International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 519

DO METALS REALLY MATTER FOR THE ENERGY TRANSITION? AN ENDOGENOUS MATERIAL SUPPLY CHAIN IN A LONG-TERM ENERGY MODEL

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ABSTRACT

The aim of this paper is to assess the impact of the energy transition on raw material demand and answer the question whether or not lithium, copper, cobalt and nickel might become critical due to their high content in low-carbon technologies of the power and transport sectors. Growing need for these ores and refined metals is expected along with the energy transition toward a low-carbon system due to the fact that all decarbonisation innovations are very raw material-intensive. To achieve this goal, we have developed the first detailed global bottom-up energy model, TIAM-IFPEN (TIMES Integrated Assessment Model) with an endogenous representation of the lithium, copper, nickel and cobalt supply chain. Lot of the literature analysis have been focused on battery's materials such as lithium, cobalt and at a lesser extent nickel but none has implemented raw material supply chain in long-term energy scenario in order to evaluate if the availability of these materials could impede the energy transition. This article would also like in addition to give more focus on structural materials such as copper. Indeed, the criticality of these structural materials have been neglected despite the continuing policy focus on raw material criticality and the many reports and books written on the topic. This model would clearly assess the dynamic criticality of these strategic materials according to the optimal technology paths with environmental and/or energy solicitations through different approaches: geological, geopolitical, and economic towards a sustainable development. Two climate scenarios (4°C and 2°C) have been conducted with two shapes of mobility each. The penetration of low-carbon technologies in the transport and power sectors (electric vehicles, low-carbon power generation technologies, etc.) should increase copper, lithium, cobalt and nickel demands drastically by 2050. However, this approach would also highlight the public policy drivers that can mitigate our results. Here, the case of public policy based on an integrated approach to urban land-use and transport planning has been implemented. The study of these particular strategic materials shows that the model could be a useful decision-making tool for assessing future raw material market stresses along with energy transition for more efficient regional and sectorial screening

Keywords: Energy transition, Critical raw materials, Transport and power sector, Energy System Optimization Model, Lithium and cobalt, Copper and Nickel

1. INTRODUCTION

Considering raw material criticality in future low-carbon energy transition is a crucial challenge in order to tackle probable material scarcity, new and unexpected material dependency, in other words, raw material criticality issues. As stated in the Brundtland Report, this sustainable development should meet the needs of the present without compromising the ability of future generations to meet their own needs. Raw material criticality have been widely discussed in the literature since the last decade [2]. The question of knowing and quantifying the impacts of prospective energy scenarios for raw material resources is of crucial importance to better understand the future with more efficient resource management. Therefore, long-term energy analyses should take into account complete supply chain of available resources, otherwise they may not be relevant or may need to be reconsidered in the future in the context of new resource supply constraints. Thus, a need for a better integration of the raw material content of all technologies considered in energy system models would be more relevant. As already stated by Hache et al., energy system models normally do not take into account technology life cycle inventories (LCI) of raw materials and are consequently not able to

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

assess the implications of potential future raw material supply constraints on the future energy transition. They encompassed all raw material criticality assessment in the scientific literature into two main strands of approach:

- The first is based on the use of the outputs of prospective energy models or specific roadmapping processes as inputs into prospective life-cycle assessment analyses.
- The second relies on the use of the outputs of LCI metrics as inputs into prospective energy models

