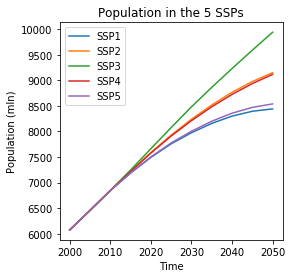
# Supplementary material A. Experimental set-up

Table 1. Overview of experimental set-up, continuous variables.  
Dmnl = Dimensionless, A = Assumption.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Continuous variable name | Minimum | Maximum | Unit | Explanation | Source |
| *Battery transition parameters* | | | | | |
| Battery capacity PHEV | 10 | 20 | kWh/Car | Battery capacity of Plug-in Hybrid Electric Vehicles | 1 |
| Battery capacity BEV | 30 | 120 | kWh/Car | Battery capacity of Battery Electric Vehicles | 1 |
| Battery capacity Etruck | 70 | 150 | kWh/Truck | Battery capacity of Etrucks | 2 |
| Battery capacity Ebus | 150 | 220 | kWh/Bus | Battery capacity of Ebuses | 3 |
| Increase in demand stationary storage | 0.2 | 0.4 | Dmnl | Factor determining increase in demand of stationary storage over time | 1 |
| Slowing of increase in demand stationary storage | 0.88 | 0.96 | Dmnl | Factor determining slowing of increase in demand of stationary storage | 1 |
| Number of cars per dollar GDP | 1.37E-6 | 2.37E-6 | Car/Dollar | Number of cars that are bought per extra dollar of GDP | 4 |
| *Variables related resources, reserves and mining* | | | | | |
| Percentage lost during artisanal mining | 40 | 60 | % | Percentage of raw metal that is lost during artisanal mining | 5 |
| Part artisanal mining from clAified reserves | 10 | 30 | % | Artisanal miners mine either from their own backyard, or from clAified mine facilities. In the first case, they mine from resources, in the second case they mine from clAified reserves. | 6 |
| Administration time | 10 | 20 | Year | Time it takes from initiation of plan to build a new time to production | 5 |
| Average time mining until refining | 0.09 | 0.11 | Year | Average time it takes for a raw metal to be refined | A |
| *Variables related to mining, smelting and refining capacity* | | | | | |
| Short forecasting period | 0.5 | 2 | Year | Time to forecast ahead | A |
| Minimum usage smelting and refining capacity | 70 | 90 | % | Minimum percentage of smelting and refining capacity in use | 7 |
| Minimum usage mining capacity | 70 | 90 | % | Minimum percentage of mining capacity in use | 7 |
| Percentage lost during operations | 4 | 8 | % | Percentage lost during mining, smelting and refining | 7 |
| Mining usage investment cap | 0 | 95 | % | Minimum percentage of mining capacity that needs to be in use before investments in new capacity takes place | 7 |
| Average permit term | 5 | 20 | Year | Average time before permits for new mining capacity are given | 8 |
| Smelter and refiner usage investment cap |  |  |  | Minimum percentage of smelting and refining capacity that needs to be in use before investments in new capacity takes place | 7 |
| Maximum increase recovery rate | 5 | 25 | % | Maximum increase in the recovery rate of cobalt | 9 |
| Sed hosted typical Co recovery rate | 65 | 75 | % | Typical percentage of cobalt in Sediment hosted deposits that is recovered when mined as by-product | 9 |
| Ni laterite Co typical Co recovery rate | 62.5 | 77.5 | % | Typical percentage of cobalt in Nickel laterite deposits that is recovered when mined as by-product | 9 |
| Magm sulfide Co typical Co recovery rate | 55 | 65 | % | Typical percentage of cobalt in Magmatic sulfide deposits that is recovered when mined as by-product | 9 |
| Maximum increase production capacity | 10 | 20 | %/Year | Maximum yearly increase in production capacity | A |
| Maximum decrease production capacity | 2 | 5 | %/Year | Maximum yearly decrease in production capacity | A |
| *Variables related to ore grade – energy requirements* | | | | | |
| Relation ore grade energy usage copper | -1.05 | -0.95 | Dmnl | Relation between ore grade of copper and the related energy usage of its mining and refining | 10 |
| Relation ore grade energy usage nickel | -0.77 | -0.67 | Dmnl | Relation between ore grade of nickel and the related energy usage of its mining and refining | 11 |
| Relation ore grade energy usage cobalt | -3.1 | -2.9 | Dmnl | Relation between ore grade of cobalt and the related energy usage of its mining and refining | 9 |
| Base energy usage copper | 0.075 | 0.085 | GJ/lb | Base energy usage of copper mining and refining per lb | 10 |
| Base energy usage nickel | 0.09 | 0.13 | GJ/lb | Base energy usage of nickel mining and refining per lb | 11 |
| Base energy usage cobalt | 0.09 | 0.11 | GJ/lb | Base energy usage of nickel mining and refining per lb | 9 |
| *Variables related to the price curves* | | | | | |
| Marginal cost bottom price relationship copper | 6.5 | 8 | % | Minimum percentage of marginal cost for determining the price of copper | 12 |
| Marginal cost bottom price relationship nickel | 3 | 3.6 | % | Minimum percentage of marginal cost for determining the price of nickel | 12 |
| Marginal cost bottom price relationship cobalt | 0.05 | 0.075 | % | Minimum percentage of marginal cost for determining the price of cobalt | 12 |
| Exponent copper price curve | -1.2 | -1 | Dmnl | Sensitivity of copper price to supply fluctuations | 12 |
| Exponent nickel price curve | -0.85 | -0.65 | Dmnl | Sensitivity of nickel price to supply fluctuations | 12 |
| Exponent cobalt price curve | -1.3 | -1.1 | Dmnl | Sensitivity of cobalt price to supply fluctuations | 12 |
| Percentage cost on top of marginal cost | 0.05 | 0.25 | Dmnl | Minimum percentage on top of marginal cost | 7 |
| *Variables related to recycling* | | | | | |
| Average time scrap until recycling | 0.38 | 0.42 | Year | Average time it takes scrap to be recycled | A |
| Maximum copper recycling efficiency score | 98 | 99 | % | Maximum percentage of copper that can be recovered from recycled scrap | 13 |
| Maximum nickel recycling efficiency score | 94 | 96 | % | Maximum percentage of nickel that can be recovered from recycled scrap | 13 |
| Maximum cobalt recycling efficiency score | 94 | 96 | % | Maximum percentage of cobalt that can be recovered from recycled scrap | 13 |
| Percentage of primary scrap | 25 | 40 | % | Percentage of metal that becomes scrap during production | 14 |
| Initial average lifetime of metal in use | 5 | 15 | Year | Average lifetime of metal in use in 2000 | 13 |
| *Variables related to demand* | | | | | |
| Cu per dollar GDP | 6E-5 | 8E-5 | lb/Dollar | Nickel demand per dollar increase in GDP | 15,16 |
| Ni per dollar GDP | 4E-6 | 8E-6 | lb/Dollar | Nickel demand per dollar increase in GDP | 15,17 |
| Co per dollar GDP | 1E-6 | 1.5E-6 | lb/Dollar | Cobalt demand per dollar increase in GDP | 15,18 |
| Long term substitution strength | 1 | 5 | %/Year | Percentage of demand that is substituted if requirements for substitution hold for a long period of time | A |
| Short term substitution strength | 2 | 6 | %/Year | Percentage of demand that is substituted if requirements for substitution hold for a short period of time | A |
| Copper substitution threshold | 2.5 | 5 | Dmnl | Threshold for copper substitution: if the price of copper is higher than this amount times the price of its substitute, substitution happens | 7 |
| Nickel substitution threshold | 5 | 10 | Dmnl | Threshold for nickel substitution: if the price of nickel is higher than this amount times the price of its substitute, substitution happens | A |
| Cobalt substitution threshold | 2 | 4 | Dmnl | Threshold for cobalt substitution: if the price of cobalt is higher than this amount times the price of its substitute, substitution happens | A |
| Substitution strength battery compared to traditional | 0.01 | 0.05 | 1/Year | Battery demand is assumed to be more likely to be substituted, this variable determines by how much. | A |
| Price elasticity long term | 0.1 | 0.25 | 1/Year | Price elasticity of demand in the long term | 5 |
| Price elasticity short term | 0.02 | 0.08 | 1/Year | Price elasticity of demand in the short term | 5 |
| Price amplifying factor | 0.5 | 0.3 | Dmnl | Price amplifying factor | 5 |
| *Variables related to marginal costs* | | | | | |
| Cobalt taxes in DRC | 0.3 | 0.8 | Dollar/lb | Taxes charged per lb cobalt in DRC | 12 |
| Innovation in mining sector | 0.7 | 1 | Dmnl | Innovation causing decrease of costs of mining | A |
| Transport costs copper | 0.02 | 0.06 | Dollar/lb | Total transport costs over copper production chain | 12 |
| Transport costs nickel | 0.1 | 0.3 | Dollar/lb | Total transport costs over nickel production chain | 12 |
| Transport costs cobalt | 0.1 | 0.3 | Dollar/lb | Total transport costs over cobalt production chain | 12 |
| Price averaging period | 0.1 | 0.4 | Year | Period over which forecasted price gets averaged | A |
| Power for ore grades | 0.38 | 0.42 | Dmnl | Ore grade is assumed to decline. This variable indicates how fast the decline is. | 9,10,19 |

