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Confronting Nationally Determined Contributions to IPPC's +2 °C Carbon Budgets through the Analyses of France and Wallonia Climate Policies

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ABSTRACT

A method to objectively compare and link climate policies, expressed in CO_{2eq}, to IPCC's carbon budgets, expressed in CO_2-only, is exhibited, as countries often omit to so in their Nationally Determined Contributions. Furthermore, they are usually pledging only towards territorial targets despite the fact that imported emissions are now greater in occidental countries, thus relying on the countries they are importing from to achieve their own territorial emissions reductions. This paper demonstrates that the +1.5 °C carbon budgets of France and Wallonia will be exceeded even with territorial emissions only. For the +2 °C carbon budget to be secured, France should reduce its imported emissions at least to the same extent as their projected territorial emissions. For Wallonia, this is even emphasized since it has no margin in the +2 °C carbon budget with only the territorial emissions. It should therefore legally adopt more ambitious territorial and imported emissions reduction pathways with short-term commitments.

Keywords: global warming. carbon footprint. imported emissions. Nationally Determined Contributions. carbon budget. climate policy.

INTRODUCTION

At the 2015 United Nations Climate Change Conference (COP21), worldwide countries have adopted what is called as the "Paris Agreement", which consists in engaging themselves towards limiting global warming to 1.5 °C above pre-industrial levels, the absolute maximum acceptable increase being +2 °C (United Nations, 2015). The +1.5 °C target has been confirmed by the HAC (High Ambition Coalition) at the 2022 United Nations Climate Change Conference, known as the COP26 (HAC, 2021a) and was supported by 41 signatories at the time (HAC, 2021b), including the European Union (HAC, 2021a), therefore including France and Wallonia, concerned by this paper.

In 2018, IPCC (Intergovernmental Panel on Climate Change) officially published a report establishing the maximum amount of carbon dioxide that humankind still can emit in the atmosphere to be confident enough to respect the +1.5 °C or +2 °C targets set in the "Paris Agreement", i.e. reporting the notion of "carbon budget" (IPCC WGI, 2018). It does not matter whether these amounts of CO_2 are emitted today, tomorrow or in ten years and, the carbon budget being limited, it also trivially implies that humanity necessarily reaches zero net CO_2 emissions at some point. As illustrated later in Figure 2, the remaining carbon budget is linked to the increased global temperature, called "TCRE" or "transient climate response to cumulative emissions" (Rogelj, et al., 2019). Actually, in its Sixth Assessment Report (AR6), IPCC's Working Group I (WGI) has updated the carbon budgets set in 2018. As presented in Table 1, IPCC WGI reports that if humanity does not exceed 1150 $GtCO_2$ of emissions from January 1st 2020, it will have 2 out of 3 chances of not exceeding the +2 °C maximum limit set in the "Paris Agreement" (IPCC WGI, 2021). It is worth mentioning that even more recently, IPCC's Working Group III (WGIII) has reevaluated the non-CO_2 global warming contribution and has decreased

Table 1. IPCC's AR6 remaining carbon budgets from January 1st 2020

Likelihood of limiting global warming to temperature limit	Temperature limit of interest compared to preindustrial levels	Estimated remaining carbon budget from the beginning of 2020 ($GtCO_2$)
50%	+1.5°C	500 (IPCC WGI, 2021) / 510 (IPCC WGIII, 2022)
67%	+2°C	1150 (IPCC WGI, 2021) / 890 (IPCC WGIII, 2022)

the remaining 2020 budget from 1150 GtCO2 to 890 GtCO2 with updated modeling method and other non-CO2 mitigation scenarios (IPCC WGIII, 2022). Indeed, the non-CO2 mitigation scenarios previously considered in the WGI AR6 (IPCC WGI, 2021) are coming from the former IPCC report established back in 2018 (IPCC WGI, 2018). This work focuses on both the +2°C IPCC's AR6 carbon budget values (Table 1) because the +1.5°C target is already considered as unrealistic since IPCC's has reported that "global Greenhouse Gases (GHG) emissions in 2030 associated with the implementation of NDCs announced prior to COP26 would make it likely that such warming level will be exceeded during the 21st century" (IPCC WGIII, 2022).

One of the biggest challenges that still needs to be performed is to establish how these carbon budgets should be splatted fairly. Developing countries argue that they have the right to pollute as occidental countries have been doing it for 200 years. Colder countries argue that they require more energy to satisfy their primary need of heating whereas warmer countries argue that they need more air-conditioning. If the carbon budget were to be splatted by population, which is saying that every human being has the same carbon budget ("equity" principle between humans), developed countries would argue that "Third World" already achieve those emissions targets per capita and that it is impossible to make such tremendous and urgent changes in their well-established way of living (Gignac & Matthews, 2015). Fortunately, many countries have still already set their own GHG reduction targets, called "Nationally determined contributions" (NDCs), but the lack of consultation between each other is an important drawback.

The significance of this work therefore relies in confronting (and showing the gap between) the NDCs that individual countries/regions are actually trying to implement regarding climate change and the original promises their representants have stated at the yearly Convention on Climate Change, such as the latest +1.5 °C target supported by the HAC (which includes, amongst others, all European Union). The method used to highlight that gap, objectively based on IPCC's well accepted work, is also important as it could be easily reproduced by the many countries that are setting (or updating) their own NDCs, in order that they will hopefully respect IPCC's reported carbon budgets. Since most NDCs are expressed in terms of all-GHG emissions mitigation (CO_{2eq}), their comparison with IPCC's carbon budgets expressed in terms of CO_2-only is indeed not trivial. Therefore, this method is demonstrated in this paper through the case of France and Wallonia (one of the main Belgian regions).

This work also reports other limitations of current climate targets and strategies of France and Wallonia (and by extension, of many other public authorities that have currently similar NDCs).

MATERIALS AND METHODS

Carbon budgets background information

As reported in Table 1, carbon budgets are generally expressed in CO_2-only and not in total GHG emissions (CO_{2eq}). The main reason is that non-CO_2 GHG global warming potentials evolve in time differently accordingly to their own natural degradation or absorption rate. Similarly, their long-term behavior is very different to the one of CO_2, as illustrated in Figure 1 (IPCC WGI, 2013). It is indeed well-established that, unlike for CO_2 (and N_2O), the annual rate rather than the cumulative emissions of so-called short-lived climate pollutants (SLCPs) have the strongest effect on peak warming (Smith, et al., 2012). For example, it has been established that a 20-years delay in stringent methane mitigation has only an influence of 5 percentage points on the +2 °C carbon budget compared to a stringent short-term methane mitigation (Rogelj, et al., 2015), even though it has a 100-year global warming potential (GWP100) quite high, around 28 (Paulus, et al., 2022).

