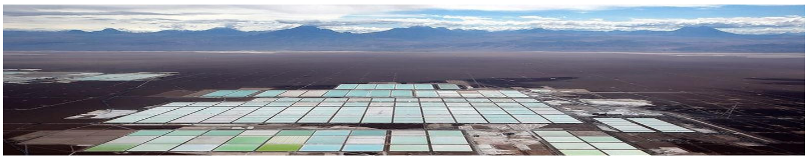

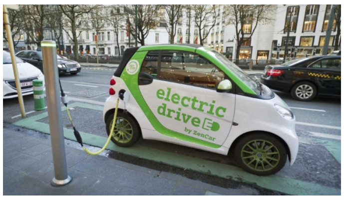

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CRITICAL RAW MATERIALS AND ENERGY TRANSITION: LITHIUM, COPPER, COBALT AND NICKEL

A DETAILED BOTTOM-UP ANALYSIS

Dr. Emmanuel HACHE, Dr. Gondia-Sokhna SECK, Marine SIMOEN, Dr. Clément BONNET

GENERATE Project (Renewable Energies Geopolitics and Future Studies on Energy Transition)
AAPG 2017-Project 2017-2019

IFP Energies nouvelles

OUTLINE

- ✓ Review of literature
- ✓ TIAM Model Methodology
- ✓ Results of the World transportation modelling
- ✓ Conclusion

IFP Energies nouvelles

REVIEW OF LITERATURE

- ✓ Raw materials supply risk and criticality have been widely discussed since the past decade:

Erdmann, L., Graedel, T.E., (2011); Achzet, B., Helbig, C., (2013); Moss et al. (2013); Helbig et al. (2016); Graedel, T.E., Reck, B.K., (2016); Dewulf et al. (2016); Jin et al. (2016); Hache (2018); Bonnet et al. (2018)

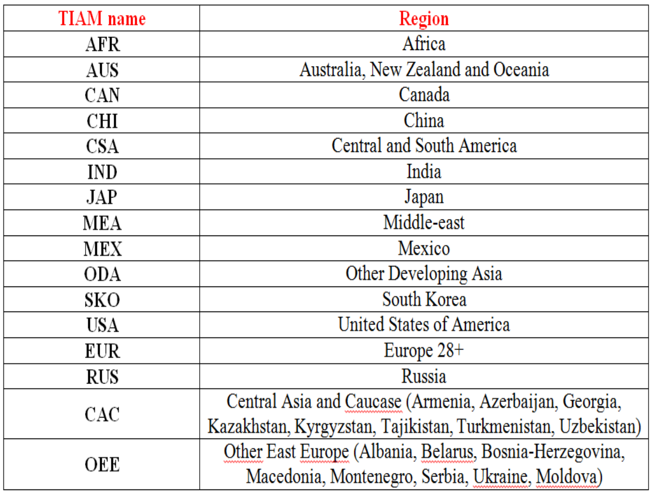
- ✓ An extensive part of the first literature was devoted to rare-earth elements criticality

Koltun P., Tharumarajah A., (2010); Du X., Graedel T.E., (2011); Goonan T. G., (2011); Hatch G.P., (2011); Alonso E. et al. (2012); Baldi et al. (2014); CRS, (2012); Golev et al. (2014); Klossek et al. (2016)

- ✓ One of the major challenges is the development of criticality assessment methods
- ✓ The dimensions of interest considered in criticality assessments are usually vulnerability and supply risk relying on economic, geological or technical concerns sometimes extended by environmental impacts or by social implications.
- ✓ Originality of the paper : In this paper, an endogenous integration of raw materials content into our detailed bottom-up model, TIAM-IFPEN, has been implemented in order to allow them to interact endogenously with the different scenarios which could be considered
- ✓ Dynamic assessment of raw materials criticality

