Nuclear energy and bio energy carbon capture and storage, keys for obtaining 1.5°C mean surface temperature limit

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Abstract: A rapid development of nuclear energy production reaching 173 EJ/y in 2060 and 605 EJ/y in 2110 limits the Global Mean Surface Temperature (GMST) increase to 1.5°C with respect to preindustrial value, with a reduction of the stored carbon dioxide from 800 Gt in the original MESSAGE-Efficiency scenario to 275 Gt in the present one, while multiplying by 6 the Total Primary Energy Supply between 2015 and 2110.

Keywords: climate warming; nuclear energy; carbon dioxide emissions; carbon capture and storage; bio energy; renewable energies.

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1 Introduction

To limit the increase of Global Mean Surface Temperature (GMST) with respect to the pre-industrial period to 1.5°C, as required by the IPCC following the Paris COP21 conference, the CO_2 budget is limited to 600 Gt CO_2 (Figueres et al., 2017; IPCC COP19, 2013). Figueres et al. (2017) propose an emission profile peaking around 43 Gt/y in 2025. To determine if such an objective is realistic, we use, as a reference, the scenario MESSAGE Efficiency of the GEA (2012) (Global Energy Assessment) which respects the RCP 2.6 as defined by the IPCC for limiting the increase of the GMST to 2°C.

2 The MESSAGE-efficiency scenario

The MESSAGE framework developed by the Vienna IIASA[1] (IIASA, 2012),[2] includes three scenarios fulfilling the 2.6 W/m^2 Representative Concentration Pathway as required by the IPCC (2014) in its fifth report (AR5). Scenario 'Supply' with a high energy consumption, scenario 'Efficiency' which implies the end of nuclear energy, paid by a decrease of energy consumption by 45% with respect to the "Supply scenario", and the intermediary 'MIX scenario'. All scenarios assume an extensive use of Carbon Capture and Storage, up to 24 Gt CO_2/y in 2100 for the Supply scenario and 15 Gt CO_2/y for the Efficiency scenario. Since the success of the CCS technology is far from being guaranteed at this level, we have offered an alternative by assuming a fast and important development of nuclear power in the Supply-N and Mix-N scenarios which followed the RCP 2.6 without necessity of CCS. This work has been published in *IJGEI* (Berger et al., 2017). The article was published before the Paris COP21 conference. The RCP 2.6 condition led to an increase of the Global Mean Surface Temperature (GMST) limited to 2°C with respect to pre-industrial conditions. Following the COP21 it was decided by the IPCC to lower the increase of the GMST to a maximum of 1.5°C (approximately RCP 1.9). Due to lack of time we have chosen to test our "high nuclear" approach with the MESSAGE Efficiency scenario transforming it from a no-nuclear to a high-nuclear scenario. The main reason for this "paradoxical" move was that Efficiency was the most sober scenario, thus improving the prospect to obtain a scenario agreeing with the new IPCC recommendations.

Figure 1 shows that the gross CO_2 emissions (addition of net emissions and CCS mass) should vanish around 2110. Carbon Capture and Storage has an important role in order to decrease the amount of CO_2 remaining in the atmosphere. Figure 1 also shows the evolution of the mass of CO_2 stored annually, as proposed in the "Efficiency" scenario. It reaches 15 Gt/y at the end of the century, with a fast rise beginning around 2050. In 2100 most of the CCS mass comes from bioenergy production (BECCS). The cumulated amount of stored CO_2 reaches 800 Gt by the end of the century. Whether it will be possible to store such a huge mass of CO_2 remains to be seen. Even if the technology proves to be effective, the amount of CO_2 present in the atmosphere will increase by 1100 Gt in 2100, while, if the CCS technology is not developed this additional amount will reach 1900 Gt, three times more than the allowed CO_2 budget. Berger et al. (2017) have shown that a rapid and significant development of nuclear production would be effective in reducing the use of fossil fuels and related CO_2 emissions. In the following, we keep the rate of increase of nuclear power described by Berger et al. (2017).

We name the present scenario "Efficiency-N". Figure 2 shows the increase of nuclear production over time. From 2030 to 2050 the newly built nuclear power would amount to 2700 GWe, an average annual growth of 135 GWe of new capacity. This appears to be a very large number. However, this is comparable to the rate obtained in France in the 1980s. Electricity production in France was around 400 TWh. In the present scenario electricity production would be around 26000 TWh, i.e. 65 times more than in France. Assuming a building rate proportional to the electricity production the 2700 GWe built in 20 years translates into 40 GWe while France built its 60 GWe reactors fleet in the same period.