Since studies indicated that other GHG seem to be have less mitigation potential than for CO_2 (Gernaat, et al., 2015), their radiative forcing impact has been considered by implementing "an

absolute security" on the global warming temperature target, as illustrated in Figure 2 by the term called "Non-CO_2 contribution" (Rogelj, et al., 2019). Therefore, respecting such carbon budgets and thus achieving zero carbon emission at some point will ensure respecting the temperature increase limit, even if the non-CO_2 GHG net emissions do not reach zero as well. This "absolute security" on the global warming target has been estimated from the resulting radiative forcing of future non-CO_2 GHG emission at the moment at which global CO_2 emissions reach net zero (IPCC WGI, 2018). This has been performed by computing different non-CO_2 mitigation scenarios always consistent with a carbon neutral future implied by IPCC's carbon budgets (Rogelj, et al., 2019). This means that IPCC's CO_2 budgets of Table 1 implies that other GHG shall be mitigated parallelly. Indeed, it would not be relevant to consider CO_2 mitigation scenarios along with constant SLCP emissions over time because some of them are emitted by common sources, such as in many combustion processes (Rogelj, et al., 2015).

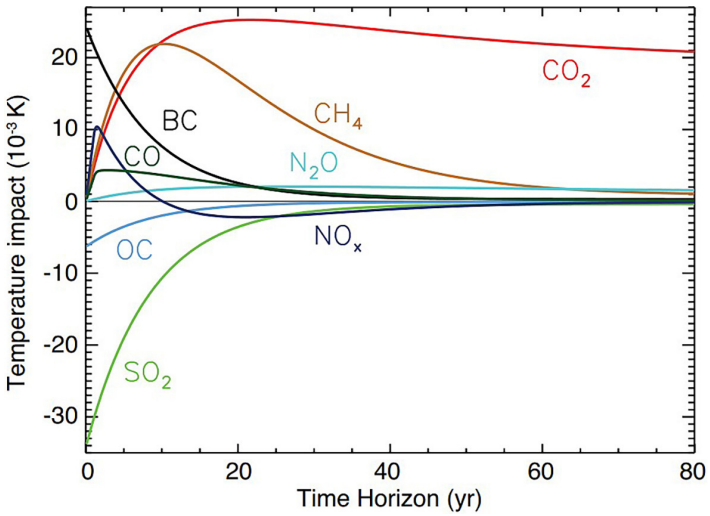

Figure 1. Short-term and long-term temperature response by component for a 1-year emission pulse. Emissions levels from 2008 except for black carbon (BC) and Carbon Monoxide (CO) for which their 2005 levels have been considered. Reproduced from reference (IPCC WGI, 2013)

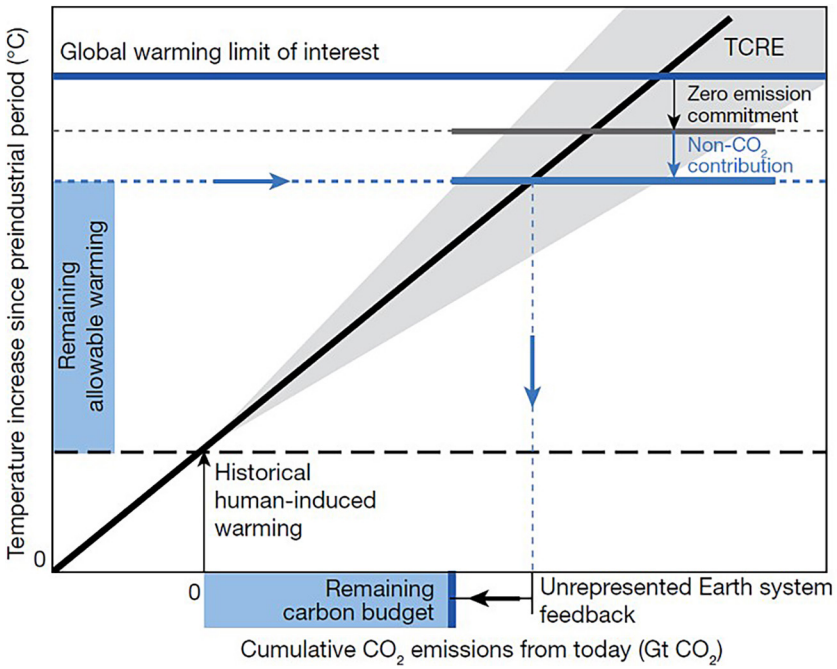

Figure 2. How non-CO_2 GHG are considered in IPCC's carbon budget expressed in CO_2-only emissions. Reproduced from reference (Rogelj, et al., 2019)

IPCC's carbon budgets also consider the fact that global mean surface air temperature might still increase after cessation of net CO_2 emissions. For example, this could occur because of the effect of thermal equilibration that mainly results in the decline of ocean heat uptake (Ehlert & Zickfeld, 2017). To ensure that the maximum temperature target is not exceeded due to that "inertia" effect, another "absolute security" term, called "Zero emission commitment", is considered. As it is shown in Figure 2 (Rogelj, et al., 2019), this term is also applied to the global warming temperature target.

At last, IPCC's carbon budgets include an additional security adjustment called "Unrepresented Earth system feedback", as presented in Figure 2 (Rogelj, et al., 2019). It is this time directly subtracted to the carbon budget (expressed in $GtCO_2$) because it accounts for (often "natural") additional uncontrolled "direct" GHG emissions linked to anthropogenic global warming. Although a lot of potential Earth system feedbacks exists and have been listed, such as the increased frequency of wildfires (Steffen, et al., 2018), their associated level of uncertainty is so wide (Lowe & Bernie, 2018) that the main one that is typically accounted for in carbon budgets is the amount of GHG that could be released by thawing of the permafrost (Rogelj, et al., 2019).

Current France and Wallonia NDCs

France and Wallonia, as well as the whole 27 countries of the European Union, are trivially supporting the European Green Deal initiated in 2019, which aims to a 55% minimum reduction of GHG compared to 1990 and a territorial carbon neutral objective for 2050 (Maris & Flouros, 2021). However, as it will be reported in Table 2, the European Green Deal objectives have not yet been totally implemented in legally adopted NDCs of Wallonia and France.

In 2020, France legally adopted its carbon budget for the years to come corresponding to its official goal of carbon neutrality to be achieved by 2050 (Ministère de la transition écologique, 2020a), as described in Figure 3. However, current France's law defines "carbon neutrality" only territorially and there is no direct link with the notion of "carbon footprint" (Ministère de la transition écologique, 2020a). That is unfortunately why Figure 3 only mentions territorial emissions and carbon sinks.