Many studies have been recorded for the first approach in the literature while fewer have been found for the second one and solely focused on environmental implications. Finally, to the best of our knowledge no long-term energy model have yet incorporated complete supply chains of raw materials in its structure. This paper contribute filling this gap identified in the scientific literature on energy system optimization models. It will allow examining all risks, geological, geopolitical, trade, production, etc., related to the question of raw materials in the energy transition. We have then developed the first detailed global energy model with an endogenous representation of raw materials. However, contrary to our previous article [2] based on a detailed implementation of lithium supply chain; we add for this paper the supply chain of copper, cobalt and nickel in order to assess dynamic criticality of two other battery commodities (cobalt and nickel) and a structural commodity (copper) along with technological changes through to 2050. And the main results would focus on how the fast shifts in power sector and transport can impact material resource demand. Section 2 succinctly describes the structure of our TIAM-IFPEN model and the main assumptions related to the selected raw material; Section 3 summarizes some results related to the evolution of the world power mix and transport fleet by 2050, and their inherent impacts on lithium, cobalt, nickel and copper demands in the future according to climate scenarios and the implementation of a public policy on future mobility shape. In addition, a special sectorial focus has been done on copper, as an example of a structural raw material, because it would certainly have a central role in this context of low-carbon energy transition due to the large and increasing number of applications.

2. METHODOLOGY

2.1 TIAM-IFPEN model [1]

TIAM-IFPEN model, a bottom-up linear programming model, have been developed recently at IFP Energies Nouvelles (IFPEN). It is the global incarnation of the TIMES[1] model. TIAM-IFPEN has been set up to explore the development of the World energy system from 2005 till 2050 and is calibrated to the 2005-2010 data provided by energy statistics. The objective function is the criterion that is minimized by the TIMES model which is the total discounted cost of the system over the selected planning horizon.

The model is disaggregated into 16 regions and includes explicit detailed descriptions of technologies in each region, logically interrelated in a Reference Energy System, the chain of processes with transforming, transporting, distributing and converting energy into services from primary resources and raw materials to the energy services needed by the end-use sectors. All power generation technologies have been covered by the model and transport sector has been disaggregated into passenger light-duty vehicles (small, medium and large), bus, minibus, commercial vehicles (light, heavy and medium trucks) and 2/3-wheelers. The raw material content is based on the NMC[2] battery technology, disaggregated per vehicle size (See[1] for more details on TIAM-IFPEN model, its data and sectorial overview). Indeed, the raw material content per unit capacity (for copper, cobalt and nickel) has been disaggregated by technology type in order to take into account the large disparities in material needs between conventional and low-carbon technologies (Ecoinvent,[2]).

2.2 Main assumptions

In this section, in addition to the lithium assumptions already presented in Hache et al. [1], the new main assumptions related to copper, cobalt and nickel are listed below:

- The geographical distribution of copper (USGS[3],[3][4]), nickel (INSG[4],[5]), cobalt (USGS,[6]) ore reserves and resources has been provided in the model
- Two ways of the copper (pyrometallurgy and hydrometallurgy) and nickel (Class I and II) ore transformation have been considered in the model (Fig. 2 & Fig. 3) while cobalt is depicted in Fig. 4.
- Regionalized mining CAPEX and OPEX have been done and obtained from weighted averages of real projects around the world (Companies reports, INSG, USGS,[7][8][9]).

[1] The Integrated MARKAL-EFOM System
[2] Battery with cathode which includes lithium nickel manganese cobalt (NMC)
[3] United States Geological Survey
[4] International Nickel Study Group

