-best theory
At the beginning was an economist, student of Maurice Allais, and working after a brilliant academic training and important research contributions in the state-owned French electric utility EDF. His issue was how to price an activity exhibiting increasing returns to scale with a balanced budget constraint, i.e. how to determine the tolls –difference between the effective price and the marginal cost- to apply to the various products. There existed the Ramsey solution, but it was not based on a rigorous analysis.
Boiteux understood that it was a general –not partial- equilibrium problem and very cleverly exhibited the solution –the optimal shadow tolls-, being then first economist to develop consistently the general second-best framework and by the way to provide the associated technical tools.
The big « mistake », rather « omission » of Boiteux, concentrated on shadow taxation, was to discard effective taxation, departure between production and consumption prices, narrowing the number of degrees of liberty in the model. Several reasons can be given : probably the main was that effective taxation is not the issue facing a firm, however big and important it may be. Secondly, the results would have been more complex and difficult to grasp. A last reason was that at the time in France (who invented the VAT) proportional taxation was efficient or close to efficiency[38].
This lack was later perceived by economists who rushed in the flaw and developed the Boiteux model including effective taxation (Diamond & Mirrlees). But in order to obtain simple results they made an heroic assumption that there is no constraint on taxation, commodity and profit taxation, with result that optimal profit taxation is 100%. The model is then representative of a centralized economy, in which all production and allocation of income to consumers is managed or controlled by public authorities.

Application to carbon pricing
In this framework, the main results are particularly simple : they are « production –both private and public- efficiency ; a marginal cost of public fund equal to one ; and concerning the climate change issue, the equality between the carbon tax and the marginal cost of abatement. Clearly then a world equilibrium between countries managed according to the D&M second-best rules implies a world carbon price to be applied domestically in each country (because for each country this carbon price is equal to his marginal cost of abatement).
What if there exists constraints on taxation, and in particular on profit taxation (partial, eventually zero taxation) ? The model loses its simplicity and its general results, concerning

[38] But of course a general proportional taxation means no receipts and then no taxation at all. At least one commodity or service must be untaxed or subsidized (labor usually).
This omission also weights –and more critically- on the other seminal though largely unknown paper by Boiteux (perte économique).

public production and commodity taxation become much more complex and difficult to apply. A simplified inroad can be obtained by assuming that there is a single (for instance representative) consumer. I personally followed this path and presented a communication to a seminar in Turin (1974).

What are the main results when applied to the issue of international carbon trade? For each country facing such a market, the optimal (competitive) behavior is to equal its marginal abatement cost, deflated by its marginal cost of public fund, to the world price. Optimal domestic abatement results from the implementation of a domestic carbon tax (or an equivalent device such as a domestic market of quotas) which is a priori different from the world carbon price.

Trade of international quotas is of the responsibility of governments which are accountable of the total emissions of the country. They are the players in this world market, however decentralization to private agents (mainly firms) can be contemplated but then a compensation between the domestic and the international prices must be provided (a firm that sells a permit in the international market at a price higher than the domestic one must hand back the difference to the treasury).

The issues for the world management of the system are first the total amount of world (or regional if the system is limited to a group of countries, developed ones for instance at the beginning) and the allocation of quotas.

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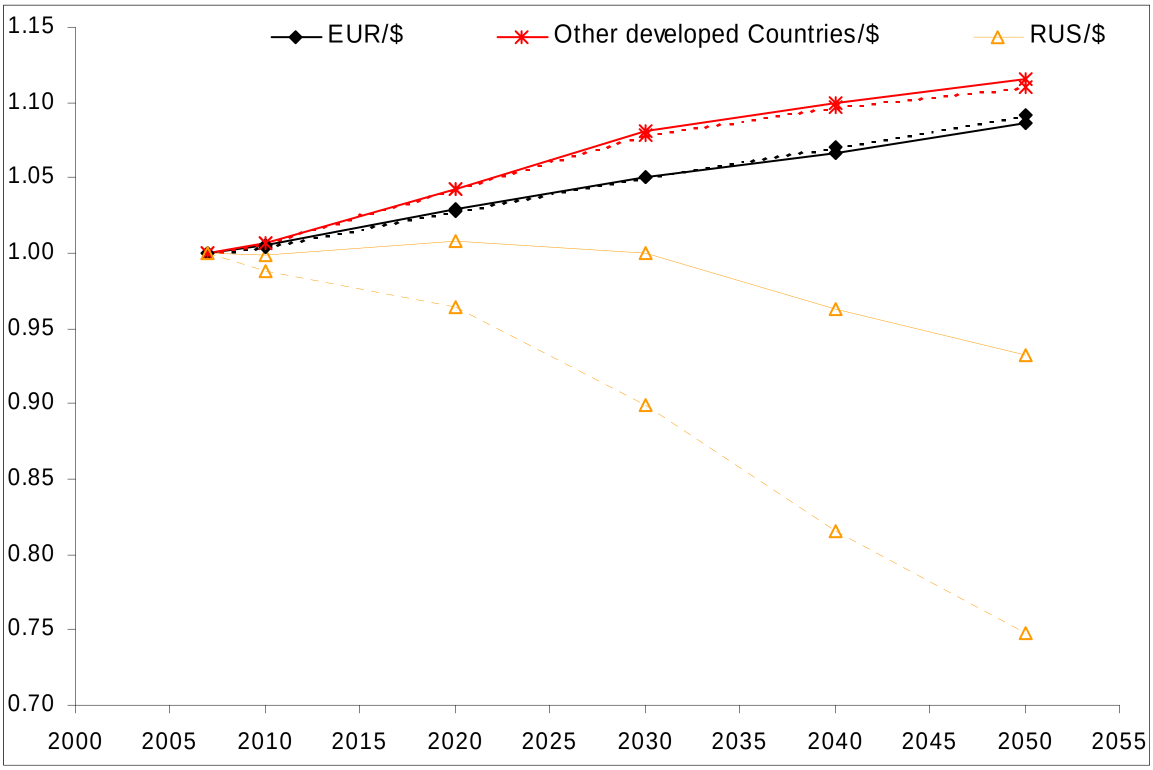
Appendix: Figures

Figure 1: Exchange rates with respect to US$
(solid lines, BAU; dotted lines, Benchmark scenario)