The trajectory to get to the 2050 target is considered linear from 2020 (Ministère de la transition écologique, 2020b). It is worth mentioning that France has not yet legally adopted the -55% GHG reduction objective of the European Green Deal (compared to 1990) in its GHG mitigation strategy, as visible in Figure 3 and reported in Table 2.

In Wallonia, such a projective GHG emission reduction curve with time and its resulting carbon budgets no longer exist. Indeed, the proposed 2023–2027 carbon budget (SPW, 2014) should have been voted by 2017 but it is not yet the case. Since March 2023, the legal current commitment of Wallonia in terms of GHG finally matches the European Green Deal (Gouvernement Wallon, 2023) but there is no legally adopted path on how to get to the 2050 target even though linear reduction pathways can be assumed, even by Belgian experts (AwAC, 2018) and officials (Gouvernement Wallon, 2019b).

Main criticisms of France and Wallonia NDCs

First of all, Wallonia's NDCs main limitation comes from the fact that it has only set a long-term objective and no longer adopts short-term carbon budgets, as stated in the previous section. Without short-term objectives and monitoring, it is likely that reduction in CO_2 emissions will be delayed, which must absolutely be prevented to avoid emptying all the carbon budget in the few years to come.

In addition, the either official (France) or unofficial (Wallonia) linear GHG reduction pathways could be discussed. Indeed, GHG mitigation has be known face barriers and would likely to be better represented with an inverted "S-curve" (Vandevyvere & Nevens, 2015), with a reduced slope in the beginning (important mitigation projects take years to be implemented and to be efficient) and in the end (further CO_2 emission reduction will be harder close

Table 2. Current NDCs for France and Wallonia compared to the European Green Deal

European Green Deal targets (Maris & Flouros, 2021)	France	Wallonia
55% reduction of GHG emissions by 2030 compared to 1990	Not yet legally adopted Current target is -40% (Ministère de la transition écologique, 2020a)	Targets finally legally adopted in March 2023 (Gouvernement Wallon, 2023). Previous 2050 target was -95% (Gouvernement Wallon, 2019a).
Carbon neutrality by 2050	✓ Legally adopted (Ministère de la transition écologique, 2020a)	

to the carbon neutrality goal as main mitigation projects will already be in place). Unfortunately, those are not the only limitations of current France and Wallonia NDCs, as explained here below.

What about imported emissions and total carbon footprint?

What is common between the two studied public policies is that they only express targets based on territorial emissions. However, other GHG emissions accounting methods exist, such as the Consumption-Based System (CBS), which covers all emissions resulting from the consumption of local and imported goods and services (Lombardi, et al., 2017). Therefore, it is considered more comprehensive than production-based and territorial models (Feng, et al., 2014), especially for European countries for which imported emissions represent the main part of the carbon footprint (Klemeš, et al., 2017), as it is for example shown for France in Figure 4 (HCC, 2020).

This figure also demonstrates that even though territorial emissions are decreasing, imported emissions are greater and they are increasing up to a point that the resulting carbon footprint remains stable. This figure even finds its equivalent in France's official governmental documents: the French government establishes that their imported emissions were 1.8 times greater than territorial emissions in 2018 and it acknowledges that "in the French situation, imports that substitute national production generally degrade the carbon footprint" (Ministère de la transition écologique, 2020a). This is because the imported goods might be produced in a region where the energy mix is more CO_2-reliant, where climate strategies are less ambitious. Furthermore, transportation emissions increase with imported goods.

This problem is also implicitly shown in Wallonia's official governmental documents, as it is demonstrated in Figure 5. This curve is showing that historical territorial reductions of emissions are almost never resulting from measures taken in the context of GHG mitigation strategies. Indeed, they are mainly due to tremendous changes in the industry or in the economy that only occurred at the local scale. For example, the world steel industry has not been decreasing as in Wallonia and it has even been growing, like its resulting global CO_2 emissions (Mohan, et al., 2010).

Thus, one can expect that Wallonia (or Belgian) carbon footprint has also not been reduced during that time and that is what literature is showing, at least up to 2007 (Hambÿe, et al., 2018) and even up to 2011 (Towa, et al., 2022). Those study has evaluated Belgian's 2007 and 2011 carbon footprints respectively to 16 tCO_{2eq}/year and 15.4 tCO_{2eq}/year per capita considering a Belgian population of about 11 million in 2011 (Towa, et al., 2022). This is consistent with other sources that evaluated Belgian's 2001 carbon footprint to 16.5

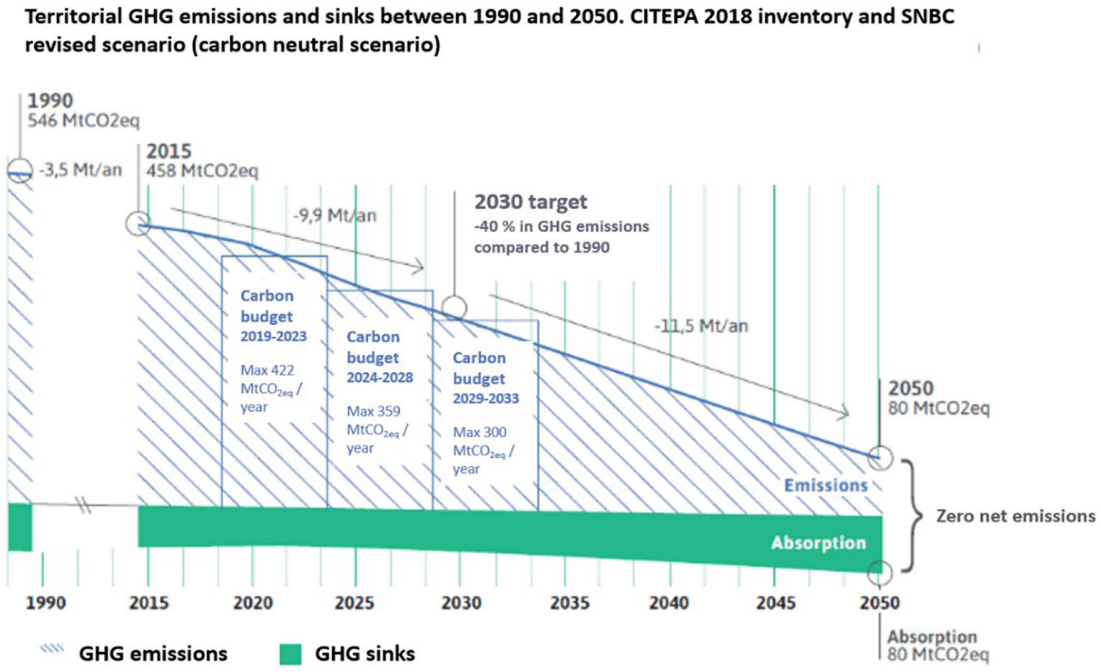

Figure 3. Official carbon budgets adopted in April 2020 for France. Traduced reproduction of official revised France low carbon strategy (Ministère de la transition écologique, 2020b)