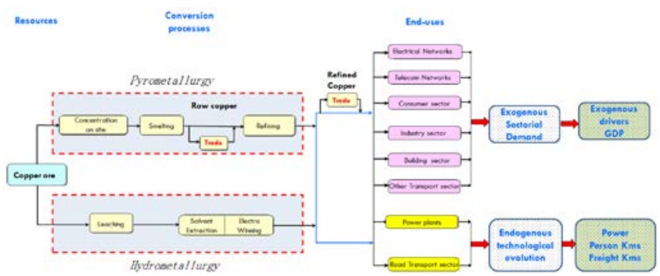

Fig. 1: Detailed description of the copper supply chain in each TIAM region

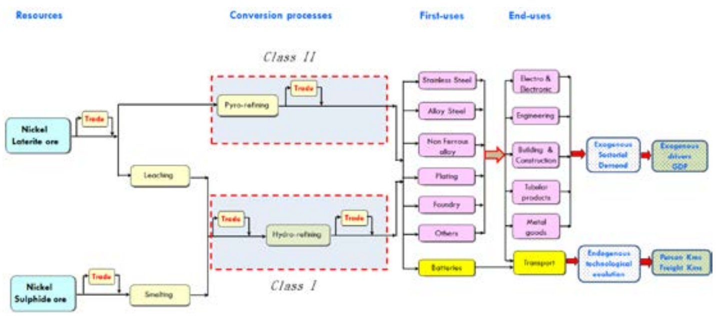

Fig. 2: Detailed description of the nickel supply chain in each TIAM region

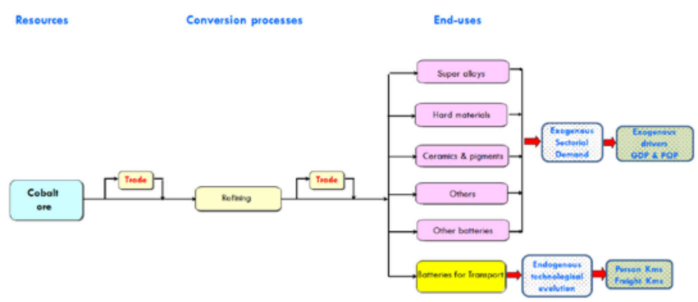

Fig. 3: Detailed description of the cobalt supply chain in each TIAM region

- The End-of-Life Recycling Rate (EoL-RR) indicator has been implemented by end-use sectors in our model for copper, nickel and cobalt in order to take into account the efficiency of each sectoral old scrap recycling. This indicator is determined as the fraction of metal contained in EoL products that is collected, pre-treated and finally recycled back in the anthropogenic cycle([10],[11]).
- Trades have been also considered in the model in order to analyse future international raw material exchanges and strategies according to each regional needs and growth as already observed for example for China in the case of copper between 2005 and 2015 (UNcomtrade database).

3. RESULTS

Three points could be developed as results here:

- Fig. 5 depicts the evolution of the world power mix in the 4°C and 2°C scenarios.

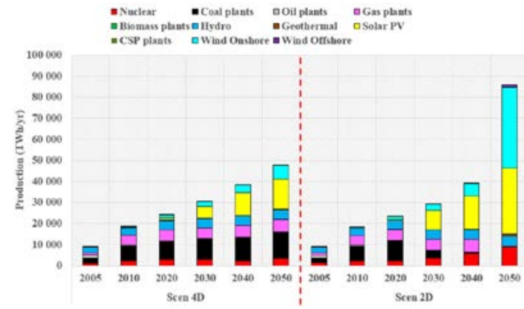

Fig. 4: Evolution of the world power mix in 4°C and 2°C scenarios

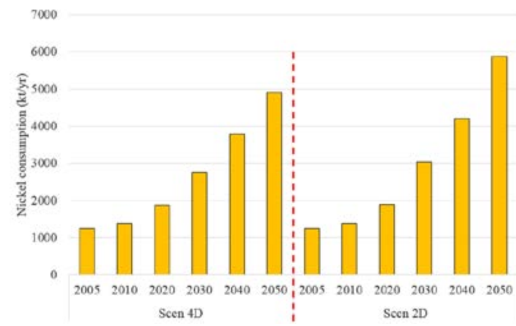

Fig. 5: Evolution of the nickel consumption (2005-2050)

As expected, wind and solar are expected to be the dominant energy with more stringent environmental constraints, while it would be fossil-based (mainly coal) in the 4°C scenario. These fasts shifts in transport (Fig.7 below) and power sectors will have an impact on raw material demands because renewable energy technologies (RETs) end electric vehicles (EVs)[5] are very raw material-intensive. In Fig. 6, global nickel consumption has almost increased fourfold and fivefold in the 4°C and 2°C scenarios between 2005 and 2050, respectively. Between 2005-2020, China's consumption passed from one third to half of global nickel consumption due to its power sector development with its numerous hydro commissioned between 2008 and 2016 (Three gorges dam 22.5 GW in 2008, Xiluodu dam 13.9 GW in 2013, Xiangjiaba dam 6.4 GW in 2015, etc.) and transport sector development (increase of car ownership rate).

