

A SYSTEM DYNAMICS MODEL FOR SIMULATING REBOUND EFFECTS INDUCED BY ENERGY SAVINGS WITH RE-SPENDING SCENARIOS

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Motivation

Jevons' Paradox

It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth. ... no one must suppose that coal thus saved is spared – it is only saved from one use to be employed in others, and the profits gained soon lead to extended employment in many new Forms (Jevons, 1866)

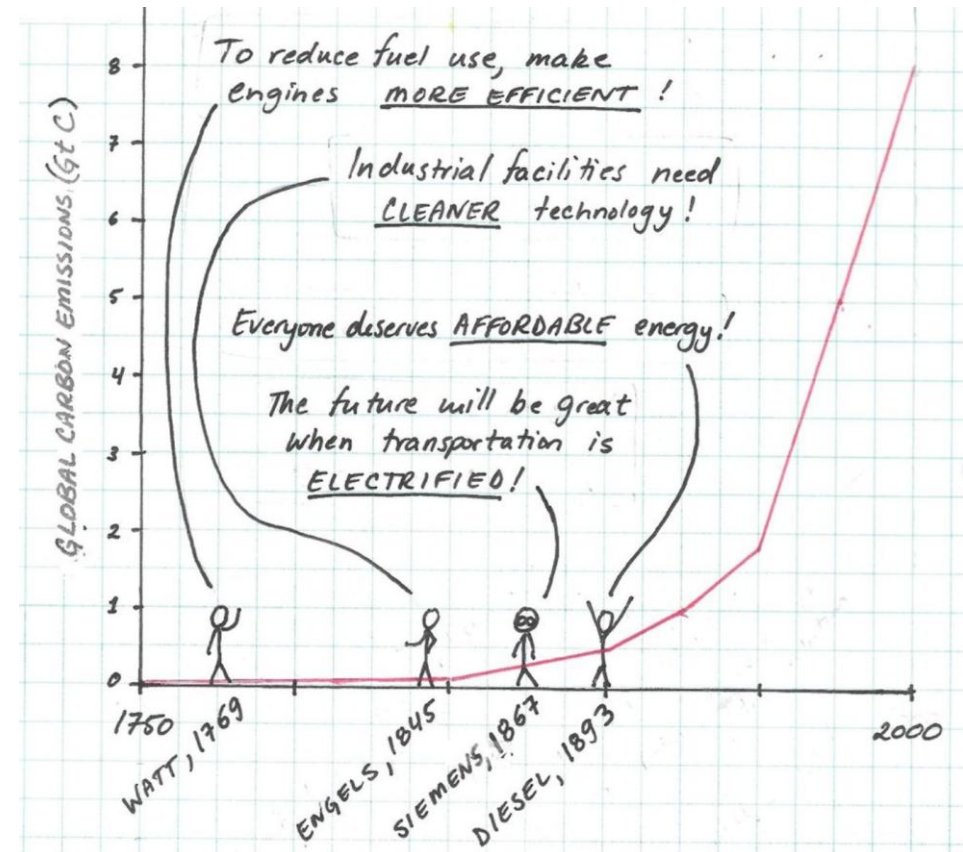


Figure 1. Relationship between innovation and carbon emissions
Source: Mulrow, 2021

Motivation

- Vélez-Henao et al., 2019:
 - Attempts to capture the indirect rebound effect individually or simultaneously with the direct rebound effect through the STIRPAT model have not been made.
 - ...a correct proxy for T should be a measure of efficiency, since the variable T is defined as the environmental impact per unit of economic activity...
 - **Consequently, it is fundamental to pay close attention on how the variable T has been modeled within the STIRPAT model. Even more if this variable is considered closely related to key issues such as the (environmental) rebound effect (E)RE.**

Research Question

1. How to model technology improvements with indirect rebound effects?
2. What are the impacts of indirect rebound effects induced by efficiency gains on carbon emissions?