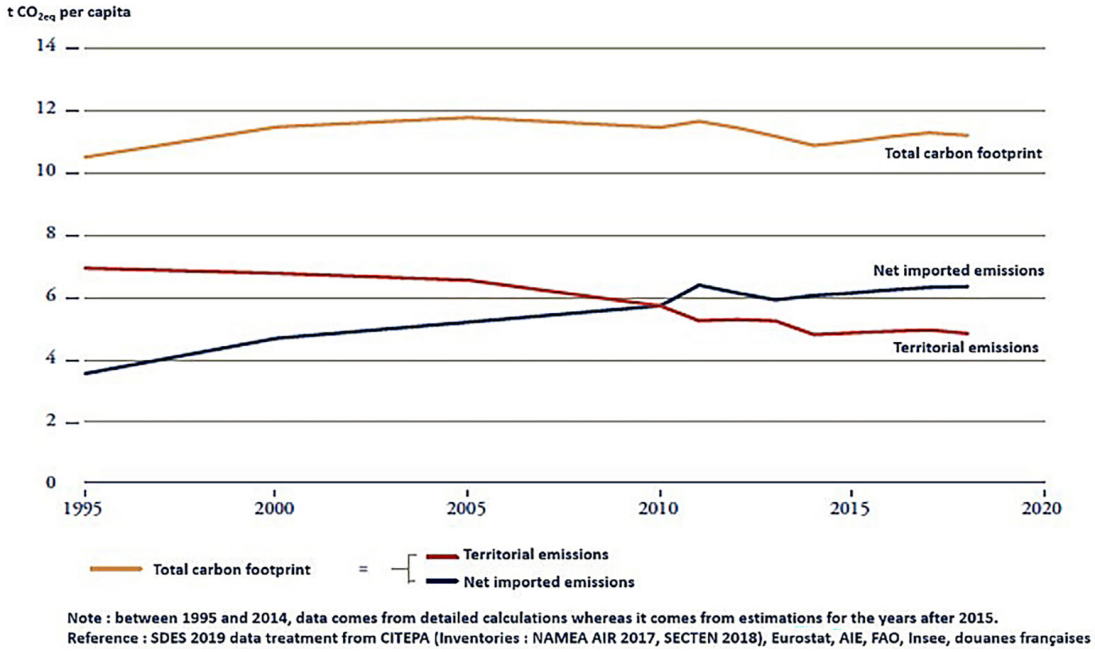

Figure 4. Historical evolution of France's individual carbon footprint between 1995 and 2018, which remains quite constant and around 11 tCO_{2eq}/year per capita. Traduced reproduction of HCC report on how to handle carbon footprint (HCC, 2020)

tCO_{2eq}/year per capita (Hertwich & Peters, 2009). Unfortunately, no Belgium carbon footprint figure has been found after 2011 but there is nothing that indicates that it has been significantly lowered if one looks at the French case stated here (Figure 4). Regrettably, to the knowledge of the authors, Wallonia's carbon footprint has only been established once in a detailed study to 15 tCO_{2eq}/year per capita for the year 2011 (Towa, et al., 2022).

It is worth mentioning that the imported emissions problem is already acknowledged by public authorities. On the one hand, France is recognizing in its legally adopted documents (Ministère de la transition écologique, 2020a) the need to monitor carbon footprint as an indicator to evaluate the results of climate mitigation measures, the need to push people decrease their carbon footprint, the need to associate with economic partners that are also ambitious about emissions reduction. It even mentions, without any binding commitment, that the final 2100 objective should be between 1.6 and 2.8 tCO_2/year per capita to limit global warming to maximum +2 °C (CO_2-only, not the whole GHG footprint).

On the other hand, Wallonia is way behind because its legally adopted strategy only mentions the need to give a special attention to "the carbon footprint of vehicles and their fuels" (Gouvernement Wallon, 2019a) or of "numerical technologies" (Gouvernement Wallon, 2023), for examples.

Since, in both cases, there is no unambiguous legally adopted carbon footprint target, no tangible method defined, those few recommendations regarding carbon footprint might be considered as simple "wishful thinking". Only considering territorial emissions and not the imported ones (thanks to tangible carbon footprint targets, for example) represents a wide opened door to all kind of populist oppositions to global warming mitigation measures. Firstly, this individualism behavior only tends to delocalized GHG emissions and not reduce them (as demonstrated in the last decades with Figure 4 for France and Figure 5 for Wallonia). Secondly, by having lower territorial emissions compared to the countries which goods are imported from, a sentiment of "whataboutism" (Lamb, et al., 2020) could arise and even slow down further territorial emission reductions: "Why should we decrease our territorial emissions even further because their only represent a small fraction of worldwide GHG emissions?". For example, this sentiment could strengthen the already strong "NIMBYsm" ("Not-In-My-Backyard") public resistance (Petrova, 2013) and slow down renewable energy penetration.

How can people relate to territorial emissions targets only

Furthermore, populations will hardly relate to territorial objectives, as they will rightly consider that