Figure 1 CO_2 emissions (Gross and Net) and CCS mass (total and biomass energy) for scenario efficiency. With respect to the original scenario we have moved the time reference by 10 years

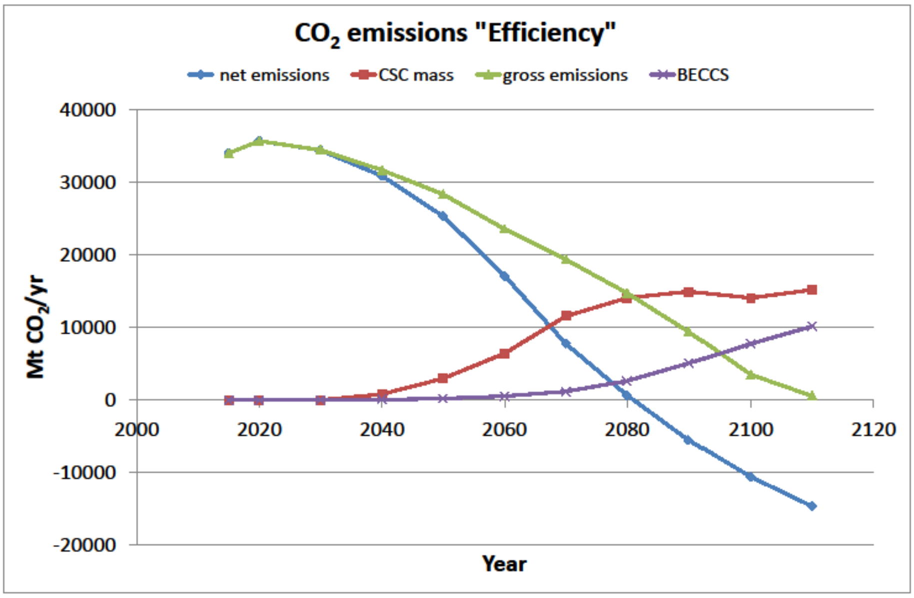
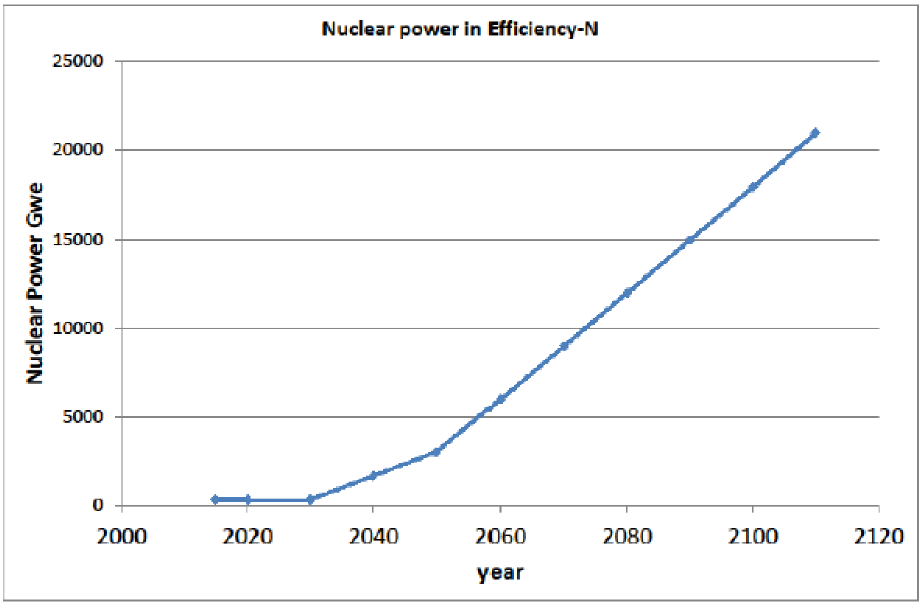