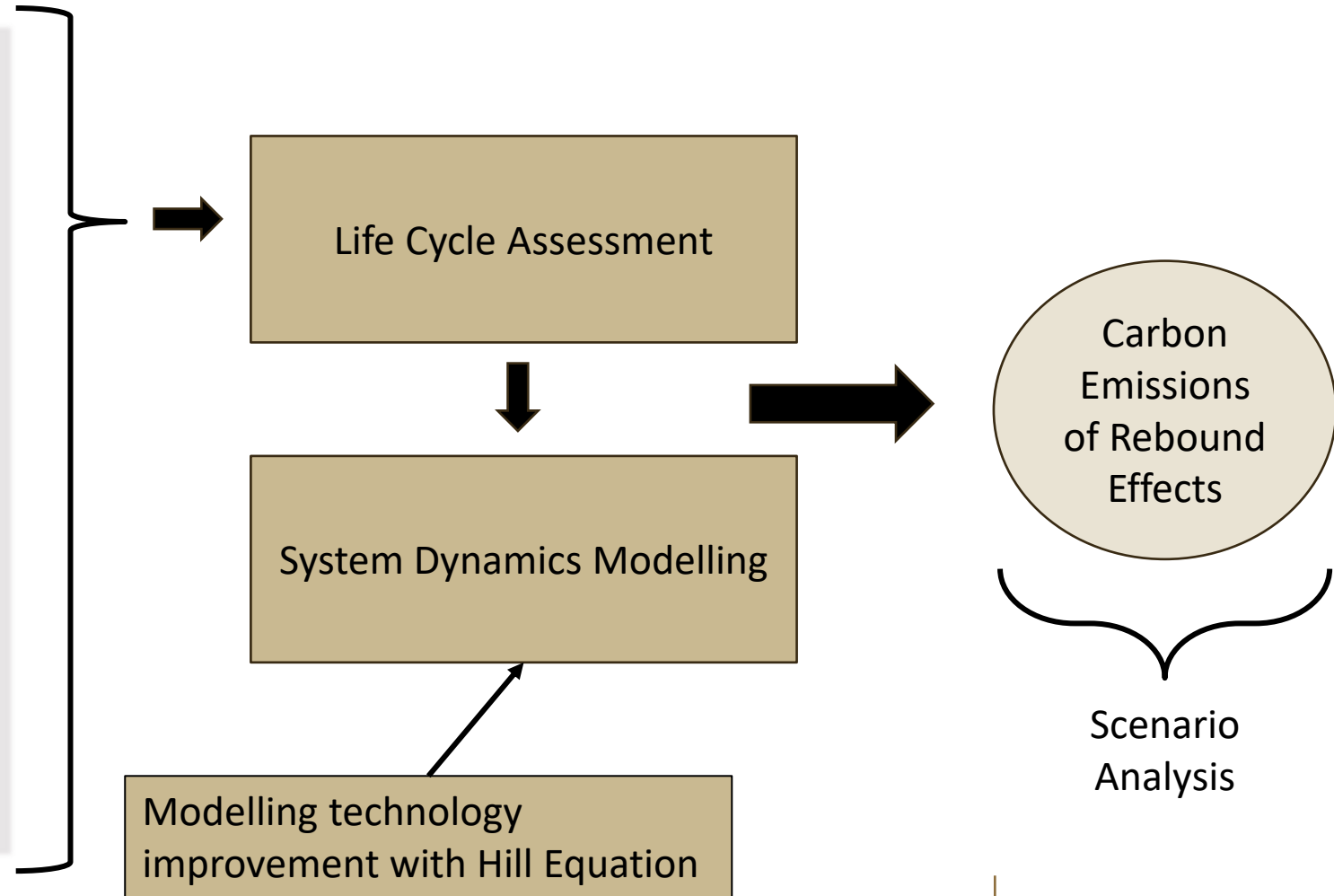
Methods

U.S. Demand for Services

- EPA, EIA, Census → Car travel
- Carbon Independent, IPCC → Air Travel
- (Poore & Nemecek, 2018), Feeding America → Food

Consumer credit card spending (Alldredge et al., 2022)

Industry growth and technology improvement relationship (Kim, 2009)