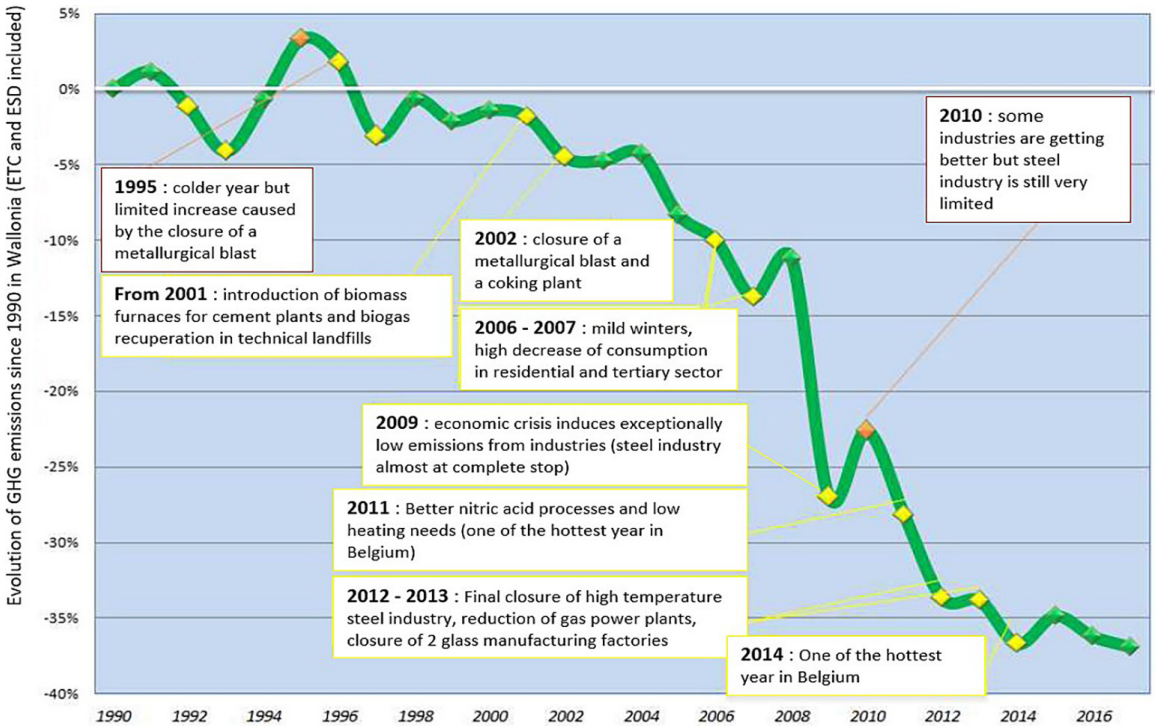

Figure 5. Historical evolution of GHG emissions in Wallonia. Traduced reproduction of legally adopted Wallonia 2030 strategy for air, energy and climate, originally requested by Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11th December 2018 (Gouvernement Wallon, 2019a)

those apply primarily to the public authorities and to private companies. Again, some kind of "what-aboutism" sentiment (Lamb, et al., 2020) is likely to occur. And it has already been stated that there is nothing that prevents those authorities and private companies from relocating their production even in less ambitious countries to cope with territorial GHG targets.

In fact, it is well-established that solving the climate crisis relies on changing human behavior (Semenza, et al., 2008) and, to achieve it without redhibitory resistance, applied policies and economics must meet people where they are, with "audience-specific messaging and framing" (Moser, 2009). Using carbon footprint targets, especially expressed per capita or per household, along with providing people with simple carbon footprint calculators for them to evaluate themselves and their actions, is one the first step for inducing those required behavior changes. Even though methods of calculating carbon footprint are from a global consensus (Pandey, et al., 2011), they allow public sensibilization about the order of magnitude of their emissions (including the imported ones).

Methodology and data source

As conducted in the following section, the methodology considered in this paper computes the whole projected CO_2-only emissions over the 2020–2050, based on current emission levels and on the mitigation pathways reported in the studied NDCs, so they can directly be compared to the relevant IPCC's "equity" carbon budgets (expressed in CO_2-only). Unfortunately, whereas current CO_2-only emissions are easily obtained, studied NDCs consider all-GHG 2050 targets (expressed in CO_{2eq}) and 2050 CO_2-only targets are not officially reported. However, 2050 non-CO_2 emission levels, which cannot be fully mitigated and which occur in stabilized GHG emissions future, once CO_2 neutrality has managed to be reached (Gernaat, et al., 2015), have been established by IPCC to 8 $GtCO_{2eq}$/year (IPCC WGIII, 2022). This (worldwide) figure can also be allocated to countries following the "equity" principle (according to population shares, that must therefore be considered). So, the 2050 CO_2-only emissions can be obtained by subtracting the allocated non-CO_2 2050 projected emissions to the all-GHG target reported in the respective NDCs. The CO_2-only emission pathways from 2020 to 2050 are assumed linear as it is the mitigation pathway assumed by both France (Ministère de la transition écologique, 2020b) and Wallonia (AwAC, 2018) officials.

RESULTS

Are the NDCs in line with IPCC's +2 °C carbon budgets?

With 2020 population data for Wallonia (Bureau du Plan, 2020) and for the World (PRB, 2020), Wallonia currently accounts for 0.048% of the world's population. With IPCC's Sixth Assessment carbon budget of 1150 $GtCO_2$, its carbon budget from January 1st 2020 can be established to 540 $MtCO_2$. However, one might consider that this 540 $MtCO_2$ budget is overestimated because it should not only take into account the demographics of a single year but of its evolution through time. Since the share of the European Union in the total population of the world will decline (van Nimwegen & van der Erf, 2017), the remaining budget of Wallonia can be considered lower. Indeed, for example, considering 2050 Wallonia (Bureau du Plan, 2020) and world's (PRB, 2020) demographic projections, the share of Wallonia in the world's population will decrease down to 0.039%. That would account for a remaining 2020 budget of 449 MtCO2, 17% lower than the carbon budget based on population data of 2020.

It has been considered in this study that the actual remaining carbon budget shall simply be averaged between the carbon budgets calculated with 2020 and 2050 population data and projection, even though it would be more relevant to implement yearly updates based on updated population data and projections. The main reason is that having a constantly changing carbon budget would be confusing to the public that, as stated, needs to relate to the GHG mitigation objectives. Therefore, to compare Wallonia's commitment to the +2 °C IPCC's Working Group I remaining budget of 1150 $GtCO_2$ (IPCC WGI, 2021) considered here, this study will consider a 2020 carbon budget of 494.5 $MtCO_2$. With updated IPCC's Working Group III remaining budget of 890 $GtCO_2$ (IPCC WGIII, 2022), Wallonia's 2020 carbon budget can be considered equal to 382.7 $MtCO_2$. All those calculations have been reported in Table 3 (which also presents the case of France). Table 3 also reports the projected CO2 emissions from 2020 to the 2050 according to Wallonia and France's current NDCs to allow the comparison with those remaining IPCC "equity" carbon budgets.

Based on territorial emissions only, it has been established from Table 3 that French current NDC indeed ensures IPCC's carbon budgets with a minimum margin of about 20% (about 1400 $MtCO_2$) against the lower IPCC's AR6 carbon budget (the one of Working Group III, equal to 890 $GtCO_2$).

On the other hand, Wallonia's projected CO_2 emissions are estimated just in between the carbon budgets of IPCC's Working Group I and IPCC's Working Group III (that have been established to "likely" remain below the +2 °C target). However, territorial absorption, expressed in CO_{2eq} or in CO_2-only as it is the main GHG naturally or technologically absorbed (McLaren, 2012), has not been considered. Wallonia's natural CO_2 absorption capability is not well-known but has been estimated to 1 $MtCO_2$/year (Gouvernement Wallon, 2019b), which could/should be increased by 2050 and fortunately decrease the accumulated CO_2 to potentially ensure both IPCC's carbon budget. It is worth mentioning that in a carbon neutral future, carbon sinks must not only compensate for CO_2-only emissions, but also the unavoidable GHG emissions (see Table 3). Subsequently, the calculations of their beneficial aspects on CO_2 accumulation is not trivial. One method would consist in only considering the impact of non-CO_2 SLCPs for the 20 years prior to peak warming (Allen, et al., 2018), which would mean that current natural CO_2 sinks could be fully considered at least in the 2020–2030 period.