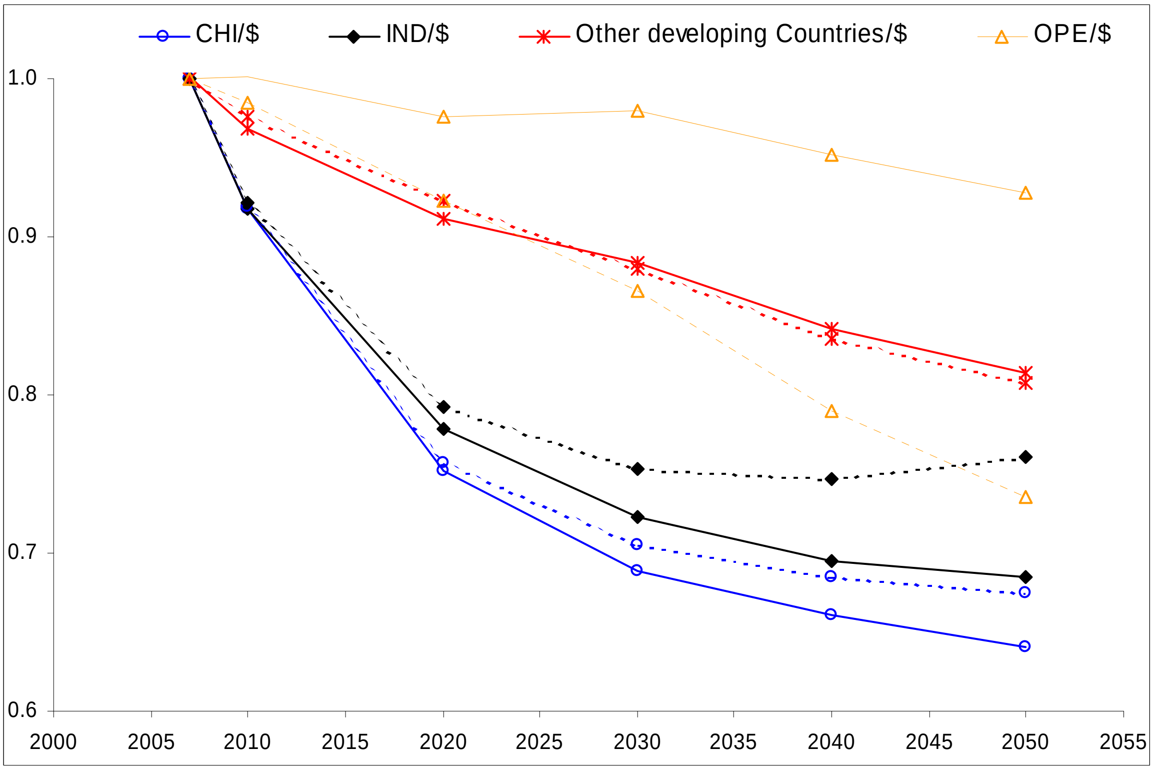


Figure 1b : Correlation across countries between exchange rate and growth rate

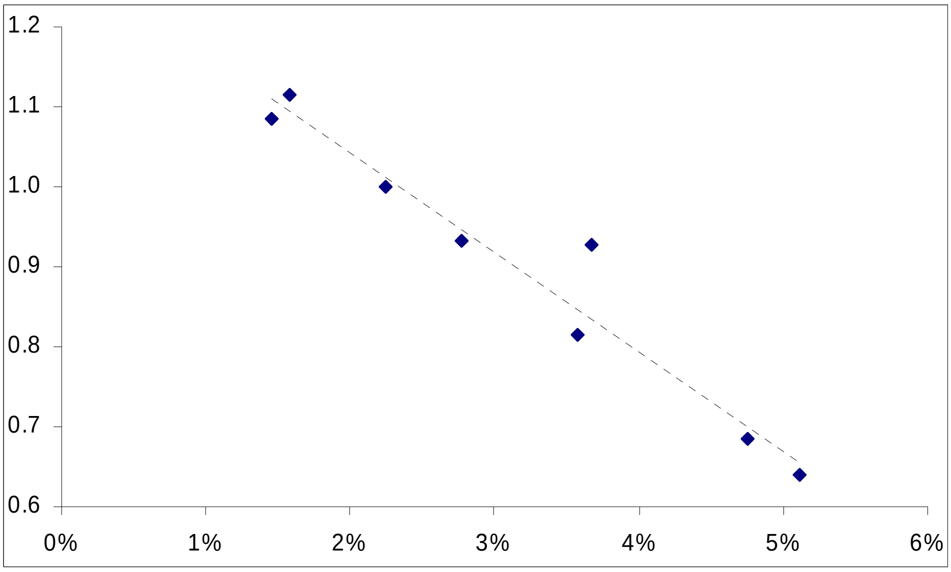
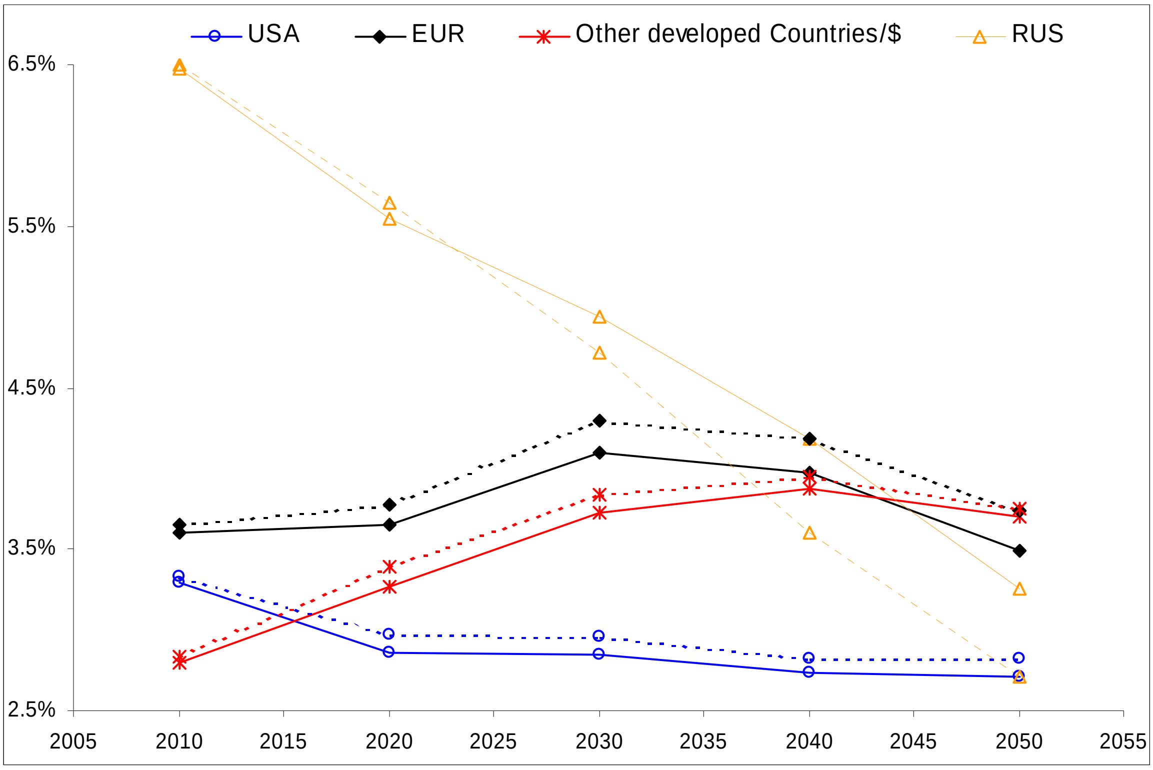


Figure 2: Interest rates (solid lines, BAU; dotted lines, Benchmark scenario)