TIAM-IFPEN MODEL

Table 1 : Regions of the TIAM-IFPEN

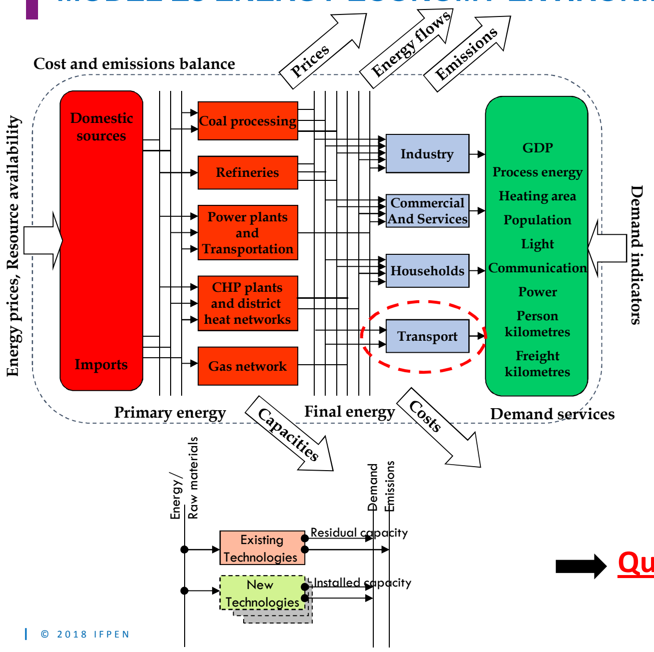


TIAM name	Region
AFR	Africa
AUS	Australia, New Zealand and Oceania
CAN	Canada
CHI	China
CSA	Central and South America
IND	India
JAP	Japan
MEA	Middle-east
MEX	Mexico
ODA	Other Developing Asia
SKO	South Korea
USA	United States of America
EUR	Europe 28+
RUS	Russia
CAC	Central Asia and Caucase (Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan)
OEE	Other East Europe (Albania, Belarus, Bosnia-Herzegovina, Macedonia, Montenegro, Serbia, Ukraine, Moldova)

- ✓ The model is disaggregated into 16 regions where each region has its own energy system with their main demand sectors.
- ✓ Each region can trade fossil resources, biomass, materials or emission permits with other regions or in a centralized market.
- ✓ Thus, the model fully describes within each region all existing and future technologies from supply (primary resources) through the different conversion steps to end-use demands.

ENERGY SYSTEM MODELLING: MODEL E3 ENERGY-ECONOMY-ENVIRONMENT

ENERGY MODELLING


Cost and emissions balance
Prices
Energy flows
Emissions
Energy prices, Resource availability
Domestic sources
Imports
Coal processing
Refineries
Power plants and Transportation
CHP plants and district heat networks
Gas network
Industry
Commercial And Services
Households
Transport
GDP
Process energy
Heating area
Population
Light
Communication
Power
Person kilometres
Freight kilometres
Demand indicators
Primary energy
Final energy
Demand services
Capacities
Costs
Energy/ Raw materials
Demand
Emissions
Existing Technologies
New Technologies
Residual capacity
Installed capacity