- The impact of a public policy on transport sector has been analyzed via the model. Two future shapes of mobility have been assumed and derived from the IEA Mobility Model (MoMo Model): "BAU Mob" where a continuing increase of the car-dependencies is assumed while in "Sustainable Mob" priority is given to sustainable modes of mobility such as public and non-motorized transport. The latter has induced a decrease of the global vehicle fleet both in 4°C and 2°C scenarios (Fig. 7). For example, EV stock (2/3-wheelers

[5] Electric vehicles include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs) and fuel-cell electric vehicles (FCEVs)

included) has decreased by 325 million in the 2°C scenario (of which 3/4 are 2/3 wheelers, mostly located in in Asian countries).

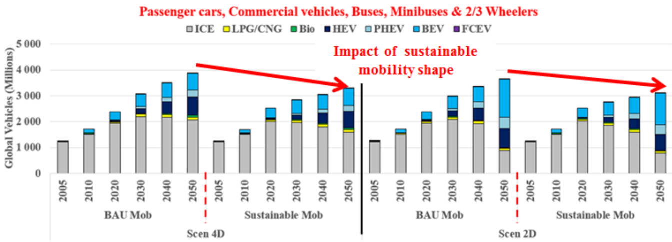

Fig. 6: Evolution of the global vehicle stock between 2005-2050

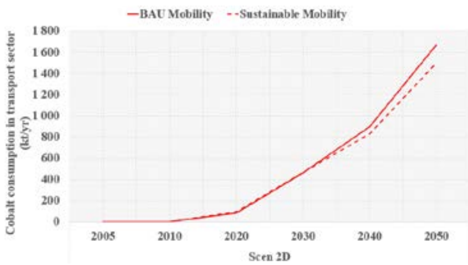

Fig. 7: Evolution of annual cobalt demand from 1990 to 2050 (historical data until 2016)

It leads to a slowdown by 2050 by more than 10% in the annual cobalt consumption depicted in Fig. 8. Thus, there are unprecedented opportunities in changes of individual travel behavior in road transport for raw material criticality analyses.

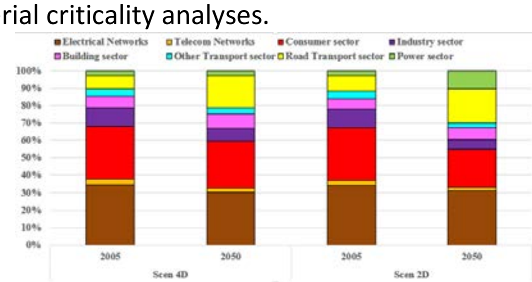

Fig. 8: Evolution of the share in copper end-use sectors 2005 & 2050.

- In the case of a structural material, Fig. 9 summarizes how transport and power sectors are getting more import in copper consumption in detriment of other end-use sectors between 2005 and 2005 in both 4°C and 2°C scenarios. It highlights the fact that the electrification of transport and decarbonisation of power sector would induce a high structural effect through the raw material end-use sectors as observed here in the case of copper or in lithium [1]

4. CONCLUSION

The first long-term energy model which has integrated complete raw material supply chains, has been developed in order to be able to assess dynamic raw material criticality but as well to quantify all geological, geopolitical and economic risks related to any future material or climate constraints.

ACKNOWLEDGEMENT

This study received the financial support of the French National Research Agency (ANR) and this article is part of the GENERATE (Renewable Energies Geopolitics and Future Studies on Energy Transition) project. It receives also funding from the French Environment & Energy Management Agency (ADEME) with a project dedicated to lithium. The authors are very grateful to Amit Kanudia who has contributed to the TIAM-IFPEN model on behalf of his company KANoRS through providing assistance.

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