IEooc_Methods6_Exercise1: Coupling between sectors. The example of passenger vehicle light-weighting

Sample solution

Goal: *Estimate the system-wide impact of a climate change mitigation strategy in a specific sector. Learn about light-weighting of vehicles as emissions savings option.*

Task 1) The global passenger vehicle fleet:
Given a global population of 9 billion people in 2050, an average car ownership of 250 per 1000, an average kilometrage of 14.000 km/car*yr, an average fuel efficiency of 2.2 MJ/km, and the emissions from producing and burning gasoline of 0.02 and 0.07 kg CO2-eq/MJ, respectively.
What are the total GHG emissions for operating this fleet for one year, and how does it compare to current (2015) total annual emissions, both total and from passenger vehicles?

Total GHG emissions for all cars in 2050: 6.24 Gt CO_2-eq (cf. accompanying Excel sheet). That is roughly a doubling of present emissions of the vehicle fleet, and slightly more than one sixth of current total emissions (35 Gt/yr).

Task 2) The relation between light-weighting (vehicle weight reduction) and fuel consumption:
Most passenger vehicles show a weight fuel relation of 0.6 (means that 10% weight reduction lead to a reduction of fuel consumption of 6%) (Johannaber et al., 2007). Why?

Every time the car accelerates, the energy needed to get it up to a certain speed is proportional to its mass. Especially in cities, where cars frequently stop and go, the fuel consumption is strongly mass-correlated, but much less on highways. Vehicle models with different masses are simulated under a standardized driving cycle containing a mix of city and highway driving, and typical results are close to the factor 0.6 given above.

Task 3) Material substitution using high-strength steel:
Given an original car weight of 1400 kg, a weight fuel relation of 0.6 (means that 10% weight reduction lead to a reduction of fuel consumption of 6%), the CO_2-intensity of making steel (3 tons CO2-eq per ton of steel), the CO2-intensity of making high-strength steel
(4 tons CO2-eq per ton of steel), and the substitution rate of 1.5 (1 kg of high-strength steel replaces 1.5 kg of ordinary steel).
How big are life-cycle emissions savings for all the cars on the road in 2050, if the car lifetime is 15 years and the actual car weight (after substituting normal steel with high-strength-steel) is 1200 kg?

GHG emissions saving from steel production in 2050: 30 Mt CO_2-eq.
GHG emissions saving from gasoline use in 2050: 0.53 Gt CO_2-eq.

How do results change if aluminium is used instead of high-strength steel? The CO_2-intensity of producing 1 ton of aluminium is about 13 tons of CO_2-eq and 1 kg of aluminium replaces about 2.5 kg of ordinary steel. What would be the new weight of an individual vehicle if the same amount of ordinary automotive steel would be substituted with aluminium as in the case for high-strength steel?

Increase in GHG emission from Aluminium production of 198 Mt CO_2-eq in 2050 due to CO_2-intensive Aluminium production.
Decrease in GHG emission from gasoline use of 0.96 Gt CO_2-eq in 2050.
New Weight: 1040 kg.

Task 4): Burden shift to other sectors:
How big is the burden shift (increasing emissions in other sectors, in this case the metal production industries)? Calculate both absolute results (Mt/yr) and relative results (burden shift in % of gross and net emissions savings).

Cf. accompanying Excel sheet.

Task 5) Reflection:
Provide a brief, but concise reflection: Who benefits from ever-increasing levels of material production and why?
What are obstacles that need to be overcome when implementing the decoupling strategies proposed in the papers?
Who has the power to change the system and why?

Mining companies, currently steel producers (to provide more materials), energy companies (to provide energy required). Current policy focus lies on reducing tailpipe vehicle emissions instead of full life-cycle assessment, along with high investment in light-weighting materials. Policy makers (especially government) have the power to change the system to incentivize vehicle manufacturers in material optimization for light-weighting with the support of academia.

Additional literature:
(Allwood et al., 2011)
(Modaresi et al., 2014)

References:

Allwood, J.M., Ashby, M.F., Gutowski, T.G., Worrell, E., 2011. Material efficiency: A white paper. Resour. Conserv. Recycl. 55, 362–381.

Johannaber, M.E.., Wohlecker, R.., Wallentowitz, H., Leyers, J., 2007. Determination of Weight Elasticity of Fuel Economy for Conventional ICE Vehicles, Hybrid Vehicles and Fuel Cell Vehicles. Aachen, Germany.

Modaresi, R., Pauliuk, S., Løvik, A.N., Müller, D.B., 2014. Global carbon benefits of material substitution in passenger cars until 2050 and the impact on the steel and aluminum industries. Environ. Sci. Technol. 48, 10776–10784.