TIAM-IFPEN model

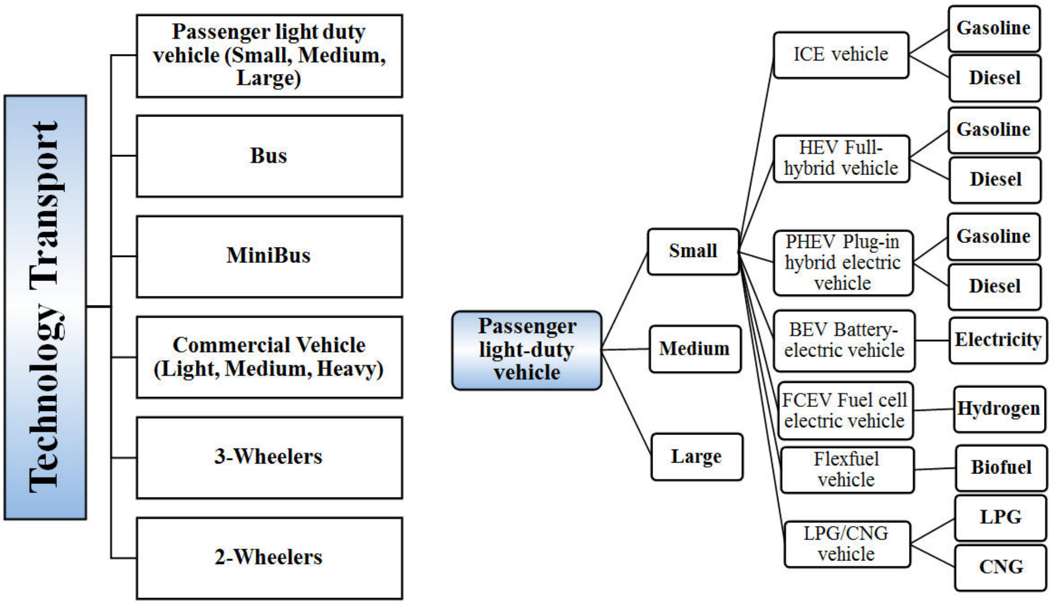
- **Main questions**
  - Climate change
  - Supply security (Energy and critical materials)
  - Extension beyond purely energy-oriented issues, to the representation of environmental emissions, and materials, related to the energy system.
  - Conditions of feasibility of the Energy transition
- **Model details**
  - Economic sectors: Agriculture, Residential, Services, Industry, Power sector and Transport.
- **Identify alternative options, levers**
  - Anticipate feasible futures
  - Resource balance – sectors – services for given goals

⇒ **Allocation of rare resources (incl. environment)**

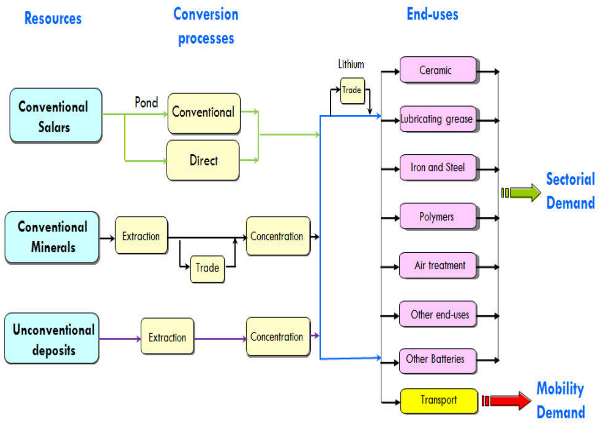
➡ **Quantify to explain and not to predict**

TIAM-IFPEN MODEL : TRANSPORT SECTOR

ENERGY SYSTEM MODELLING


Technology Transport
Passenger light duty vehicle (Small, Medium, Large)
Bus
MiniBus
Commercial Vehicle (Light, Medium, Heavy)
3-Wheelers
2-Wheelers
Passenger light-duty vehicle
Small
Medium
Large
ICE vehicle
HEV Full-hybrid vehicle
PHEV Plug-in hybrid electric vehicle
BEV Battery-electric vehicle
FCEV Fuel cell electric vehicle
Flexfuel vehicle
LPG/CNG vehicle
Gasoline
Diesel
Gasoline
Diesel
Gasoline
Diesel
Electricity
Hydrogen
Biofuel
LPG
CNG

DETAILED DESCRIPTION OF LITHIUM SUPPLY CHAIN IN EACH TIAM REGION



- ✓ Two types of trade are included in the model:
- ✓ The first one is about lithium ore from the mineral deposits to the refining sites. The main flow is as of today from Australia to China.
- ✓ The second trade concerns the main lithium-based chemicals (LiOH and Li2CO3).
- ✓ Both products are aggregated in the same trade flows as they are not distinguish according to a specific end-use. Taking into account the trade capabilities will allow analysing future international lithium exchanges according to the each regional needs and growth.