Life Cycle Assessment

Relating Life Cycle Assessment to Economics

- For flight and automotive sectors, only use phase is considered (i.e., combustion)
 - Relate combustion CO₂ emissions to fuel prices
 - Further work: Incorporate past and future fuel price time series predictions.
- For food sector, LCA utilizes cradle to gate (producer to consumer).
- Functional Unit: \$1 worth of product



3.55 kg CO₂eq / \$

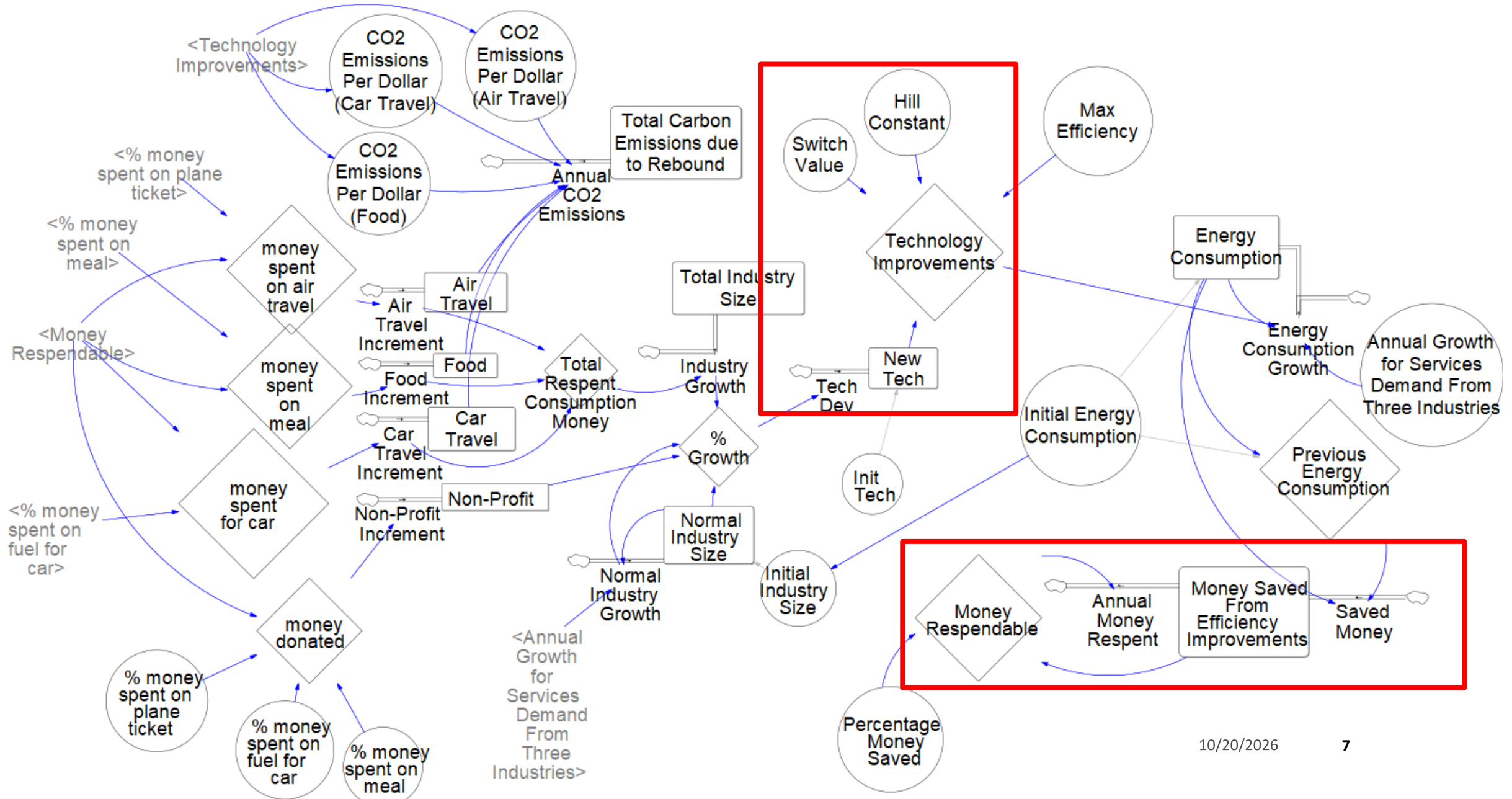


30.9 kg CO₂eq / \$



1.67 kg CO₂eq / \$
0.40 kg CO₂eq / \$ (Veg)