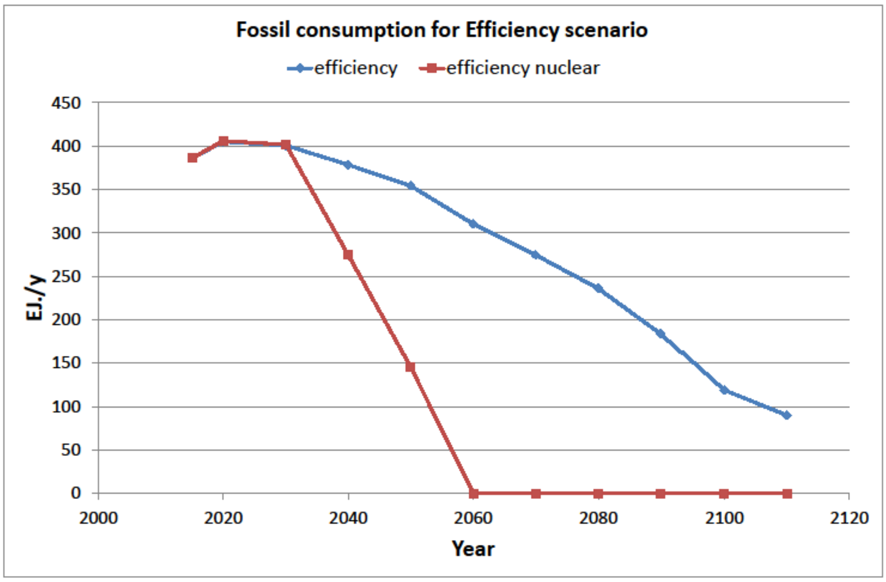
Figure 2 Nuclear power common to MESSAGE Supply-N, Mix-N and Efficiency-N scenarios



We have made the initial assumption that each MWh of new nuclear production replaces 2.7 MWh of fossil production according to the primary substitution rule given by the GEA program. This substitution is obtained first by switching fossil driven electricity production to the nuclear driven one, then switching heat production by fossils (especially natural gas) to electricity, and, finally, fossil mobility (gasoline, diesel, natural gas) to electric mobility.

Under these assumptions we obtain a prompt disappearance of the fossil component as seen on Figure 3. Fossils would stop being used in the energy sector by 2060.

Figure 3 Fossil consumption for the Efficiency and Efficiency-N scenarios (1 EJ = 10^{18} Joules = 277 TWh = 24 Mtep)



The disappearance of fossil contributions in the energy sector is expected to lead to a similar behaviour of CO_2 emissions, as shown on Figure 4. On the figure the standard "Efficiency" emissions are shown with and without CCS. For Efficiency-N CO_2 emissions are displayed when there is no CSS and, also when CSS is applied only to biomass energy.

On Figure 4 the negative emissions result from the balance between fossil emissions and CCS of biofuels. Indeed the combustion of biofuels is considered to be emission free as long as the burnt biomass is equivalent to biomass growth. Therefore, the stored CO_2 captured from biomass combustion is subtracted from the atmospheric CO_2 content.

The cumulated emissions resulting from the annual emissions of Figure 4 are shown on Figure 5.

The nuclear scenario Efficiency-N leads to a stabilisation of the atmospheric CO_2 content without the need of CCS. It limits the increase of the CO_2 content to 800 Gt, only 200 more than the 600 Gt which climatologists say would allow to limit the GST increase to 1.5°C. Insofar as the CO_2 content is stabilised (zero anthropic emissions) for some time it will start decreasing due to increased absorption by the Ocean and terrestrial biomass. One may expect that the preindustrial level of CO_2 atmospheric concentration might be reached again late in the 22nd century. This “back to normal“ behaviour might be accelerated by good biomass management.

Figure 4 Annual CO_2 emissions for the original scenarios Efficiency with and without CCS and for Efficiency-N without and with BECSS. Note that the three scenarios peak around 37 Gt/y, lower than the recommendation of Christina Figuerres et al.

