**Policies effectiveness on Lithium battery cost and Traditional Car Ban**

Are the regional/new-ban policies effectively necessary and relevant OR are simply redundant with respect to the global ones (carbon tax, Net-zero emissions 2050)?

What are their effects and impact on the common objective (emissions reduction) in comparison with our actual framework and the different scenarios? -> Do they effectively change the final outcome?

**Lithium and cobalt cost (% of a battery)**

We started from the lithium carbonate price, and we adjusted it for inflation. Then we computed the quantity of lithium in the lithium carbonate, using a stoichiometric conversion: 0,187 [], and therefore we calculated the price of lithium.Cobalt is already extracted as it is and we just adjusted it for inflation. We did not use the default data on WITCH about battery costs but we calculated them in this way: Ettore-> we developed the battery price history with more up-to-date data, the asymptote is no longer at 240 but at 90 measure unit (ref. 3)  
Then, knowing the quantities (intensities) of lithium and cobalt in a battery, we transformed also the price of lithium and cobalt as 2005 USD/kWh. Therefore, we were able to isolate the price of these materials from the rest of the battery cost, and so we could simulate the change in cost of the batteries, varying the cost of lithium and cobalt. We introduced a price variation for batteries: in 2005, the price of lithium accounted for 15% of the battery price, and the increase acts on this 15%. The chosen price growth trend is of the form and the analysis was conducted for different values of , which is the percentage increase achieved after 30-time steps.

The parametric analysis for was facilitated by creating a bash file capable of autonomously running with different values set as flags. The bash file is implemented as follows:

Immagine che contiene testo, schermata, software

Descrizione generata automaticamente

**Policies:**

**Modifications in the module mod\_transport.gms**

We set a ban on the sale of internal combustion engine vehicles (Light Duty) in Europe starting from 2035, model as a constraint on investments (I\_EN) in traditional cars.

In addition, we set a ban on the sale of internal combustion engine vehicles (Light Duty) in USA starting from 2035, modelled as an equation about investments (I\_EN) in traditional cars. The coefficient is set to 0.75 because this policy will affect only 25% of the light duty vehicles.  
The main modifications in the transport module are the following:

1. In the phase VARS



1. In the phase EQS (Ref. **2**)

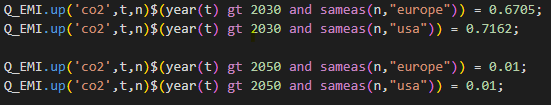
Immagine che contiene testo, Carattere, schermata, linea

Descrizione generata automaticamente

**Modifications in the module core\_policy.gms**

Regarding the EU, we also implemented the Fit-for-55 policy, with the constraint about net-zero emissions after 2050 (modelled as a zero emission altogether), and the intermediate goal of reducing emissions by at least 55% by 2030, with respect to 1990 levels (0.6705 Gton of Carbon) (Ref. 4)

Then, we also implemented IRA (Inflation Reduction Act) with the constraint about net-zero emissions after 2050 (modelled as a zero emission altogether), and the intermediate goal of reducing emissions by at least 50% by 2030, with respect to 2005 levels. (0.7162 Gton of Carbon)



**Further Developments:** implementation and algorithm

As part of our project's additional analysis, we have tried to analyze the energy security changes in EU

policies in the event of Chinese invasion of Taiwan, focusing on the effect of lithium scarcity on energy system (OR: we aimed to examine the potential impact of lithium scarcity on the energy system in EU policies in the event of a Chinese invasion of Taiwan. This analysis was managed as a lithium case study focusing on the changes in energy security). Hence, we attempted to track the trend of the electric transportation industry in response to a variation in lithium prices caused by a disruption in trade, with particular attention to the variations that a country lacking raw materials could experience

**Lithium Extraction and Curve Interpolation**

The implementation of the lithium extraction model incorporates a pre-solve algorithm that manages the process prior to each iteration of the main solver. This algorithm assigns the price and regional productions based on calibrated global and regional production curves, taking into account the global demand.

Since the algorithm is based on global and regional supply curves, we calibrated them from [bp Statistical Review of World Energy](https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/xlsx/energy-economics/statistical-review/bp-stats-review-2022-all-data.xlsx) data on lithium production and reserves (*lithium\_excel*). Specifically, we developed a new code on RStudio to interpolate the curve for all the 17 regions of the WITCH model, starting from the available lithium data. Using the *R stats* package, we performed a polynomial regression on the cumulative production of each region to estimates the lithium price, we decided to interpolate the curve with a fourth order polynomial because it allows to capture a more appropriate trend of the variable of interest. For further details on implementation and code see the *Curve\_interpolation.R* file, that contains also the transformation of the data frame into the GDX table *data\_mod\_lithium.gdx* (**GitHub** Repository).  
The main part of the R code for curve fitting and storing the polynomial coefficients is the following:

Immagine che contiene testo, schermata, Carattere, algebra

Descrizione generata automaticamente

As for the Gas and Coal extraction of WITCH, we assumed that the lithium extraction operates under the assumption of perfect market competition, and additionally, the cost of the infrastructure is embedded within the supply curves.

The algorithm, located in the lithium module outside the main loop, is heuristic and functions as follows:

1. Read the global price corresponding to global cumulative production, for each period;
2. Read the cumulative regional production level from the regional production curves that corresponds to the price of the previous step;
3. Compute the production levels as difference between consecutive cumulative production and send them to solver.

At each iteration, the main solver optimizes the utility of each region by making decisions with perfect foresight. It internally determines the demand while treating production as a fixed value. The consumption of lithium directly impacts the overall price and its competitiveness in the market. The iterative nature of the WITCH model ensures consistency between global supply and demand, (possibly to cut indeed the imbalances between global supply and demand are eliminated, removing the need for market clearance using the core iterative algorithm of the model. )

To address this, inspired by the gas module already presented in the WITCH integrated assessment model, we developed a new module within the model, specifically dedicated to modeling the lithium extraction.

Firstly, we attempted to include the lithium module, assuming lithium as a fuel in order to retrieve the equations for pricing and investments used by actual fuel elements. Then, after encountering execution errors, we tried to define a separate set for material and specific equations, but even in this case and despite our efforts, we were unable to successfully integrate this module into the rest of the model.

**GitHub repository** of the project containing all the code: [Energy Climate Change Project Repository](https://github.com/ettoremodina/ECC-Project2)

References

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