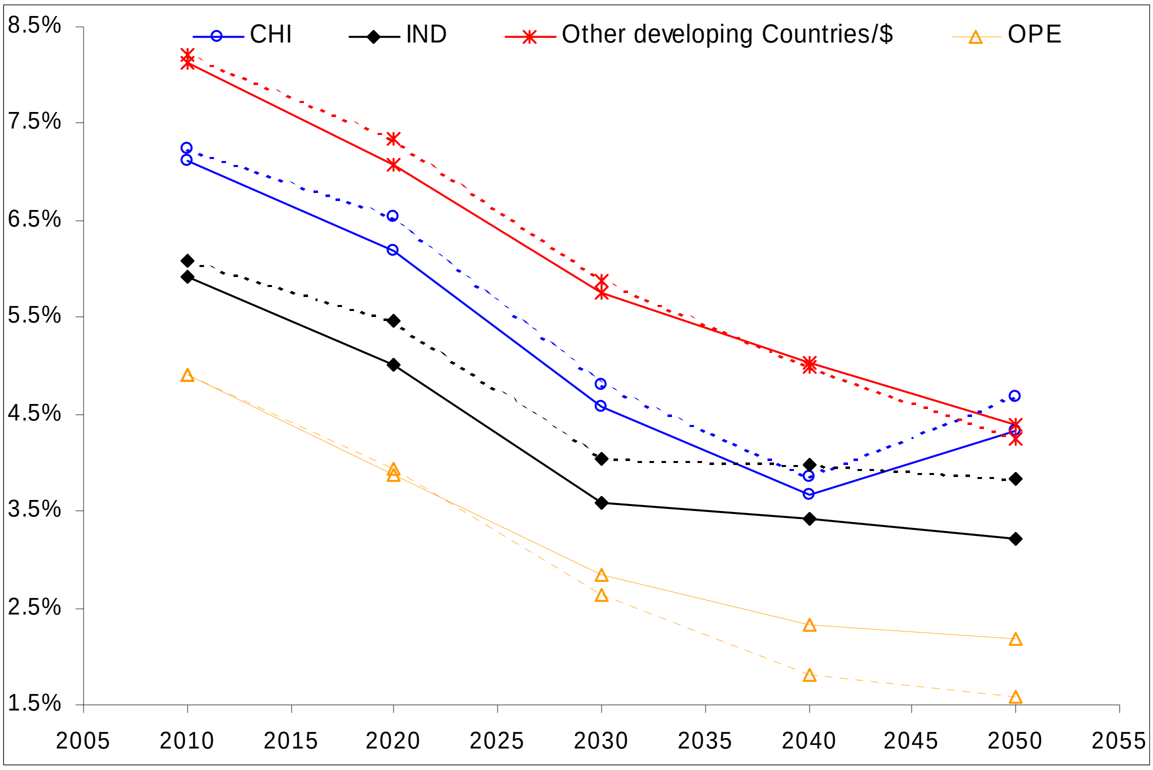
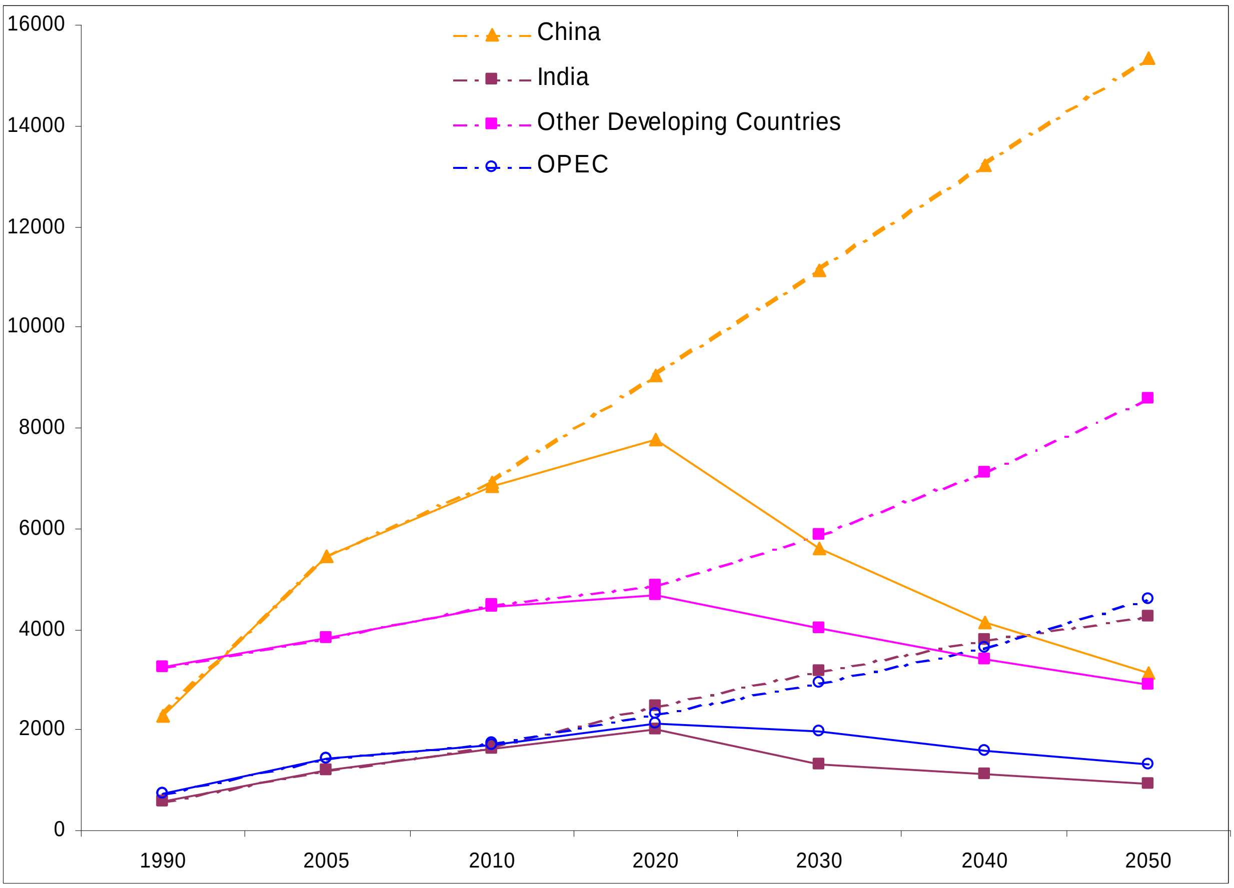


Figure 3 : Benchmark Pathway to Long Term Decarbonization (BPLTD)
(solid lines, BAU; dotted lines, Benchmark scenario)



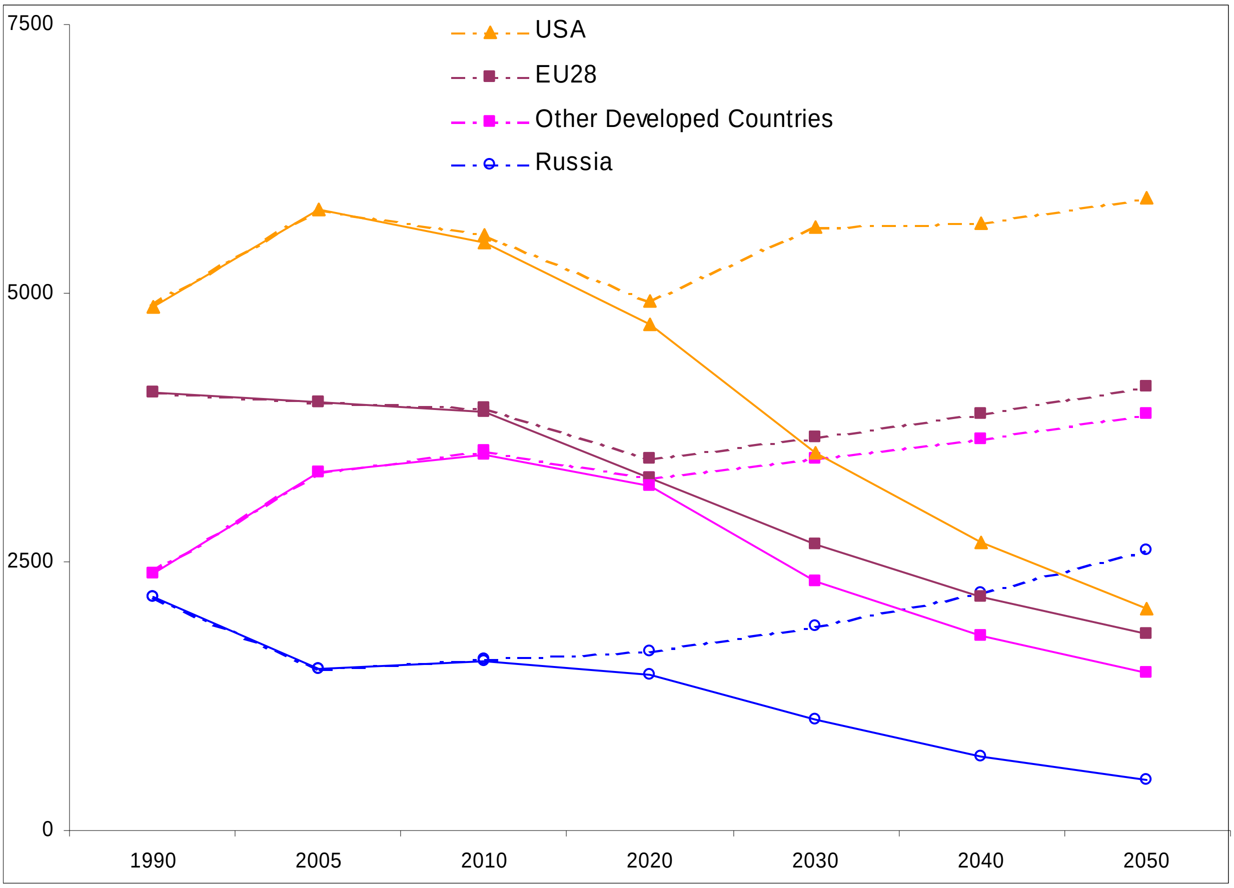


Figure 4: Unconditional and conditional INDCs compared to BAU and 2°C scenarios from IPCC AR5 and GEMINI-E3