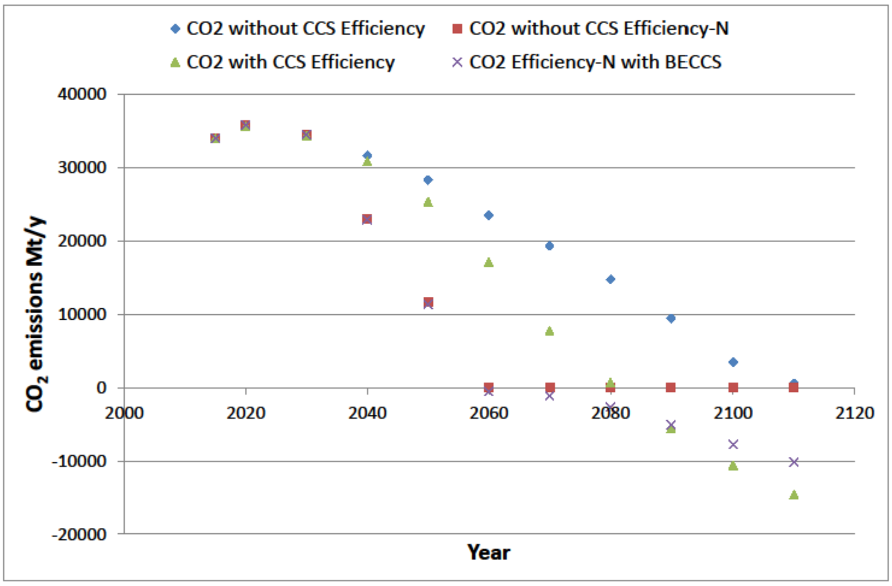
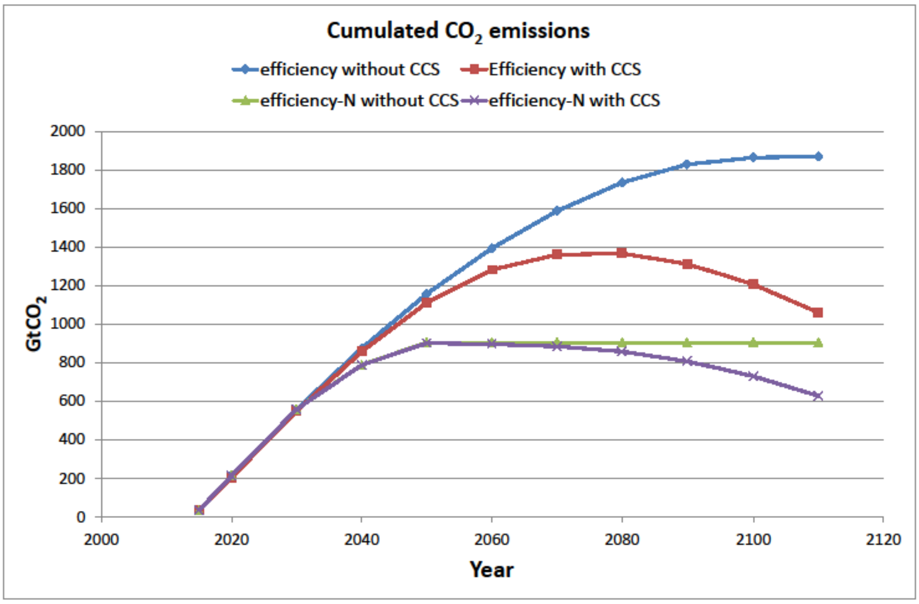


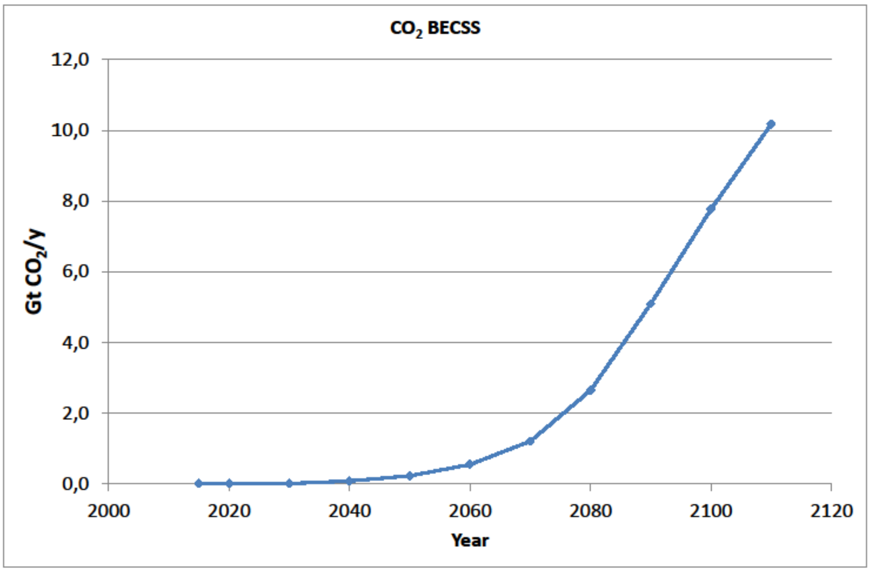
Figure 5 Cumulated CO_2 emissions with and without CCS



