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Time Dependent Environmental Impact of Transportation

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Problem. Energy technologies emitting differing proportions of methane (CH_4) and carbon dioxide (CO_2) vary in their relative climate impacts over time, due to the distinct atmospheric lifetimes and radiative efficiencies of the two gases. Standard technology comparisons using the global warming potential (GWP) with a fixed time horizon do not account for the timing of emissions in relation to climate policy goals. In this project we developed an alternative approach for policy makers, engineers, and private investors to use in evaluating the time-dependent greenhouse gas emissions impacts of energy technologies, and in optimizing energy technology portfolios.

Approach. We use a dynamic portfolio choice approach that selects a technology portfolio to maximize energy consumption while meeting a policy target. The results of this project have been published in a peer-reviewed academic journal[1] and presented at an international conference (ISIE 2015). The optimal results are compared to choices relying on the standard GWP- based method for a set of transportation technologies.

Methodology. We formulate dynamic technology choice as a simplified forward-looking multi-period portfolio optimization problem, maximizing energy consumption over a planning horizon in the presence of a radiative forcing (RF) constraint. This leads naturally to an analytical expression for technology impact that changes over time depending on the marginal RF impact in the stabilization year. This expression can be used to derive the ICI emission equivalency metric,[2] which may be applied in a similar fashion for dynamic technology choice.
The benefit of this method is numerically quantified for three transportation technology pairs: compressed natural gas (CNG) and gasoline, electric vehicle (EV) and algae biodiesel (algae), switchgrass E85 (switchgrass) and renewable natural gas (RNG), with the first in each pair being relatively CH_4-heavy compared to the second. Data on emissions intensities of the greenhouse gases (GHGs) CO_2, CH_4, and N_2O are obtained using the GREET model. The RF impact of each GHG over time is calculated using the values of radiative efficiency and decay lifetimes given in the IPCC AR5 report[3]. The global RF target used is 3 W/m^2, which is consistent with an equilibrium temperature change of 2°C above pre-industrial levels.

Findings. Solving the optimization model we find that the optimal technology portfolio calls for the use of the more CH_4-heavy technology in earlier years, switching to the CH_4-light technology as the intended RF stabilization year approaches. This switching portfolio facilitates greater energy consumption than the exclusive use of either technology alone. The early use of the CH_4-heavy technology is optimal only if the horizon exceeds 22 years for CNG and gasoline pair, 14 years for algae and EV pair, and 19 years for the RNG and switchgrass pair. Given a stabilization horizon from the present to mid-century, a switching portfolio can allow a gain in energy consumption of up to 15% (50%) over the corresponding CH_4-light (CH_4-heavy) technology (see Figure 1).

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[1] Roy, M., M. R. Edwards, and J. E. Trancik. 2015. Methane mitigation timelines to inform energy technology evaluation. *Environmental Research Letters*, 10, pp. 114024.

[2] Edwards, M. R. and J. E. Trancik. 2014. Climate impacts of energy technologies depend on emission timing. *Nature Climate Change* 4, 347-352.

[3] Stocker, T. et al (ed.). 2013. Climate Change 2013: The Physical Science Basis (Cambridge: Cambridge University Press).

In contrast, using a standard GWP based method leads to the choice of a single technology over the entire horizon, which for the most commonly used 100-year GWP results in either a significant overshoot of the RF target (see Figure 2) or, if constrained by the target, allows significantly lower energy consumption (see GWP(100) capped in Figure 1). The use of a 35-year GWP does not lead to a target overshoot but allows lower energy consumption.

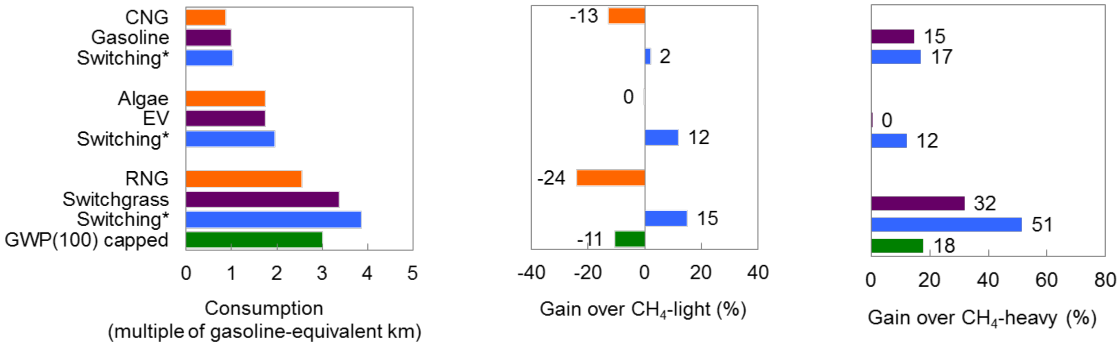

Figure 1: Optimal energy consumption. Total energy consumption allowed over the stabilization horizon while meeting the radiative forcing stabilization target (left panel); gain in energy consumption over the CH_4-light technology (center panel); and gain in energy consumption over the CH_4-heavy technology (right panel).

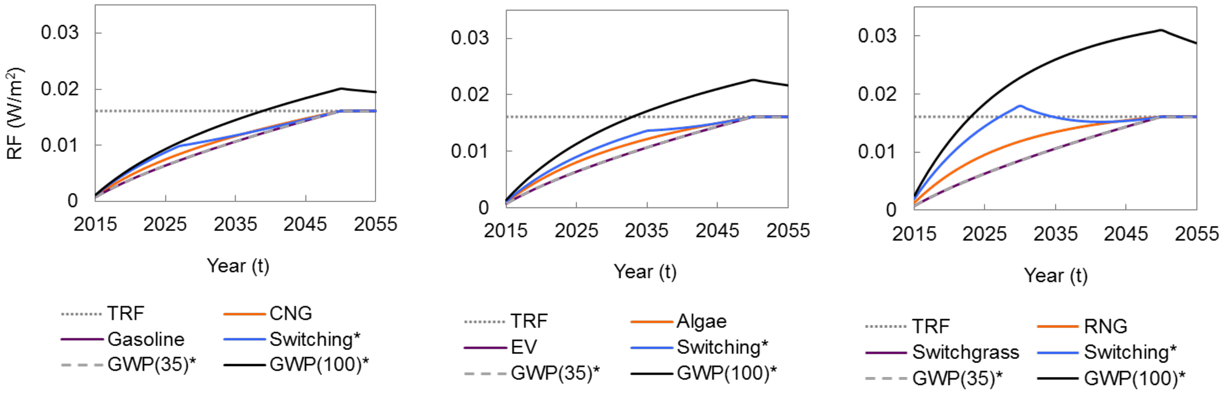

Figure 2: Radiative forcing over time for the CNG and gasoline technology pair (left), algae and EV pair (center), and RNG and switchgrass pair (right). For each pair the lines shown are CH_4-heavy technology (orange), CH_4-light technology (purple), optimal switching portfolio (blue), GWP(100)-based portfolio (black) and GWP(35)-based portfolio (grey).

Conclusions. We show that the optimal technology choice using a dynamic technology evaluation method is a switching portfolio, where a more CH_4-heavy technology is used initially, followed by a CH_4-light option. Such a switching portfolio allows greater energy consumption than using a single technology alone. This result supports the case for using appropriate CH_4-heavy bridging technologies to increase allowed energy consumption. Our model also demonstrates the benefits of using a dynamic technology evaluation method as compared to using a static GWP-based method.