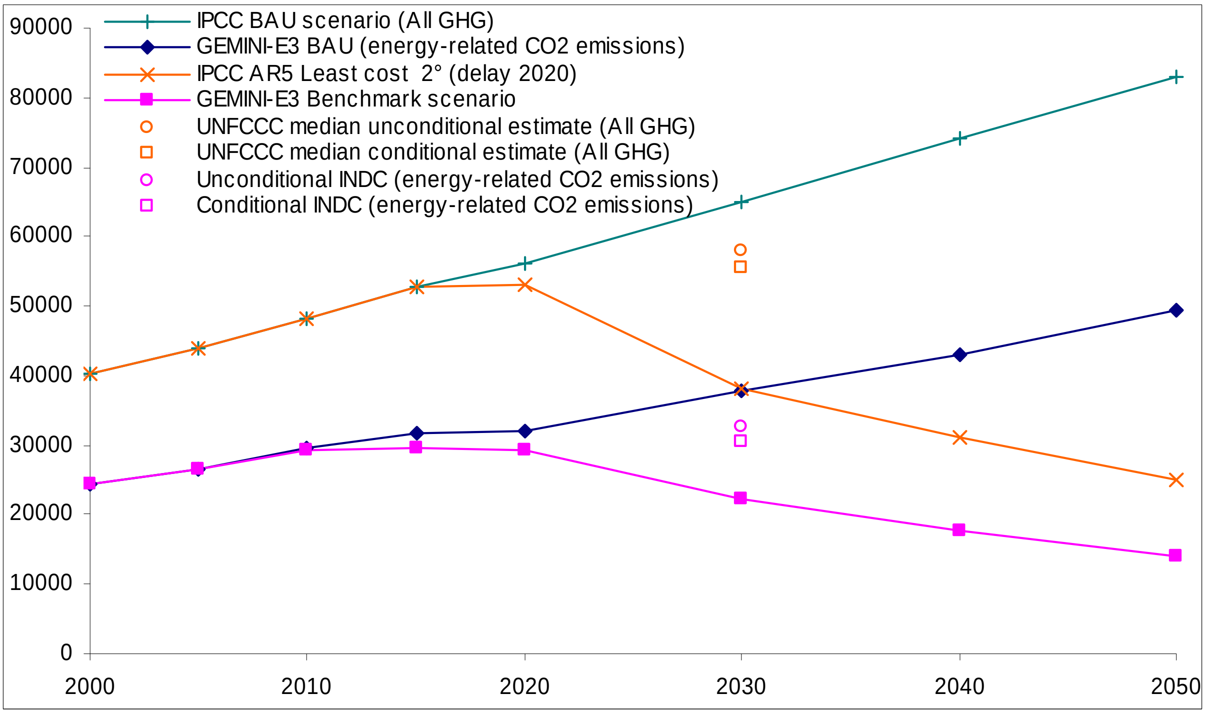
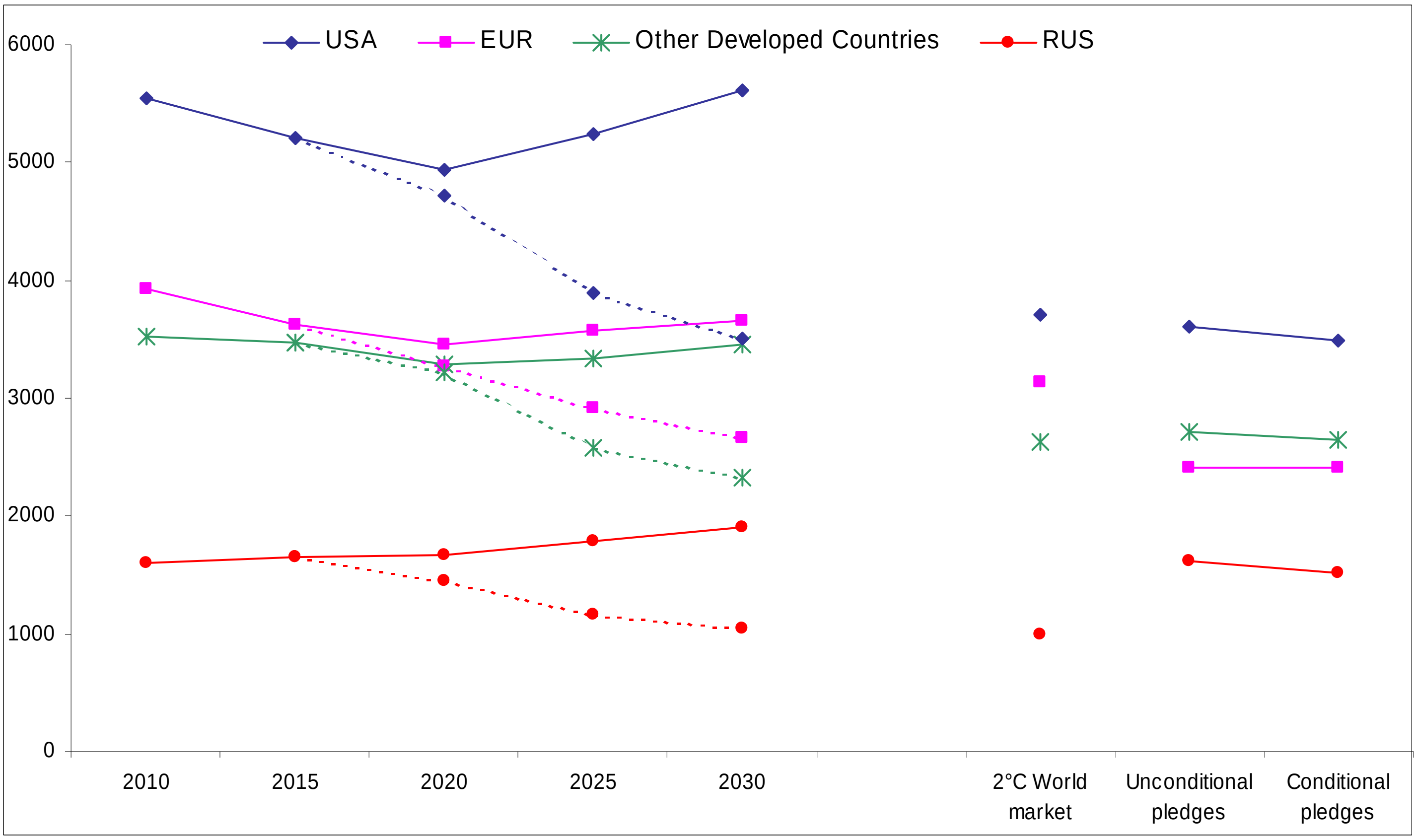


Figure 5: INDCs compared to BAU and Benchmark scenarios
(BAU: solid line; Benchmark scenario: dotted line)