SCENARIOS ASSUMPTIONS

✓ We run four scenarios where we have considered two climate scenarios with two different type of mobility each in order to assess the impact on the raw materials market along with the energy transition dynamic:

(1): Scen 4D which is consistent with limiting the expected global average temperature increase to 4°C above pre-industrial levels by 2100.

(2): Scen 2D which is a more ambitious scenario, which translates the climate objectives of limiting global warming to 2°C by 2100.

✓ In each climate scenario, two shape of mobility have been considered as abovementioned:

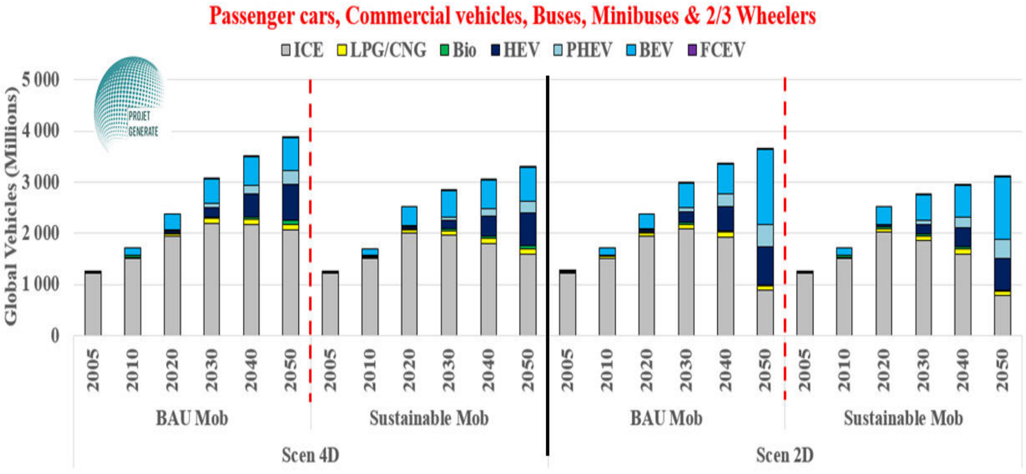
(1): Hypothesis of a High mobility where we assume the impact of urban dispersal, a worldwide phenomenon, on mobility and travel as well as the influence of urban land coverage on travel where we keep on having a huge car dependency and usage.

(2): Hypothesis of a Low mobility where the idea of a sustainability in mobility is assumed. This means taking into account social, economic and institutional dimensions to move beyond a focus on ecology and the natural environment. This assumption implies more compact cities, underpins an integrated approach to urban land-use and transport planning and investment, and gives priority to sustainable modes of mobility such as public and non-motorized transport as seen with the bus and minibus travel demands.

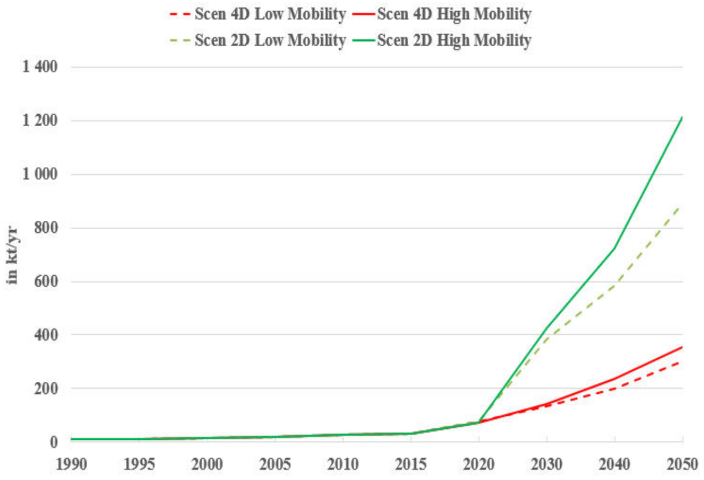
OUTLINE

- ✓ Context, Review of literature and question
- ✓ TIAM Model Methodology
- ✓ **Results of the World transportation modelling**
- ✓ Conclusion