3 Biomass CO_2 capture and storage for cooling the atmosphere

In the MESSAGE efficiency scenario, biomass produces 220 Ej/y in 2100, mostly for transportation. Almost half of this CO_2 is supposed to be captured and stored. Assuming emission of 80 Mt CO_2 per EJ produced by biomass combustion, one obtains the evolution of the mass of carbon dioxide stored annually due to biomass combustion as shown on Figure 6. This mass has to be subtracted from anthropic CO_2 emissions. The result of this operation is also shown on Figure 5. The condition corresponding to the limiting global mean surface temperature (GMST) to 1.5°C above the pre-industrial level is fulfilled at 600 Gt on a decreasing trend. The stored CO_2 amounts to 280 Gt when CCS is only applied to Bio Energy compared to 800 Gt in the original MESSAGE-efficiency scenario.

Figure 6 Evolution of the mass of CO_2 stored from applying CCS to Biomass energy in MESSAGE Efficiency scenario



4 Use of nuclear surplus

The use of fossil fuels disappears around year 2060 as seen on Figure 3. The continuous use of excess nuclear production is not strictly required after this date for the sake of reducing CO_2 emissions. The two possible options of limiting nuclear production or not are shown on Figure 7.

The two choices lead to the same CO_2 emission patterns. Differences may appear concerning the global energy consumptions as shown on Figure 8. The figure shows the evolution of the Primary Energy Supply (TPES) when nuclear production is limited to 93 EJ/y and when there is no limitation. In this case the TPES is almost twice as high as when nuclear energy production is limited to 93 EJ/y. It is to be noted that, in this last case, the TPES is practically the same as that of the nonnuclear version of Efficiency.

This is due to the fact that we have used the substitution convention whereby 1 MWh nuclear produced is equivalent to 2.7 MWh of fossil primary energy.

Figure 7 Possible developments of nuclear production in the Efficiency-N scenario. The limited nuclear production meets the 1.5°C limit in the MESSAGE-efficiency-N scenario. The full production allows higher energy production as compared to that of the original MESSSAGE efficiency scenario, or alternatively to decrease the contribution of renewable energies

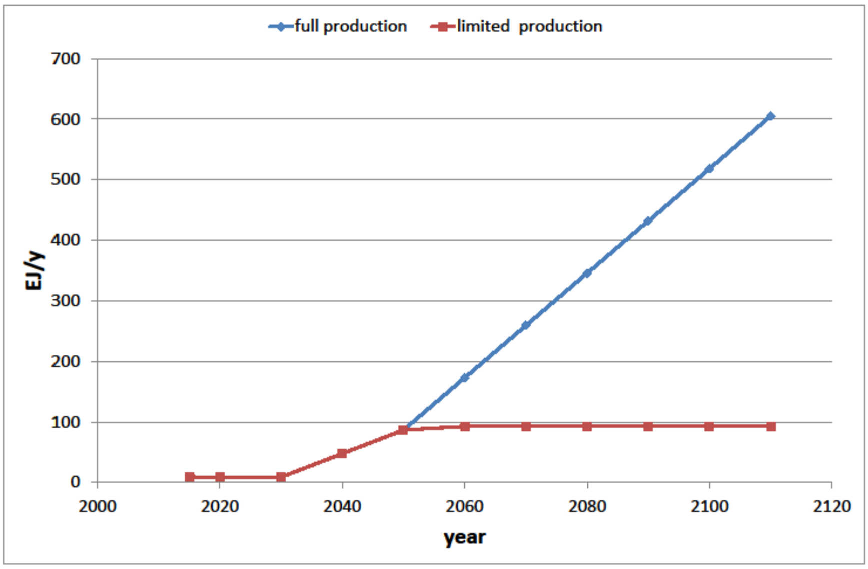
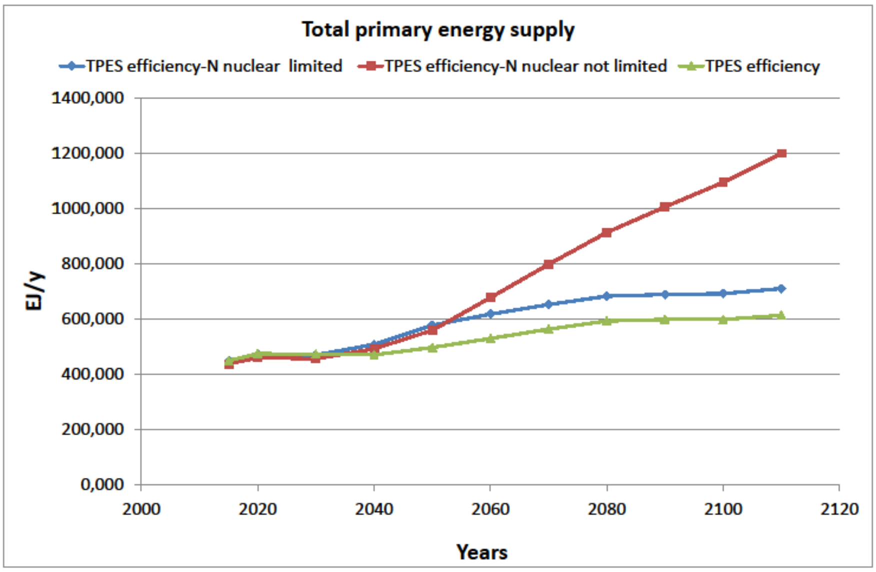