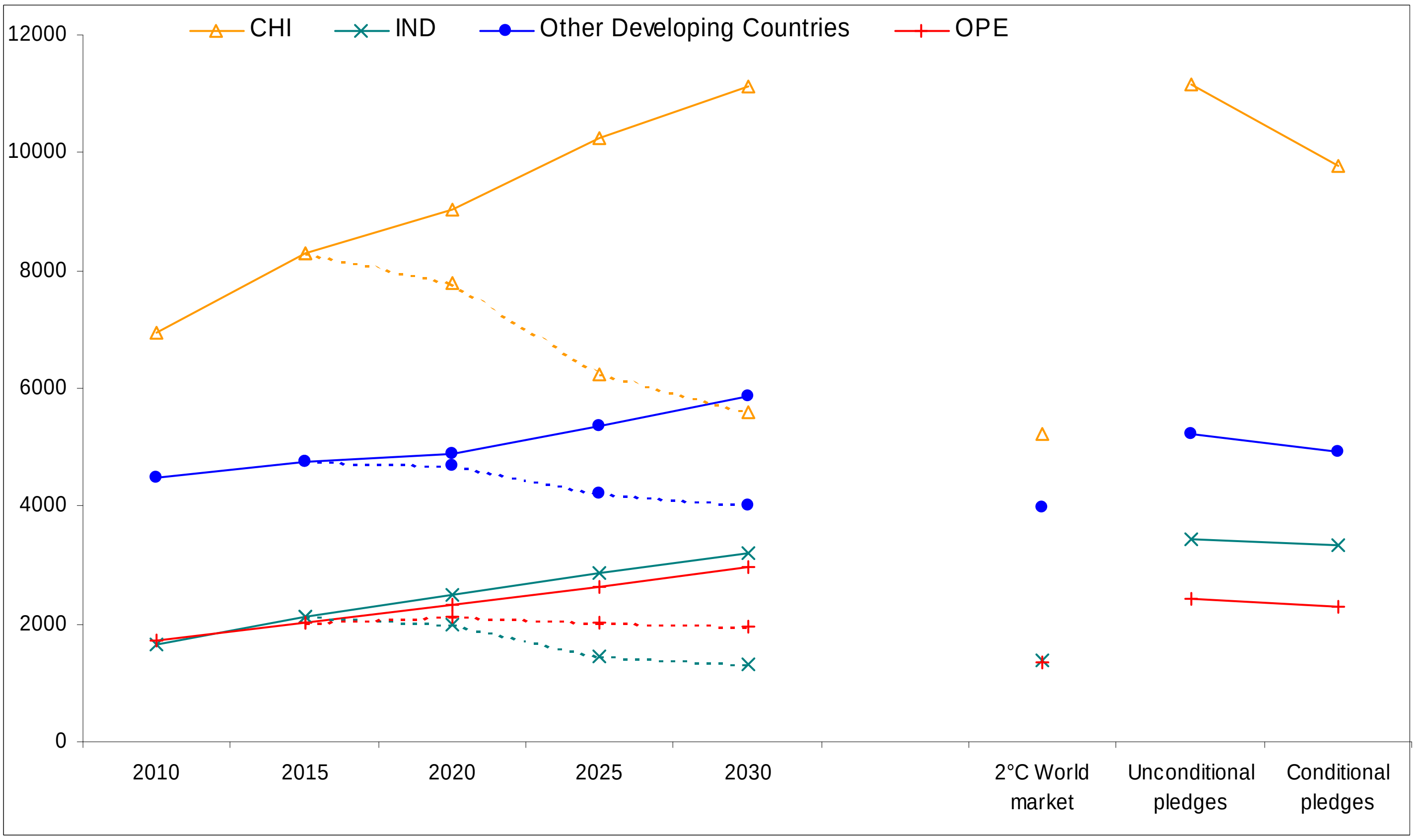


Figure 6 : Correlation across countries between Marginal Cost of Public Funds and share of Public Outlays in GDP

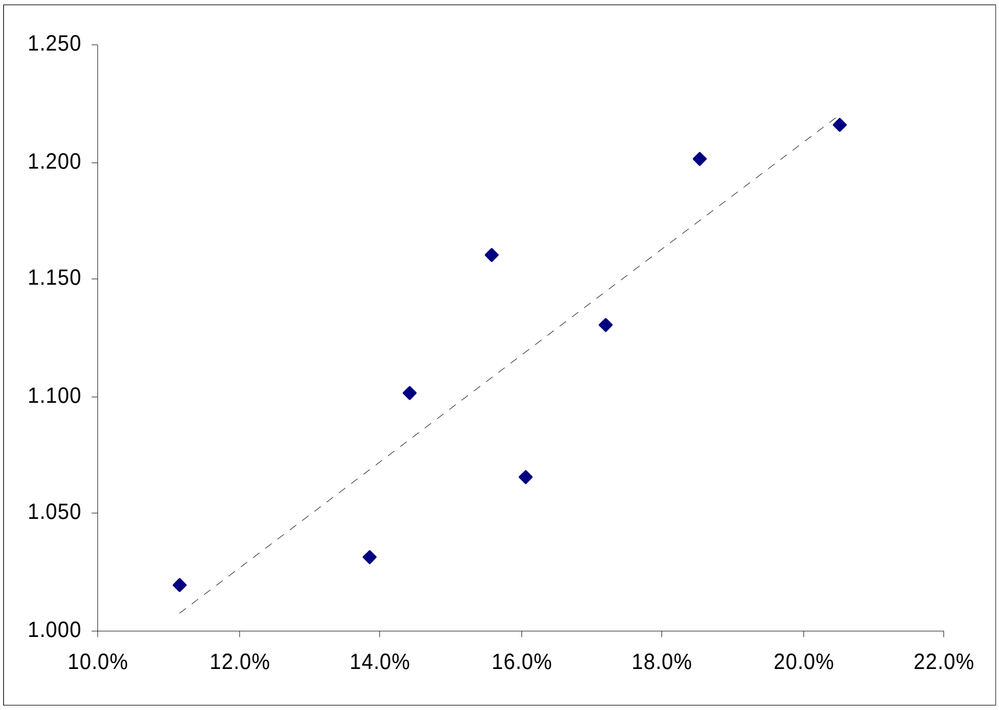


Figure 7 : Market of Tradable Permits in Developed Countries
Domestic Carbon Prices compared to the Price of Tradable Permits (in constant US$)