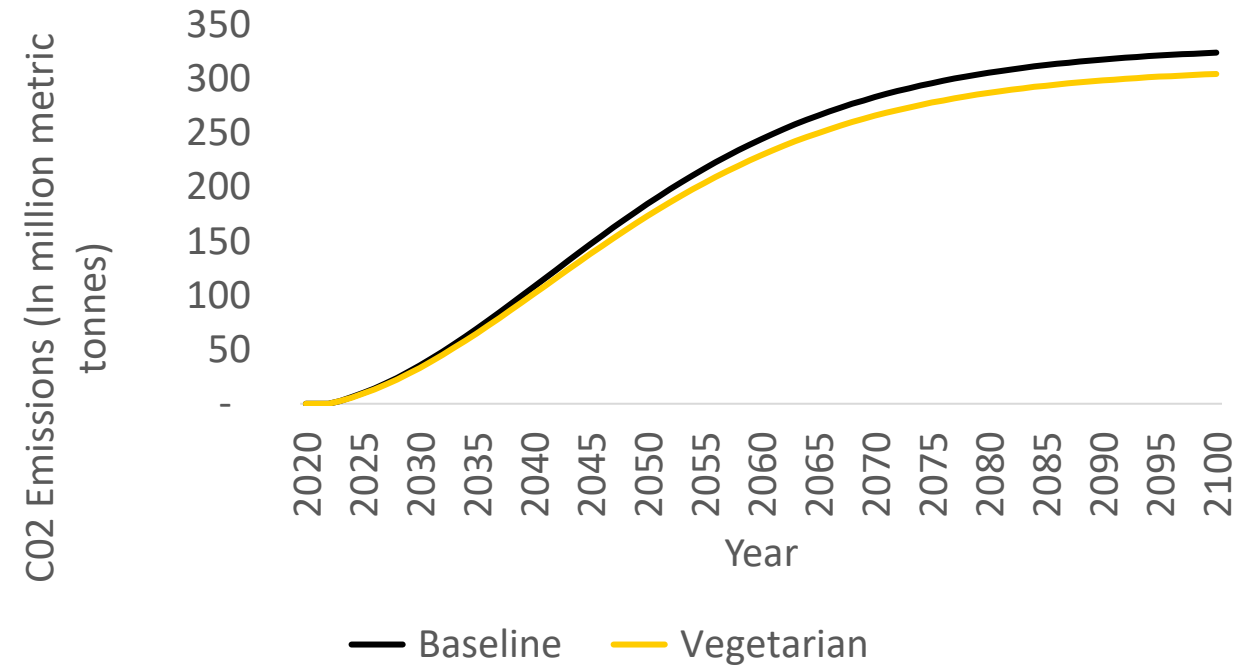
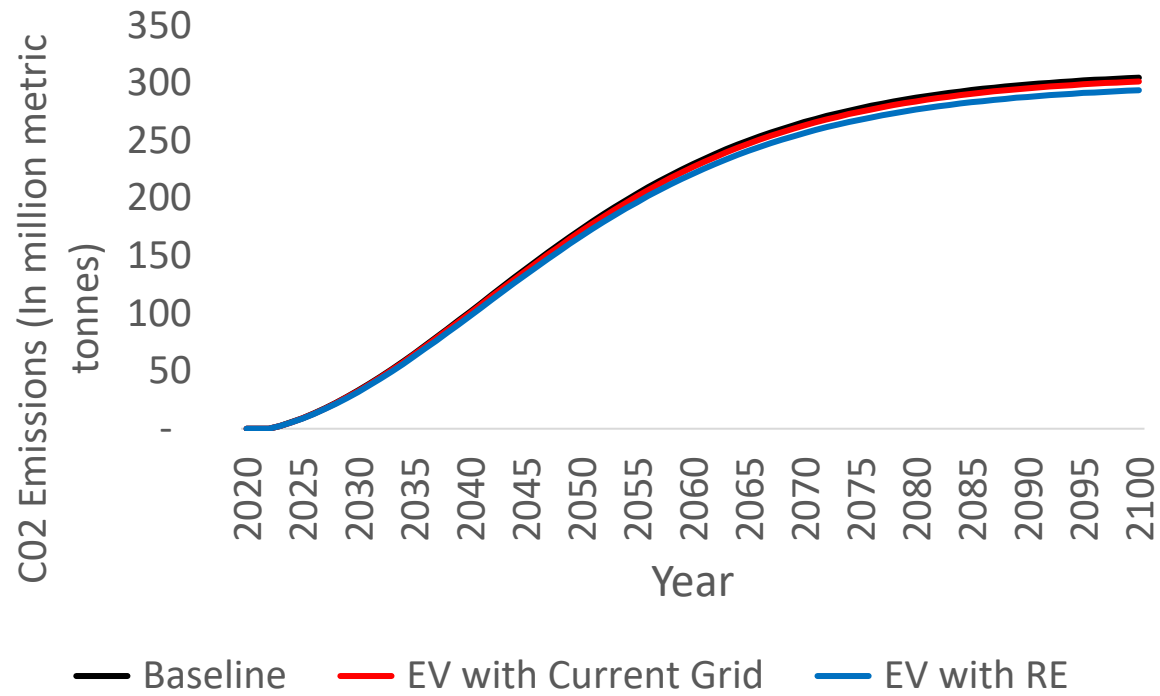
System Dynamics Model