Wallonia, having no (or even negative) margin against IPCC's carbon budgets, must therefore closely monitor their GHG emissions and prevent any decrease in their territorial natural sinks. It would also be preferable to commit to more ambitious GHG reduction targets (especially short-term targets to avoid long-lived CO_2 accumulation) and to commit to natural sinks increase in parallel of investing in CCS, i.e. Carbon Capture and Storage (Nataly Echevarria Huaman & Xiu Jun, 2014) and/or DAC, i.e. Direct Air Capture (McQueen, et al., 2021) currently unmatured technologies.

However, it must be stressed that this study considers that carbon technological sequestration and capture can only represent an uncertain opportunity that should be further developed before entering climate strategies, as CO_2 net emissions reduction must rely on tangible commitments and current proven technologies. Humanity cannot indeed afford to bet on uncertain technologies. Furthermore, if those technologies really happen to spread in the future, there is no guarantee that the economic and fiscal context will prevent the beneficial resulting CO_2 reduction not to be associated with an increase of consumption and a considerable

Table 3. Equity +2 °C carbon budgets from January 1st 2020 against Wallonia and France current NDCs

Data and calculations	Wallonia	France
Projected GHG emissions in 2050 from NDCs (without LULUCF[a])	2.8 $MtCO_{2eq}$/year[b] (Gouvernement Wallon, 2019b)	80 $MtCO_{2eq}$/year (Ministère de la transition écologique, 2020b)
Population share in 2050	0.039% (Bureau du Plan, 2020; PRB, 2020)	0.720% (PRB, 2020)
Share of the unavoidable non-CO_2 emission in 2050, i.e. 8 $GtCO_{2eq}$/year (IPCC WGIII, 2022)	3.12 $MtCO_{2eq}$/year	57.6 $MtCO_{2eq}$/year
Deduced resulting CO2-only emission in 2050 according to current NDCs	±0 $MtCO_2$/year	22.4 $MtCO_2$/year
2020 CO_2-only emission data (without LULUCF[a])[d]	28.4 $MtCO_2$/year (Iweps, 2022)	289 $MtCO_2$/year (CITEPA, 2022)
CO_2-only emissions over the 2020-2050 period assuming linear decrease (without LULUCF[a])[d]	440.2 $MtCO_2$[c]	5501.0 $MtCO_2$
Population share in 2020	0.047% (Bureau du Plan, 2020; PRB, 2020)	0.835% (PRB, 2020)
Average population share in the 2020-2050 period	0.043%	0.778%
Equity +2 °C carbon budget from AR6 WGI total budget of 1150 $GtCO_2$ (IPCC WGI, 2021)	494.5 $MtCO_2$	8947 $MtCO_2$
Equity +2 °C carbon budget from AR6 WGIII total budget of 890 $GtCO_2$ (IPCC WGIII, 2022)	382.7 $MtCO_2$	6924 $MtCO_2$

Note: [a] Land Use, Land Use Change and Forestry related net emissions, usually considered as a carbon sink in Europe (Blujdea, et al., 2015).

[b] In March 2023, Wallonia has legally adopted his new Plan for Air, Climate and Energy named "PACE 2030" to match the European Green Deal targets stated in Table 2 (Gouvernement Wallon, 2023). It confirms the 2050 target of Table 3 emitted in 2019, stating that 2050 neutrality will be achieved with technological and natural territorial absorption.

[c] This does not consider the 2030 -55% GHG emissions objective (Table 2). However, the linear pathway from 2020 to 2050 considered in Table 3 would lead in 2030 to a -66.6% reduction of GHG compared to 1990 levels, i.e. higher than the -55% legally adopted target. Therefore, the total CO_2-only emissions projected for Wallonia over the 2020–2050 period in its latest NDC would even be higher than the one reported in Table 3. The problem is that the share of CO_2-only and non-CO_2 emissions corresponding to the -55% GHG goal in 2030 is not known. However, it can be assumed that the projected non-CO_2 emissions would follow a linear pathway between their 2020 and 2050 levels, i.e. respectively 5.8 $MtCO_{2eq}$/year (Iweps, 2022) and 3.12 $MtCO_{2eq}$/year (Table 3). This would lead to a 4.85 $MtCO_{2eq}$/year non-CO_2 emissions level in 2030 to cope with the -55% GHG target, which would subsequently imply CO_2-only emissions of 20.35 $MtCO_{2eq}$/year. Again assuming linear pathways between 2020 and 2030 and then between 2030 and 2050, this would lead to 471.6 $MtCO_2$ over the 2020–2050, which is only slightly higher than 440.2 $MtCO_2$ reported in Table 3, and has no influence on any of the statements made in this work.

[d] This study considered the year 2020 for a direct comparison with IPCC's carbon budgets. However, the reported 2020 emissions levels might not be considered as sufficiently representative as it was the first year of the Covid-19 crisis which has decreased worldwide CO_2 emissions from about 7–8% compared to 2019 (Kumar, et al., 2022). However, considering slightly higher emission levels for the year 2020 would not significantly affect any of the statements made in this work.

"rebound effect", as it has been demonstrated in the past with the introduction of energy efficient technologies (Brännlund, et al., 2007).

Are the +2 °C carbon budgets still secured considering imported emissions?

Figure 4 has shown that net imported emissions are even greater than territorial emissions in France. Another study only on CO_2 has shown that Belgium and France share of CO_2 emitted abroad in total CO_2 embodied in domestic final demand was equal to about 45% in 2015 (Yamano & Guilhoto, 2020). This study also showed that the imported emission share has increased between 2005 and 2015 by about 2.5–3 percentage points, which partially correlates with Figure 4.

Therefore, for Wallonia, it is clear that IPCCs +2 °C carbon budgets of Table 3 will be highly exceeded by considering the impact of imported emissions, as it has already no margin with the territorial emissions only. This means that it is vigorously advised that GHG emissions of imported goods shall be reduced even more than the territorial emissions (possibly both in quantity and in carbon intensity), in addition to the other GHG mitigation measures stated in the previous section.

