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Abstract

To clarify the link between existing infrastructure legacy and the 2°C target, we extend the work of Davis et al. (2010) by introducing non-CO_2 greenhouse gases and the inertia in transportation-needs drivers. We conclude that climate policies able to maintain climate change below 2°C cannot disregard existing infrastructure.

In a recent article entitled “Future CO2 emissions and climate change from existing energy infrastructure” Davis et al. (2010) address the important issue of the climate change inertia created by existing infrastructure. Their methodology quantifies the legacy of existing energy infrastructure in terms of future CO_2 emissions and climate change. Given the policy relevance of their results, it seems unavoidable that readers parallel the “mean warming of 1.3°C” from Davis et al. and the political icon of the 2°C target, which was again recognized by the 16th Conference of the Parties (COP) to the UNFCCC.

Results from Davis et al. (2010) could easily, but erroneously, lead to the conclusion that climate policies needed to reach the 2°C target can disregard existing infrastructure. This letter clarifies the possible interpretations of Davis et al. results in terms of climate policy. To do so, it extends their methodology to account for infrastructure that does not itself emit CO2, but perpetuates a global economy which does. Practically, we introduce (i) the inertia in assets location and energy-services demand drivers in the transportation sector, while the initial analysis only accounts for energy-services supply inertia; and (ii) the role of non-CO_2 greenhouse gases (GHG). We reach the conclusion that climate policies able to maintain climate change below 2°C above pre-industrial temperatures cannot disregard existing infrastructure and need to act also on behaviours and existing capital early retirement or retrofit.

Considering only the capital that directly emits CO_2, Davis et al. investigate the inertia in the supply of energy services. To quantify the inertia in GHG emissions caused by installed capital, their methodology has to be extended to account as well for the inertia in demand, which is also linked to infrastructure and installed capital, including its location. For instance, building shells condition over the long-term the energy demand for heating and cooling; assets locations determine mobility needs; and transport infrastructure influence modal shares. Given the lifetimes of buildings and transport infrastructures, and the inertia of urban forms (Jaccard and Rivers, 2007; Gusdorf et al., 2008), energy-services demand inertia might be a stricter constraint on energy services production than installed supply capital.

We illustrate the effect of this additional inertia through the example of transport. Starting from the three emissions scenarios from Davis et al. (lower; middle; and upper), we modify the emissions due to the transportation sector. In the original analysis, only the existing fleet of vehicles is taken into account; beyond the lifetime of this fleet, emissions from transport is reduced to zero, like if other existing infrastructure (e.g., roads and railways) were not constraining these emissions in the future. We claim that transport infrastructure and assets locations create an additional inertia on transport emissions, which is larger than the inertia of the vehicles fleet. Our methodology is detailed in the Supplementary Online Material (SOM). In summary, we assume that mobility needs are determined by assets locations, and that existing assets relocation is impossible. We also disregard modal shifts, assuming for instance that a road that is built will be used over its entire lifetime. We thus assume constant mobility needs for each transport mode. With these assumptions, future CO_2 emissions depend mainly on the evolution of transportation fleet technologies, which cannot allow for immediate and complete decarbonisation. We retain the same assumptions as Davis et al. for vehicles lifetimes and we use new vehicles market shares from the International Energy Agency BlueMap scenario (IEA, 2009), an optimistic scenario in terms of technical change in the transportation sector.

We find that these assumptions lead to a much larger commitment to CO_2 emissions (Fig. 1, left panel) and global temperature increase (Fig. 1, right panel). For instance, emissions inherited from existing capital are 35% higher in 2030 and 134% in 2060 in our analysis than in Davis et al., for both Middle scenarios. CO_2 emissions due to existing capital in our Upper scenario (see SOM) are even very close to those of the RCP 3PD scenario (19% below in 2025 and only 9% below in 2040), a scenario with a risk of overshoot above the 2°C global temperature threshold (van Vuuren et al., 2007).