Table 2. Overview of experimental set-up, categorical variables.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Categorical variable | Categories | Explanation | | Source |
| Paradigm | Opportunity cost  Fixed stock | Two paradigms from literature with different assumptions on physical and economic scarcity | | 20–22 |
| SSP | 1, 2, 3, 4, 5 | Shared Socio-Economic Pathways (SSPs) for exploration of future interactions between societal development and climate change mitigation and adaptation The SSPs cover a wide uncertainty range concerning economic and demographic projections, see figures 1a and 1b. | | 23–29 |
| Price formula |  | Two ways to calculate the price of cobalt. | | 7,9 |
|  |  | *P*  *MC*  *m*  *D*  *Y*  *s*  *p*  *A* | *= price of cobalt*  *= marginal cost of cobalt per lb*  *= minimum percentage of marginal cost*  *= days of demand in stock*  *= days in a year*  *= sensitivity to supply fluctuations*  *= minimum percentage on top of   marginal cost*  *= available supply* |  |
| Energy price | Scenario 1, 2, 3 | Scenarios for energy price over time, see figure 2. | | 30 |
| Carbon price | No global carbon price  Global carbon price in SSP 1, 2, 3, 4, 5 | Each SSP has its own scenario for the introduction of a global carbon price, see figure 1c. This variable includes these carbon prices, or excludes them. | | 23–29 |

Afbeelding met tekst, kaart

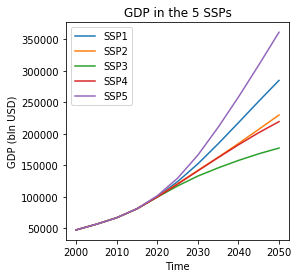
Automatisch gegenereerde beschrijving

Figure 1 a,b,c. GDP, Population and Carbon price in the 5 SSPs.

Afbeelding met tekst, kaart

Automatisch gegenereerde beschrijving

Figure 2. Three scenarios for energy price.

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