For France, lower equity carbon budget from IPCC's Working Group III will surely be exceeded as well, considering a constant share of CO_2 emitted abroad in total CO_2 embodied in domestic final demand to its current value (Yamano & Guilhoto, 2020). On the other hand, exceeding the carbon budget from IPCC's Working Group I will depend on the amount of the carbon intensity of future imported goods. Indeed, it will obviously be exceeded by considering the current fact that territorial GHG reduction is unfortunately compensated for in the carbon footprint by higher imported emissions (Figure 4). However, by considering a constant share of CO_2 emitted abroad in total CO_2 embodied in domestic final demand to its current value (Yamano & Guilhoto, 2020), it will not likely be exceeded. This basically means that the GHG reduction effort to be made on imported emissions must at least reach the same extent as the one projected on the territorial emissions.

Considering potential territorial absorption capacity will not change those statements except that for France, the projected absorption capacity of 80 $MtCO_2$/year achieved in 2050 (Ministère de la transition écologique, 2020b) will possibly secure the lower carbon budget of IPCC's Working Group III in addition of the one of Working Group I (Table 3), at least if the share of CO_2 emitted abroad in total CO_2 embodied in domestic final demand remains constant or even reduces. As expected, if Table 3 was considering the +1.5 °C carbon budgets reported in Table 1, those would be significantly exceeded for both France and Wallonia's current NDCs, even with the territorial emissions only.

DISCUSSION

A small limitation of the method considered in this paper to verify the relevance of NDCs against IPCC's carbon budgets is that it considers a linear evolution over time of the share of nationals population compared to the world's over time. It could consider the exact future population trend even though it will very unlikely change the statements made in this work.

At last, by lack of available data for 2021 and 2022, recent CO_2 emissions trends of Wallonia and France have not been verified, especially if they are following the assumed reduction (linear) pathway projected in the respective NDCs. Indeed, if that was not the case and emissions were not reduced (enough) compared to 2020 levels, the carbon budgets should be updated and would be even lower than the one considered in this work. This is even emphasized as 2020 was the first year of the Covid-19 crisis which has decreased worldwide CO_2 emissions from about 7–8% compared to 2019 (Kumar, et al., 2022). Projected and actual reduction pathway as well as remaining carbon budget shall thus be closely monitored and updated yearly.

CONCLUSIONS

This paper has identified some of the main limitations of current Nationally Determined Contributions (NDCs) for France and Wallonia climate strategies, which are likely to be applicable to similar NDCs of other countries.

Wallonia, unlike France, has currently only a long-term mitigation commitment and has unfortunately abandoned establishing short-term carbon budgets, unlike France. Absence of short-term objective constitutes a very likely risk of delaying CO_2 mitigation. Both current NDCs assume linear Greenhouse Gases (GHG) reduction trajectories whereas "S-curve" pathways seem more realistic to account more the well-established inertia of major GHG mitigation projects. People, which must absolutely embark in the transition, can hardly relate to GHG objectives that are applicable to the scale of their public authority, as it is the case in both current NDCs.

Current NDCs only treat territorial emissions, leaving the door open to GHG emissions delocalization, which has in fact been demonstrated for the last decades for France in Figure 4 (which shows that total carbon footprint does not decrease) and for Wallonia in Figure 5. GHG emissions are likely to be delocalized in countries less ambitious towards GHG mitigation or with more CO_2 reliant industries. Delocalization also often increases GHG emissions due to transportation. At last, only focusing on territorial emissions constitutes an individualistic behavior that leaves the main GHG mitigation effort on exporting countries. This could even lead to a "whataboutism" (Lamb, et al., 2020) sentiment in importing countries and slow down the acceptance of GHG mitigation measures: "Why should we decrease our territorial emissions even further because they only represent a small fraction of worldwide GHG emissions?"

On one hand, this paper also demonstrated that if the emissions targets in France's NDCs

are actually met, IPCC's +2 °C AR6 2020 equity carbon budgets will likely be ensured (based on territorial emissions only). With imported emissions, it can be considered that there is no margin left in France's carbon budget when considering a 45% constant share of CO_2 emitted abroad in total CO_2 embodied in domestic final demand (Yamano & Guilhoto, 2020). This basically means that the GHG reduction effort to be made on imported emissions must at least reach the same extent as the one projected on the territorial emissions.

On the other hand, for Wallonia, since it can be considered that there is no margin in the CO_2 budget even with territorial emissions only, the following recommendations have been made. Setting a more ambitious GHG reduction pathway (especially with short-term commitments to avoid CO_2 accumulation) to make room for imported emissions. Lowering the imported GHG emissions to an even quicker rate than territorial emissions (lowering the quantity of imported goods as well as their carbon intensity, for example by choosing economic partners that share ambitious GHG mitigation commitments). Monitoring closely the projected CO_2 reduction pathway and updating it directly in case of delay in GHG mitigation. This constitutes a parallel opportunity to also monitor carbon footprint, as it has never been established in a detailed study for Wallonia. Preserving and extending natural carbon sinks. Potentially investing in Carbon Capture and Storage (CCS) and/or Direct Air Capture (DAC) technologies (only in order to possibly increase margin in the CO_2 budgets as those technologies are unmatured).

At last, although both France and Wallonia have confirmed the +1.5 °C maximum global warming target (HAC, 2021a), this paper demonstrated that even the projected territorial emissions only will exceed IPCC +1.5 °C AR6 2020 equity carbon budgets (according to their current NDCs).

REFERENCES

1. Allen, M.R. et al. 2018. A solution to the misrepresentations of CO2-equivalent emissions of short-lived climate pollutants under ambitious mitigation. npj Climate and Atmospheric Science, 1(1).
2. AwAC. 2018. Avis du Comité des experts relatif à la proposition de budgets d'émissions pour les périodes 2023-2027 et 2028-2032. Comité des experts de l'AwAC.
3. Blujdea, V.N., Viñas, R.A., Federici, S., Grassi, G. 2015. The EU greenhouse gas inventory for the LULUCF sector: I. Overview and comparative analysis of methods used by EU member states. Carbon Management, 6(5–6).
4. Brännlund, R., Ghalwash, T., Nordström, J. 2007. Increased energy efficiency and the rebound effect: Effects on consumption and emissions. Energy Economics, 29(1).
5. Bureau du Plan. 2020. Perspectives démographiques 2019–2070: Population et ménages.
6. CITEPA. 2022. Rapport National d'Inventaire pour la France au titre de la Convention cadre des Nations Unies sur les Changements Climatiques et du Protocole de Kyoto. Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique, Ministère de la Transition Ecologique et Solidaire.
7. Ehlert, D., Zickfeld, K. 2017. What determines the warming commitment after cessation of CO2 emissions?. Environmental Research Letters, 12(1).
8. Feng, K., Hubacek, K., Sun, L., Liu, Z. 2014. Consumption-based CO2 accounting of China's megacities: The case of Beijing, Tianjin, Shanghai and Chongqing. Ecological Indicators, 47.
9. Gernaat, D.E. et al. 2015. Understanding the contribution of non-carbon dioxide gases in deep mitigation scenarios. Global Environmental Change, 33.
10. Gignac, R., Matthews, H.D. 2015. Allocating a 2°C cumulative carbon budget to countries. Environmental Research Letters, 10(7).
11. Gouvernement Wallon. 2019a. Contribution de la Wallonie au Plan National Energie Climat 2030 (PNEC 2030).
12. Gouvernement Wallon. 2019b. Stratégie à long terme pour la Wallonie (SLT 2050): «Vers une Wallonie climatiquement neutre en 2050».
13. Gouvernement Wallon, 2023. Plan Air Climat Energie (PACE) 2030, s.l.: s.n.
14. HAC. 2021a. High Ambition Coalition COP 26 Leaders' Statement, 2nd November 2021, Glasgow: High Ambition Coalition.
15. HAC. 2021b. Energy growing behind ambitious Glasgow Package, 8th November 2021, Glasgow: High Ambition Coalition.
16. Hambÿe, C., Hertveldt, B., Michel, B. 2018. Does consistency with detailed national data matter for calculating carbon footprints with global multi-regional input–output tables? A comparative analysis for Belgium based on a structural decomposition. Economic Structures, 7(11).
17. HCC. 2020. Maîtriser l'empreinte carbone de la France - Réponse à la saisine du gouvernement. Haut Conseil pour le Climat.
18. Hertwich, E., Peters, G. 2009. Carbon Footprint of Nations: A Global, Trade-Linked Analysis. Environmental Science & Technology, 43(16).