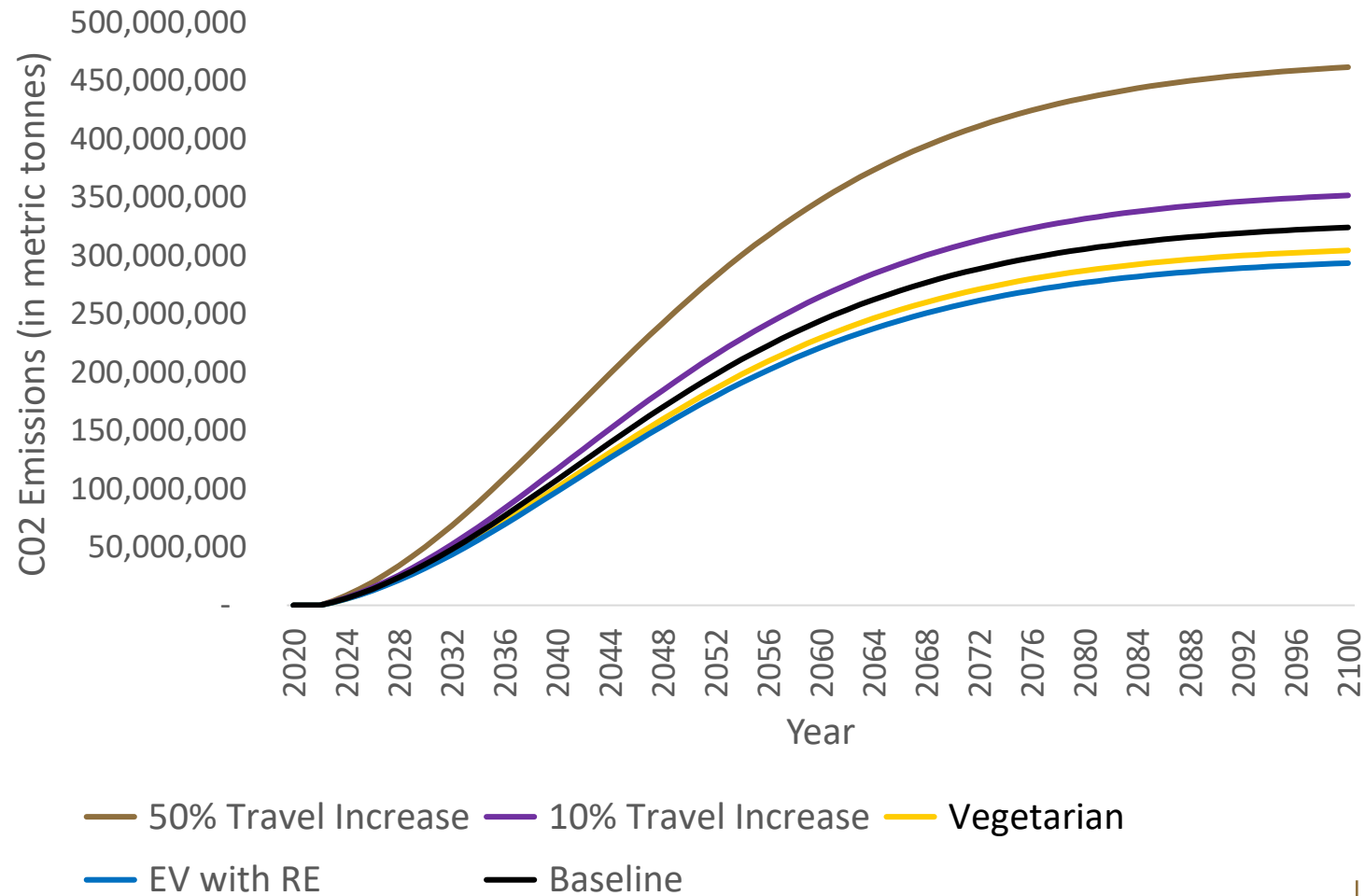
Consumer Scenarios

Scenarios	Donations	Car	Food	Air
Baseline - ICE	2%	9%	21%	12%
EV with Current Grid	2%	9% (3 kg CO ₂ eq / \$)	21%	12%
EV with Renewable Energy	2%	9% (1.86 kg CO ₂ eq / \$)	21%	12%
10% Air Travel Increase	2%	9%	21%	13.25%
50% Air Travel Increase	2%	9%	21%	18%
Vegetarian	2%	9%	21% (0.4 kg CO ₂ eq / \$)	12%