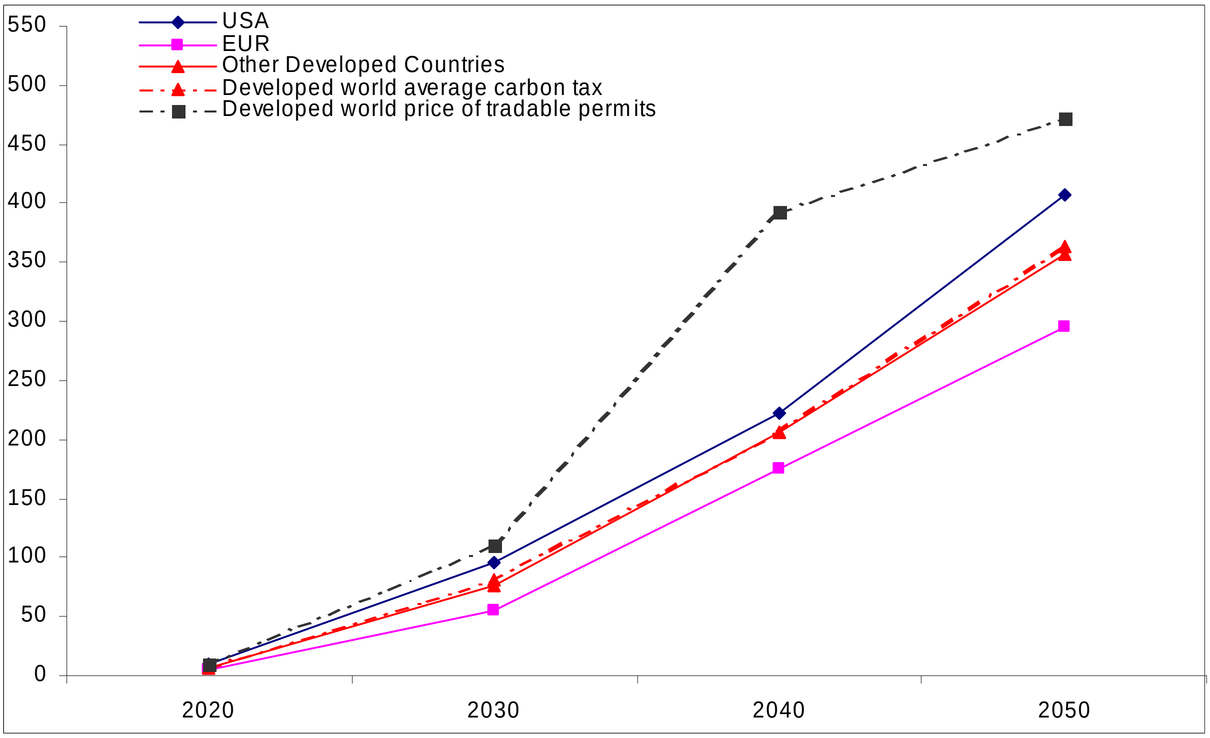


Figure 8 : Market of Tradable Permits in Developed Countries
Restitution to internationally trading firms (in constant US$)

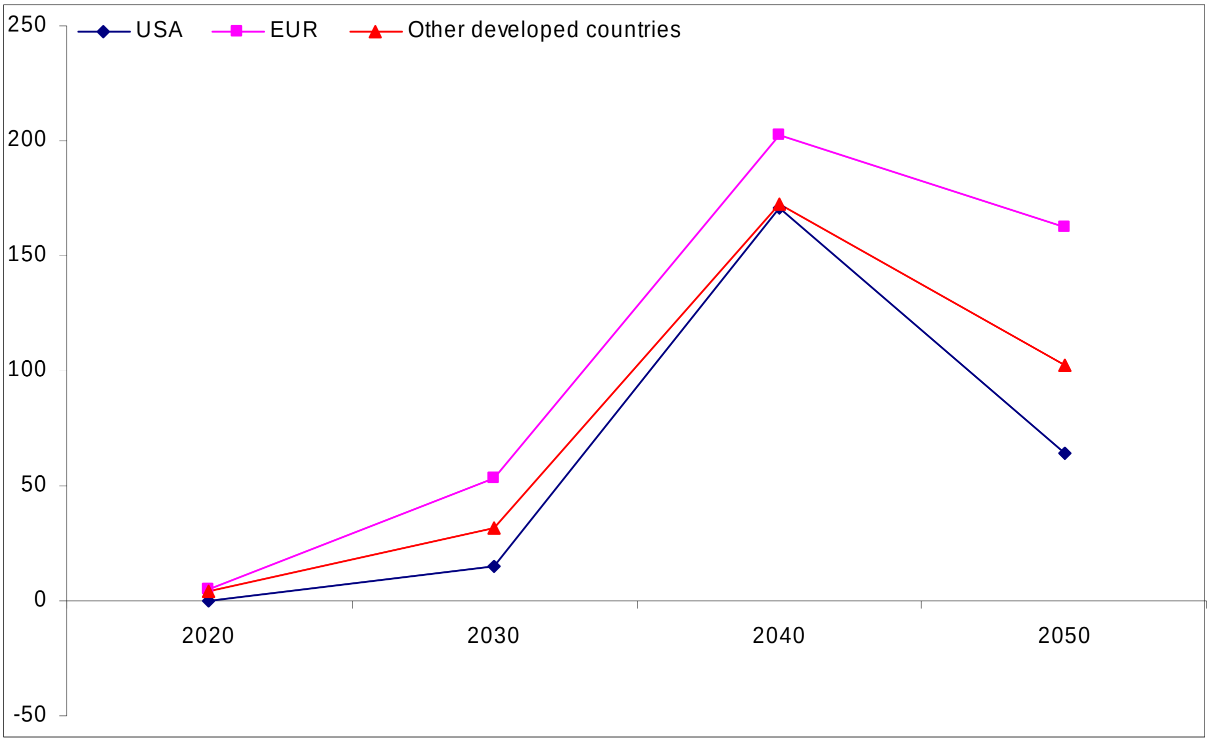


Figure9 : Market of Tradable Permits in Developed Countries
Comparison of allowances and emissions