With these assumptions, the remaining "emission budget" for new generations of capital and increase in energy-services demand is unrealistically thin if one wants to maintain climate change below 2°C above pre-industrial temperatures. For instance, the emission budget between the committed emissions in our upper scenario and the RCP 3PD is limited to 1.7 GtCO2 in 2040.

The same analysis could be carried out on building shells to assess the inertia in energy demand for heating and cooling needs. This addition would lead to even higher CO_2-emissions inertia due to existing infrastructure, but taking into account transport only is sufficient to suggest that existing infrastructure cannot be disregarded in climate policy designs.

Moreover, Davis et al. account only for the radiative forcing from CO_2, neglecting other GHG gases. But radiative forcing from CO2 represented only 79% of the total anthropogenic forcing in 2005, while other gases were responsible of the remaining 21% (0.47 W/m2). Considering other gases changes dramatically the difficulty of maintaining climate change below 2°C (see Fig. 1, right panel). For instance, starting from the Davis et al. analysis results, we include the non-CO_2 radiative forcing from the scenario Image RCP 3PD (van Vuuren et al., 2007), i.e. from a scenario representative for emissions pathways leading to very low GHG concentration levels. This inclusion leads in 2060 to a warming of 1.71°C above pre-industrial level in the Middle scenario and 1.78°C in the Upper scenario. Since the Image RCP 3PD scenario is particularly optimistic, these results show that even with the Davis et al. CO_2 emissions, reaching the 2°C target without capital retrofit or early retirement appears extremely difficult.

Taking into account both methodological extensions, namely the capital-related inertia in energy services demand and other GHG gases, it appears that the remaining emissions budget for the new capital (even low-carbon) to satisfy energy services demand from a larger and wealthier population is very thin, if we want to remain below the 2°C target. Existing infrastructure may not be the main threat, but it plays a key role in the feasibility of this internationally recognized objective.

To give some room to the future energy services demand, an action on existing capital and infrastructure appears necessary. Our results support the idea that climate policies acting solely on new energy supply and on technologies would not be sufficient to reach the 2°C goal. Surmounting the legacy of installed infrastructure is thus part of the climate challenge. To do so, it will be necessary to organize the early retirement or retrofit of some existing capital, to accelerate capital turnover and/or to target the drivers of energy services demand, and in particular modal shift and mobility needs linked to infrastructure and assets locations.