19. IPCC WGI. 2013. Climate Change: The Physical Science Basis. IPCC - Working Group I Technical Support Unit.
20. IPCC WGI. 2018. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels. IPCC - Working Group I Technical Support Unit.
21. IPCC WGI. 2021. Climate Change 2021: The Physical Science Basis - Summary for Policymakers. IPCC - Working Group I Technical Support Unit. https://doi.org/10.1017/9781009157896.001
22. IPCC WGIII. 2022. Climate Change 2022: Mitigation of Climate Change - Summary for Policymakers. IPCC - Working Group III Technical Support Unit. https://doi.org/10.1017/9781009157926.001
23. Iweps. 2022. Emissions de gaz à effet de serre (GES) - Fiche A006-REDUC.GES - dernières données régionales disponibles au 01/06/2022.
24. Klemeš, J.-J., Liu, X., Varbanov, P.-S. 2017. Virtual greenhouse gas and water footprints reduction: emissions, effluents and water flows embodied in international trade. Chemical Engineering Transactions, 56.
25. Lamb, W. et al. 2020. Discourses of climate delay. Global Sustainability, 3.
26. Lombardi, M., Laiola, E., Tricase, C., Rana, R. 2017. Assessing the urban carbon footprint: An overview. Environmental Impact Assessment Review, 66.
27. Lowe, J.A., Bernie, D. 2018. The impact of Earth system feedbacks on carbon budgetsand climate response. Philosophical Transactions of the Royal Society A, 376.
28. Maris, G., Flouros, F. 2021. The Green Deal, National Energy and Climate Plans in Europe: Member States' Compliance and Strategies. Administrative Sciences, 11(3).
29. McLaren, D. 2012. A comparative global assessment of potential negative emissions technologies. Process Safety and Environmental Protection, 90(6).
30. McQueen, N. et al. 2021. A review of direct air capture (DAC): scaling up commercial technologies and innovating for the future. Progress in Energy, 3(3).
31. Ministère de la transition écologique, 2020a. Stratégie nationale bas-carbone révisée - NOR: TRER2010109P.
32. Ministère de la transition écologique, 2020b. Stratégie nationale bas-carbone - DICOM-DGEC/PLA/19092.
33. Mohan, Y., Ranjith, P., Tharumarajah, A. 2010. Iron ore and steel production trends and material flows in the world: Is this really sustainable?. Resources, Conservation and Recycling, 54(12).
34. Moser, S.C. 2009. Communicating climate change: history, challenges, process and future directions. WIREs Climate Change, 1(1).
35. Nataly Echevarria Huaman, R., Xiu Jun, T. 2014. Energy related CO2 emissions and the progress on CCS projects: A review. Renewable and Sustainable Energy Reviews, 31.
36. Pandey, D., Agrawal, M., Pandey, J.S. 2011. Carbon footprint: current methods of estimation. Environmental Monitoring and Assessment, 178(1).
37. Paulus, N., Davila, C., Lemort, V. 2022. Field-test economic and ecological performance of Proton Exchange Membrane Fuel Cells (PEMFC) used in micro-combined heat and power residential applications (micro-CHP). Proceedings of the 35th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems.
38. Petrova, M.A. 2013. NIMBYism revisited: public acceptance of wind energy in the United States. WIREs Climate Change, 4(6).
39. PRB. 2020. 2020 World Population Data sheet - Booklet.
40. Rogelj, J. et al. 2019. Estimating and tracking the remaining carbon budget for stringent climate targets. Nature, 571(7765).
41. Rogelj, J. et al. 2015. Impact of short-lived non-CO2 mitigation on carbon budgets for stabilizing global warming. Environmental Research Letters, 10(7).
42. Semenza, J.C. et al., 2008. Public perception of climate change: Voluntary mitigation and barriers to behavior change. American Journal of Preventive Medicine, 35(5).
43. Smith, S. et al. 2012. Equivalence of greenhouse-gas emissions for peak temperature limits. Nature Climate Change, 2(7).
44. SPW. 2014. 20 FEVRIER 2014. - Décret «Climat», Moniteur belge du 10-03-2014, p. 20402: Service Public de Wallonie.
45. Steffen, W. et al. 2018. Trajectories of the Earth System in the Anthropocene. Proceedings of the National Academy of Sciences, 115(33).
46. Towa, E. et al., 2022. Toward the development of subnational hybrid input-output tables in a multiregional framework. Journal of Industrial Ecology, 26(1).
47. United Nations. 2015. FCCC/CP/2015/L.9/Rev.1 - Adoption of the Paris Agreement. Paris.
48. van Nimwegen, N., van der Erf, R. 2017. Europe at the Crossroads: Demographic Challenges and International Migration. Journal of Ethnic and Migration Studies, 36(9).
49. Vandevyvere, H., Nevens, F. 2015. Lost in Transition or Geared for the S-Curve? An Analysis of Flemish Transition Trajectories with a Focus on Energy Use and Buildings. Sustainability, 7(3).
50. Yamano, N., Guilhoto, J. 2020. CO_2 emissions embodied in international trade and domestic final demand: Methodology and results using the OECD Inter-Country Input-Output Database. OECD Science, Technology and Industry Working Papers, 11.