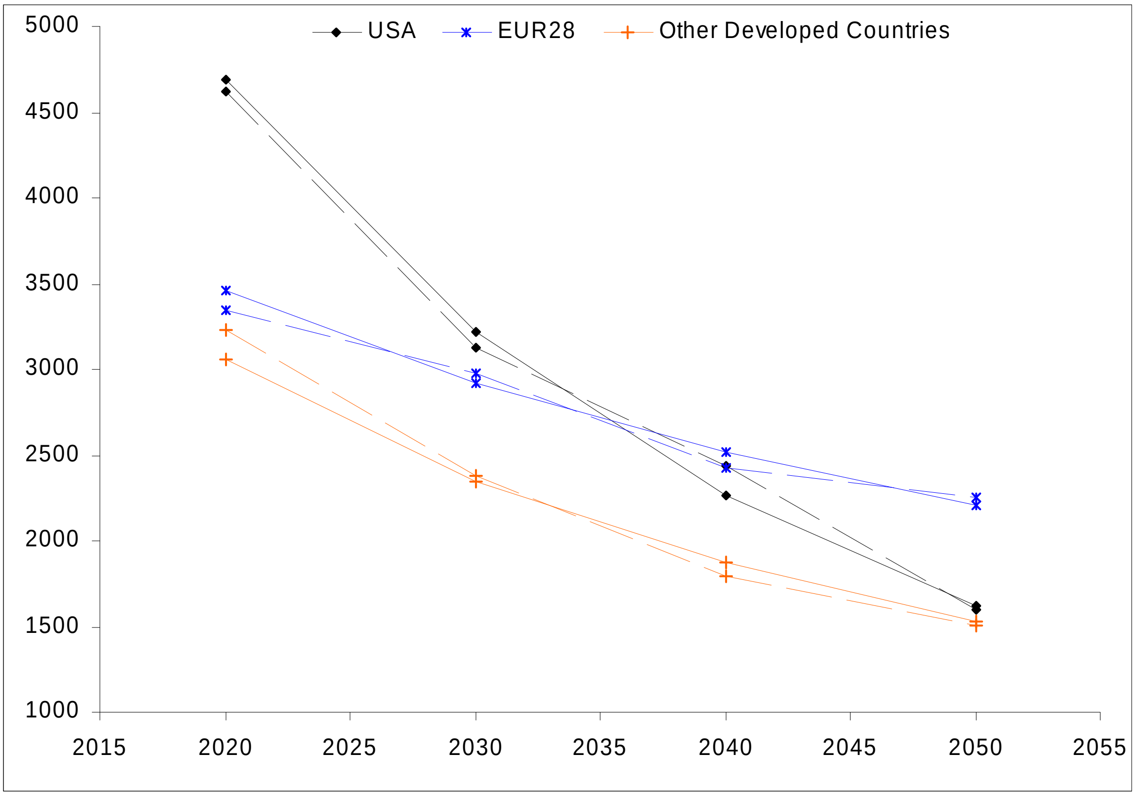


Figure10 : Comparison of Tradable Markets scenarios: price of tradable permits

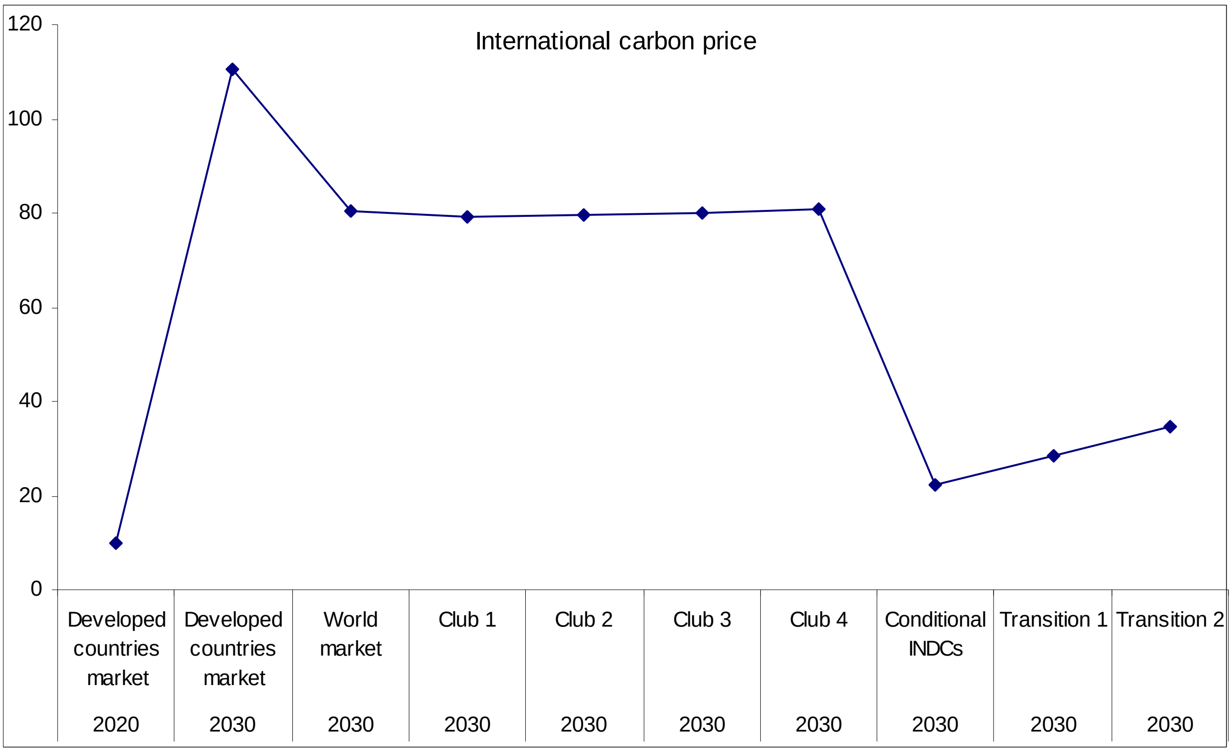


Figure11 : Comparison of Tradable Markets scenarios: CO2 emissions

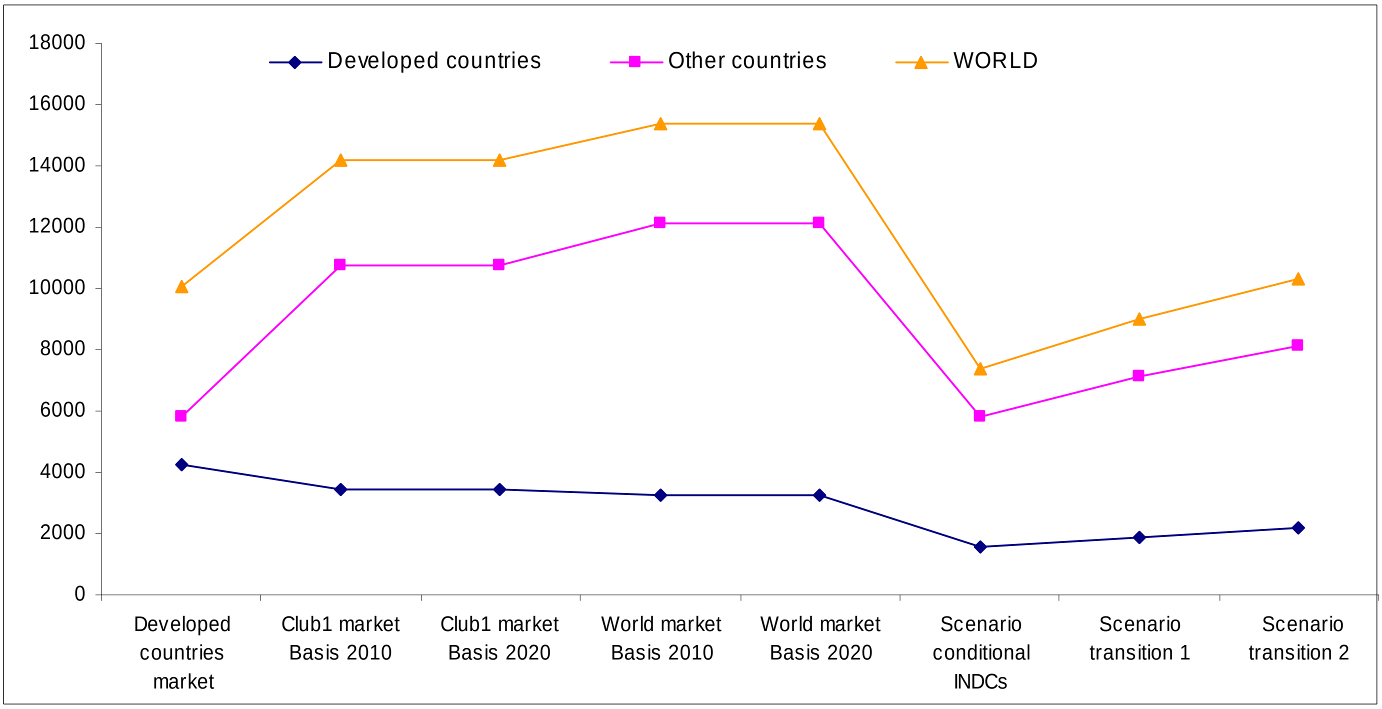


Figure12 : Market of tradable permits for Developed countries
Price of permits compared to various estimations and proposals