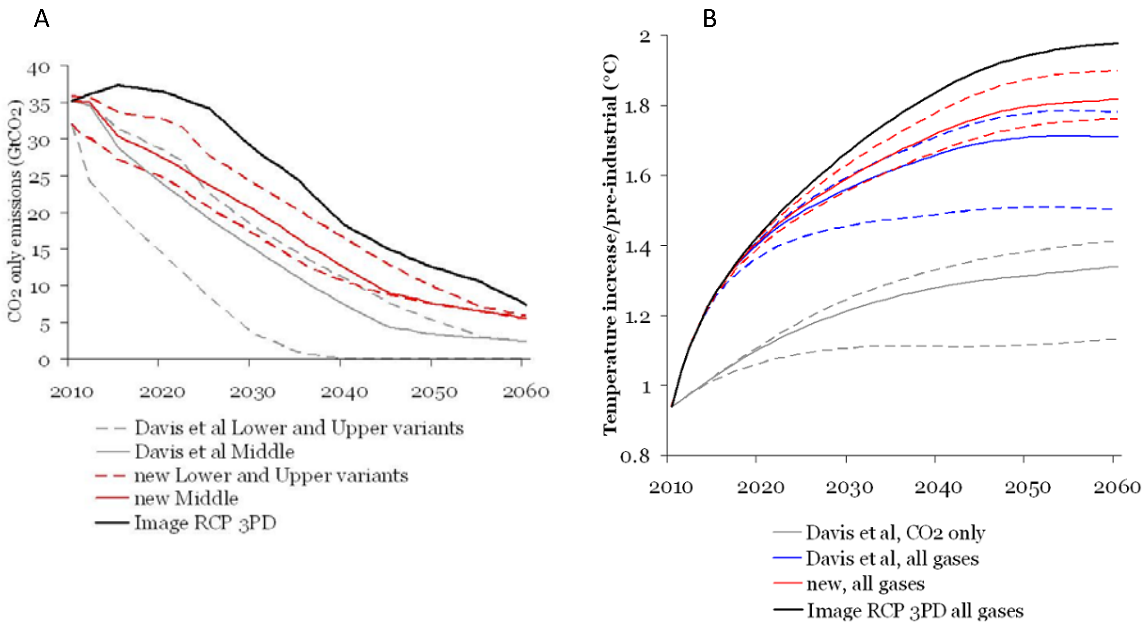

Fig. 1. (A) Scenarios of CO_2 emissions from existing infrastructure and (B) associated global mean temperature increases above pre-industrial level. The scenarios correspond to Davis et al. results, the new results from this article, and the Image RCP 3PD scenario for comparison purposes. Dashed lines indicate total CO_2 emissions and temperatures from upper and lower-bound scenarios.

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Supporting Online Material

Materials and Methods

This Supplementary Online Material details the methodologies used to include energy-services demand inertia in the assessment of transport-related built-in GHG emissions and to model the responses of the carbon cycle and the climate to anthropogenic emissions.

Committed CO_2 Emissions

In this study, committed CO_2 emissions are those from the Davis et al. (2010) analysis, except for transport-related emissions. Transport emissions in this study include all emissions under category 1A3 of the IPCC's Revised Guidelines (IPCC, 2006).

We modify the methodology from Davis et al. to account for the constraint on committed emissions from the transport sector due to the inertia in mobility demand. This demand is linked to infrastructure and installed capital, including their locations. Indeed, assets locations determine mobility needs, and transport infrastructure (e.g., roads, railways) determine transport modal shares.

Committed emissions are the emissions that would be produced in absence of new infrastructure investments. We also assume that capital cannot be relocated. We also consider that no modal shift (e.g., between individual vehicles and public transportation) takes places over the study time horizon (2010-2060). This assumption is justified by the dependency of transport modes to urban forms: in low-density cities (e.g., Atlanta), public transport cannot be a viable solution, while in high-density cities (e.g., most historical European cities, many Asian cities), public and low-carbon transport is easier to organize (Bertaud and Richardson, 2004). Considering the lifetimes of urban forms and transport infrastructures that are much longer than our 50 year time horizon (Jaccard and Rivers, 2007; Gusdorf et al., 2008) and assuming that no new infrastructure is installed leads to supposing unchanged modal shares. Passenger and freight mobility needs are thus considered constant, equal to current values, over the time horizon, and we assume that vehicle fleets are replaced such that these mobility needs can be satisfied. New activities and their locations are excluded from the study, following the philosophy of Davis et al., to consider only existing infrastructures and to disregard future activities and associated energy services demands.

With such assumptions, determining future emissions from transport comes down to the issue of the fleets of vehicles. But, contrary to Davis et al., a projection of the evolution of these fleets is needed over the 2010-2060 horizon. We assume vehicles lifetimes (Davis and Diegel, 2006) that are compatible with the assumptions from Davis et al. on vehicles survival rates. Most other assumptions are from the BlueMap Scenario from the International Energy Agency (IEA, 2009). This scenario corresponds to a 450 ppm CO_2-equivalent concentration stabilization target, and is therefore a best-case scenario in terms of reduced emission from new vehicles. This scenario provides information on (i) the market shares of substitutes to internal combustion engine (electric vehicles, hybrid vehicles, fuel cells vehicles) in the fleets of new vehicles; (ii) the improvement of internal combustion engine efficiency; and (iii) biofuels penetration.