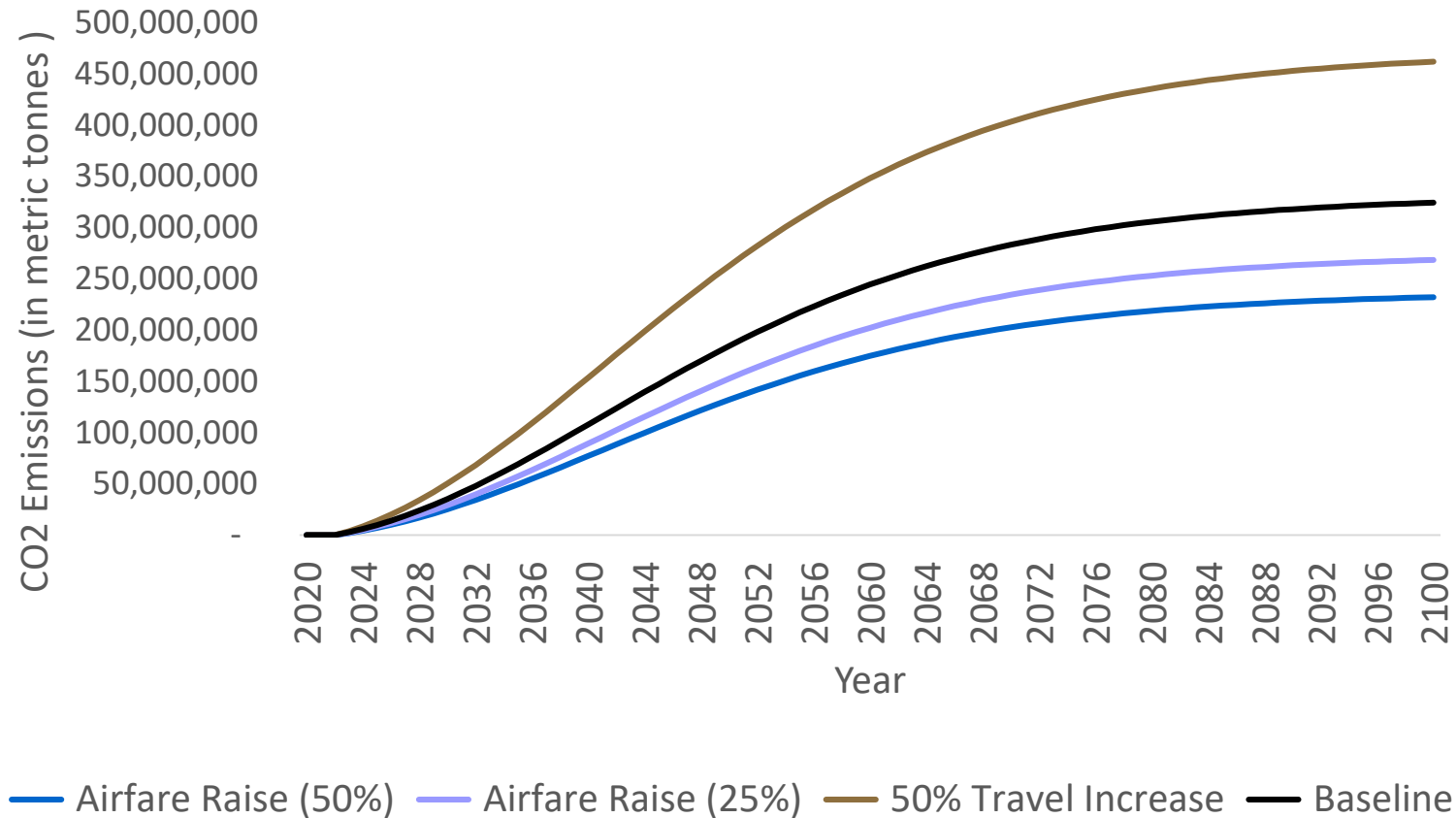
Results



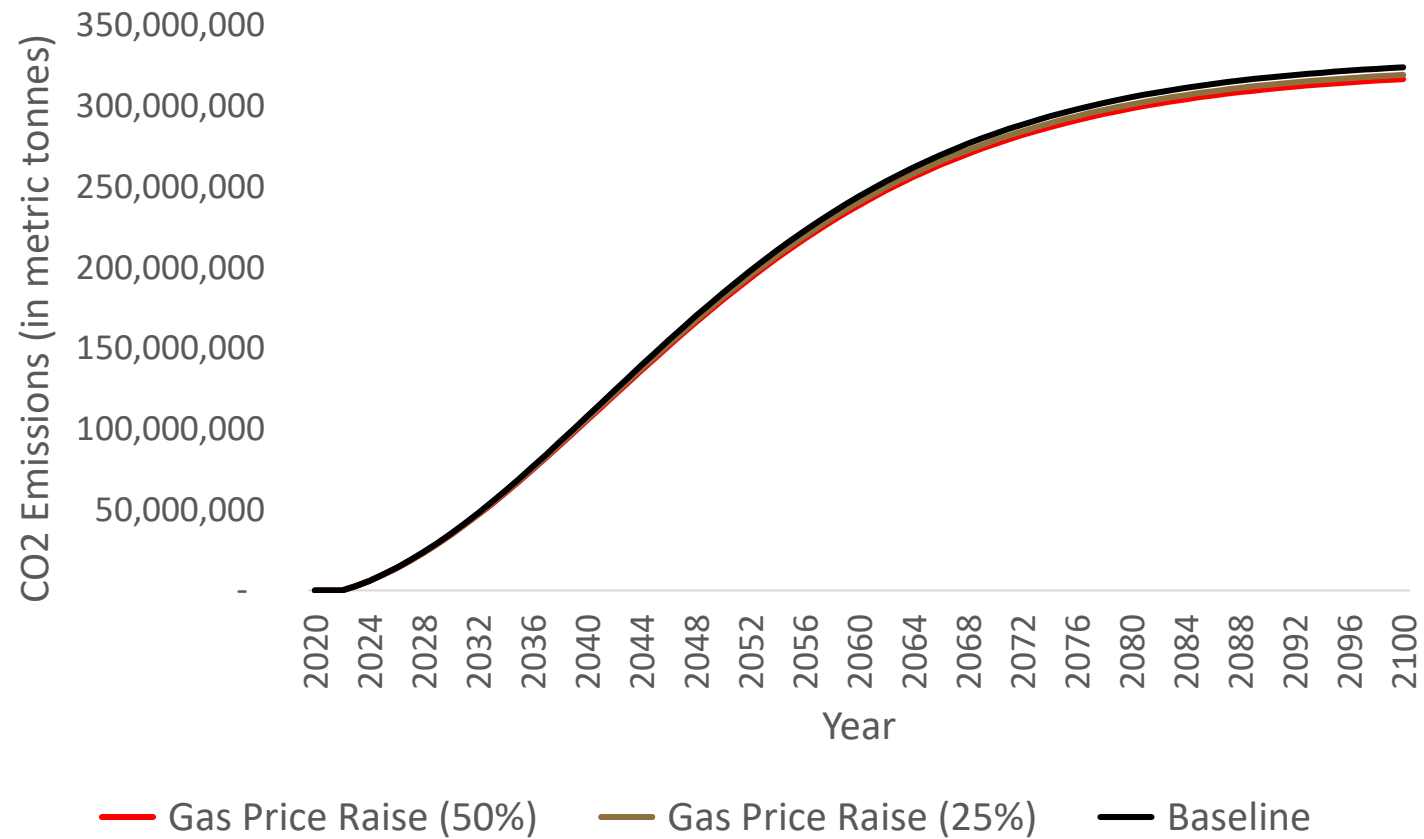
Results



Results (Airfare Increase)



Results



Conclusion

Key Takeaways

- Technological efficiency gains that save money for consumers indicate rebound effects in responding patterns.
 - They are significant in overall carbon emissions especially in the future as the money saved from energy efficiency improvements increase.
 - They need to be included in mainstream calculation not just as a discussion at the end.
- A constantly growing economy indicates that even environmental lifestyles (i.e., vegetarian or EV vehicles) lead to large carbon emissions.
- Increase in price for goods/services can 'decentivize' responding patterns.

Future Work

- Incorporating more explicit elasticities from energy savings for each spending category.