Figure 8 Total Primary Energies (direct convention) for the original Efficiency scenario and the scenarios Efficiency-N with and without limitation of the nuclear capacity



Excess heat from nuclear power could be used to carbonise biomass and store the so-produced Carbon in former coal mines, for example. Economically it would probably be necessary to fix a price to such stored carbon so that the operation is made profitable. Note that, once the stabilisation of the CO_2 concentration in the atmosphere obtained in 2060 (Figure 5) its rate of decrease is probably not an essential matter provided the 2000 level is obtained before 2200.

Another way to use the excess nuclear energy would be to decrease the share of renewable energies in the event that their intensive development would encounter difficulties.

5 Conclusion

The substitution of fossil energy by nuclear energy in the MESSAGE-efficiency scenario allows the end of fossil use in 2060 rather than 2100. With storage of 800 Gt of CO_2, the original efficiency scenario still leads to a cumulated mass of CO_2 injected into the atmosphere of 1100 Gt, while with a storage of only 275 Gt of CO_2, the scenario MESSAGE efficiency-N limits the CO_2 injected in the atmosphere to 600 Gt, compatible with the 1.5°C requirement. The nuclear direct primary energy needed for obtaining this result reaches 93 EJ in 2060 (25,600 TWh) produced thanks to a nuclear power of 3200 GWe. Without negative consequences on the climate, it should be possible to pursue the nuclear development reaching a nuclear production of 600 EJ/y in 2110. This would allow an increase of primary energy supply (following the direct primary energy convention of the GEA) from 900 EJ/y in the original efficiency scenario to 1300 EJ/y in the efficiency-N scenario with continued nuclear production development. Table 1 summarises the results we obtain for+ the scenario Efficiency-N and compares them to those of the original MESSAGE-Efficiency.

Table 1 Summary of the energy mix and CO_2 emissions for the Efficiency-N scenario in 2015, 2060 and 2110. Two options made for nuclear production. Number in brackets correspond to a nuclear production constant after 2060

	Efficiency	*Efficiency-N*	*Efficiency-N*	*Efficiency*
	2015	*2060*	*2110*	*2100*
Fossil EJ	386	0	0	90
Wind+solar EJ	0.717	96	283	283
Hydro EJ	10	21	23	23
Biomass EJ	42	98	221	221
Nuclear EJ	9	173	605 (173)	0
Primary energy EJ Direct GEA convention	448	388	1132 (700)	617
CO_2/y net Gt	34	–0.5	–10.2	–14
CO_2/y stored	0	0.5	10.2	15.2
Cumulated CO_2 stored	0	8	276	801
Cumulated CO_2 Atmosphere Gt	34	896	627	1270

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Notes

1 International Institute for Applied Systems Analysis.

2 The scenarios MESSAGE covered the period between 2005 and 2100. In this article we have changed the period covered from 2015 to 2110, since the evolution between 2005 and 2015 has been marginal.