Upper- and lower-bound scenarios assume variants on vehicles lifetimes (upper and lower bounds from Davis and Diegel, 2006) and a 25% increase or decrease in MPY, similarly to the Davis et al. scenarios for transport emissions.

Radiative forcing form other gases

The radiative forcing from other gases follows the trajectory from the scenario Representative Concentration Pathway 3 Peak&Decline (RCP3-PD) from Image model (van Vuuren et al., 2007). This scenario is representative for the scenarios leading to extremely low greenhouse gas concentration levels in the literature. It represents a substantial reduction of GHG emissions over time and is a best-case scenario with respect to non-CO_2 emissions.

Carbon cycle model and climate model

The carbon cycle is a three-box model, after Nordhaus and Boyer (2010). The model is a linear three-reservoir model (atmosphere, biosphere + surface ocean and deep ocean). Each reservoir is assumed to be homogenous (well-mixed in the short run) and is characterised by a residence time inside the box and corresponding mixing rates with the two other reservoirs (longer timescales). Carbon flows between reservoirs depend on constant transfer coefficients. GHGs emissions (CO2 solely) accumulate in the atmosphere and they are slowly removed by biospheric and oceanic sinks.

The stocks of carbon (in the form of CO2) in the atmosphere, in the biomass and upper ocean, and in the deep ocean are, respectively, A, B, and O. The variable E is the CO2 emissions. The evolutions of A, B, and O are given by:

$$\frac{dA}{dt} = -\phi_C^{A,B} + E$$
$$\frac{dB}{dt} = \phi_C^{A,B} - \phi_C^{B,O}$$
$$\frac{dO}{dt} = \phi_C^{B,O}$$

The fluxes are equal to:

$$\phi_C^{A,B} = a_{21}A - a_{12}B$$
$$\phi_C^{B,O} = a_{23}B - a_{32}O$$

The initial values of A, B, and O, and the parameter a_{12}, a_{21}, a_{23} and a_{32} determine the fluxes between reservoirs. Nordhaus original calibration has been adapted to reproduce data until 2010 and Davis et al. results, giving the following results (for a yearly time step): a_{12}=0.0292325, a_{21}=0.0362227, a_{23}= 0.0047629, a_{32}= 0.0003102, with the initial conditions: A_{2010}=830 GtC (i.e. 391ppm), B_{2010}=849 GtC and O_{2010}=19255 GtC.

The additional forcing caused by CO_2 and non-CO_2 gases is given by:

$$F_A = F_{2X} \frac{\log\left(\frac{A}{A_{PI}}\right)}{\log 2} + F_{non-CO_2}$$

where A_{PI} is the pre-industrial CO_2 concentration (280ppm), F_{2x} is the additional radiative forcing for a doubling of the CO_2 concentration (3.71 $W.m^{-2}$), and $F_{non\text{-}CO2}$ is the additional radiative forcing of non-CO_2 gases.

The temperature model is a 2-box model, after Schneider and Thompson (1981) and Ambrosi et al. (2003) with the atmosphere temperature T_A and the ocean temperature T_O:

$$\frac{dT_A}{dt} = \sigma_1\left(-\frac{F_{2X}}{T_{2X}}T_A - \sigma_2\phi_T + F_A\right)$$

$$\frac{dT_O}{dt} = \sigma_3\phi_T$$

$$\phi_T = T_A - T_O$$

where T_{2x} is the equilibrium temperature increase at the doubling of the CO_2 concentration, that is, it represents climate sensitivity. All parameters have been calibrated to reproduce observed values and the results from Davis et al., leading to the following parameter values (for a yearly time step): σ_1=0.1396048 $C.W^{-1}.m^2$, σ_2=0.6833236 $C^{-1}.W.m^{-2}$ and σ_3=0.0206022, and a climate sensitivity parameter equal to 2.85°C.

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