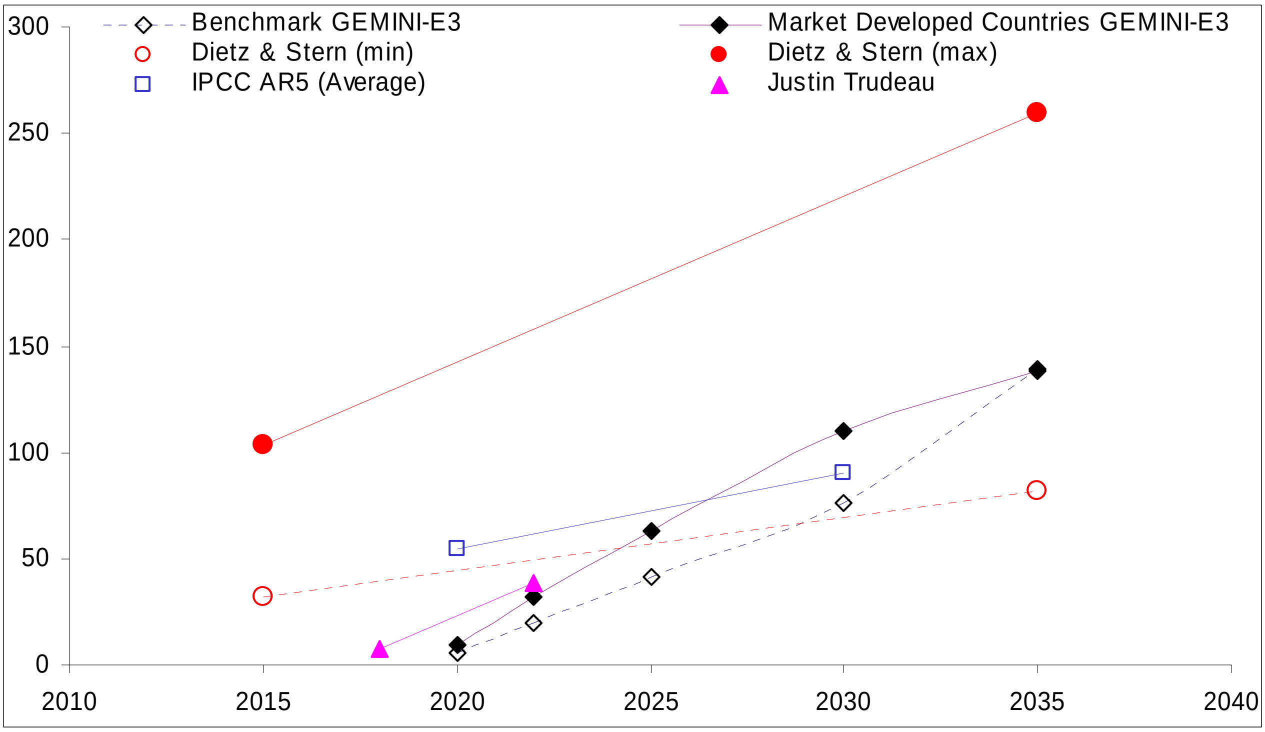


Figure13 : Transition from Developed Countries' to World Market scenario- Emissions

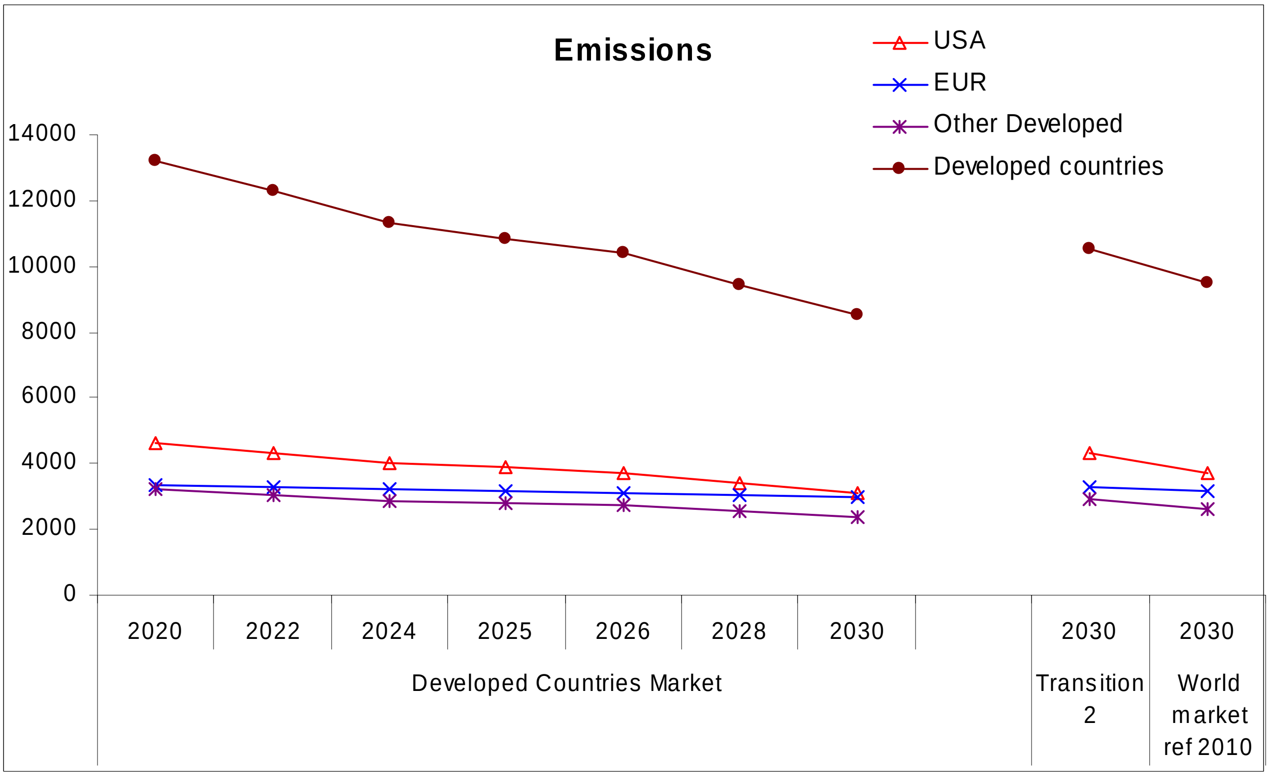


Figure14 : Transition from Developed Countries' to World Market scenario- Abatements

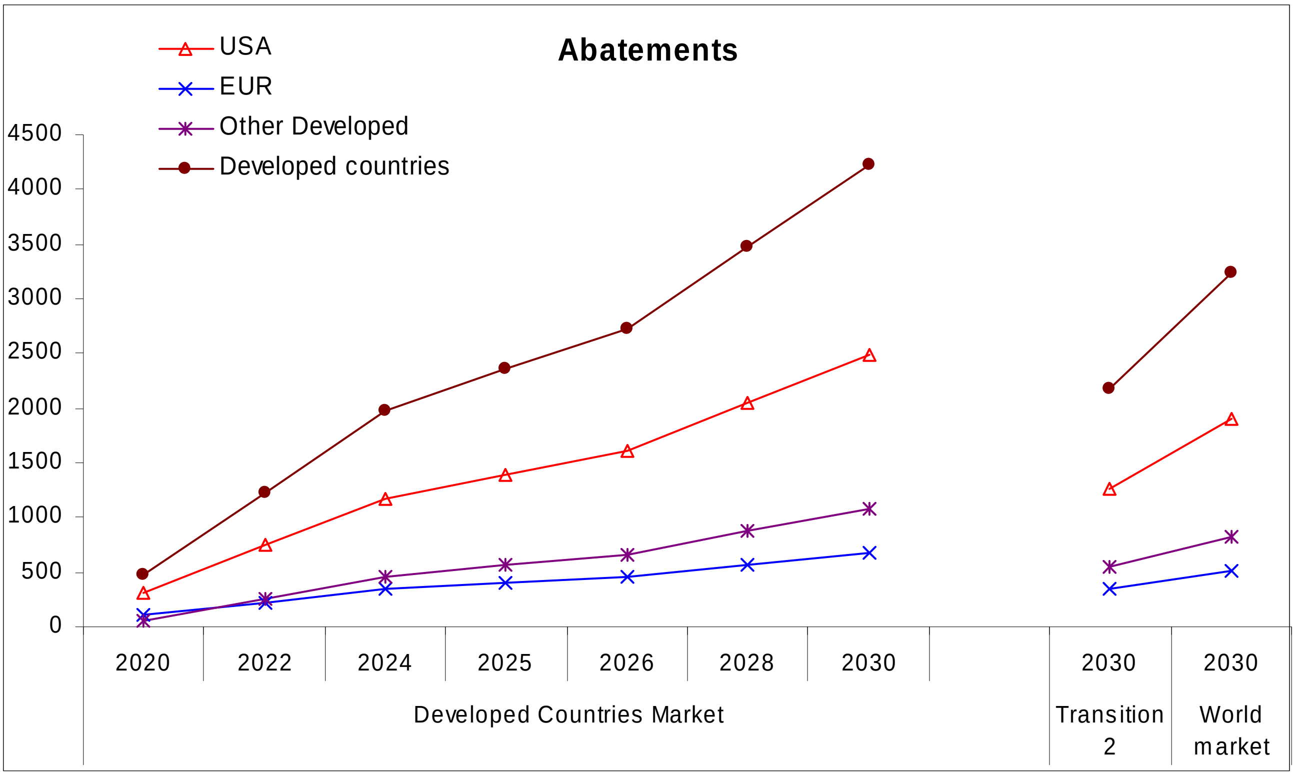


Figure15 : Transition from Developed Countries' to World Market scenario- Quotas