- Model technological improvement for exogenous and endogenous industries independently
- Incorporate this sub-model in larger STIRPAT model
- Explore different policy actions and consumer behaviors to identify optimal policies
- Analyze GDP stagnation as a potential policy action

THANK YOU!

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Assumptions

- Average Annual Economic Growth for 3 Sectors: 3.1% (EIA, 2021)
- Initial Energy Consumption for 3 Sectors: 28.3 quadrillion btu (EIA, 2021)
- Energy Consumption Growth = Previous energy * (Ann Growth% - Tech Eff%)
- Carbon Intensities decrease proportionally with Technology Efficiency Gains
- Technology efficiency gains follow sigmoid function
- Technology efficiency has maximum of 10% improvement from baseline (~Carnot efficiency)
- R&D Budget = Growth * 0.068 (Kim, 2009)
- R&D Budget spent on innovation = R&D Budget * 0.37 (Kim, 2009)
- Innovation success rate = R&D Budget spent on innovation * 0.004 (Kim, 2009)
- Innovation duration time = 24 months
- Commercial product delay = 36 months
- Baseline money respending follows 2021-2022 Consumer Credit Card Reports (Alldredge et al., 2022)
- Assume homogeneity within US consumers

LCA Assumptions

- Car Travel
 - Average MPG of Car: 25.4 mpg (EPA)
 - Average miles driven per year: 13,500 miles (FHWA)
 - Gas Cost: \$2.50 / gal (EIA)
 - Gas CO₂ emissions: 0.349 kg / mi (EPA)
- Air Travel
 - Average airfare: \$271 (Hopper's Price Tracker)
 - Average trip length: 502 miles (Statista)
 - Average flight size: 90.7 passengers (Statista)
 - CO₂ emission: 0.115 kg/pass/km (EPA)
- Food
 - Average calories per day (US): 3782 kcal (Roser, 2013)
 - 3 meals a day
 - Price per meal: \$3.02 (Feeding America)

References

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