RESULTS: EVOLUTION OF THE GLOBAL VEHICLE STOCK BETWEEN 2005-2050

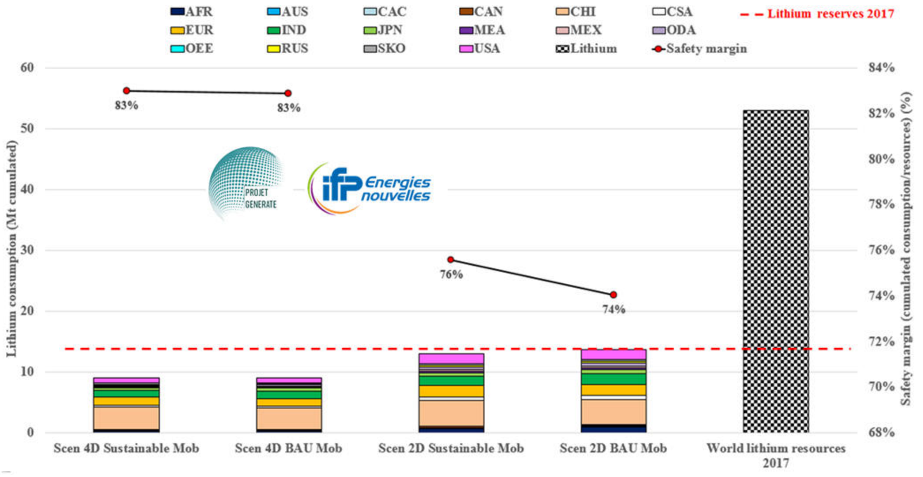


EVOLUTION OF LITHIUM DEMAND FROM 1990 TO 2050 (HISTORICAL DATA UNTIL 2016)



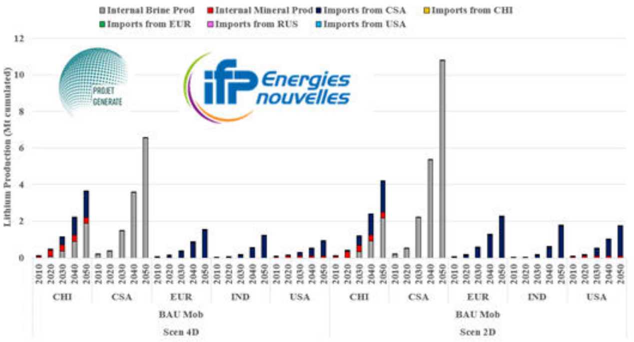
IMPACT OF THE GLOBAL EV EVOLUTION ON THE LITHIUM DEMAND

Comparison between the cumulated lithium consumption (2005-2050) and the world lithium resources in 2017

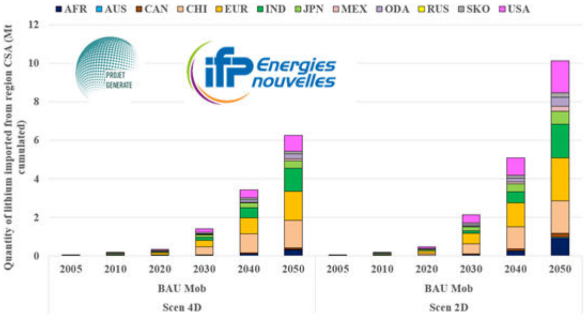


LITHIUM TRADE

Internal production and imports in five major regions: China (CHI), Central and South America (CSA), India (IND), Europe (EUR) and United States of America (USA)

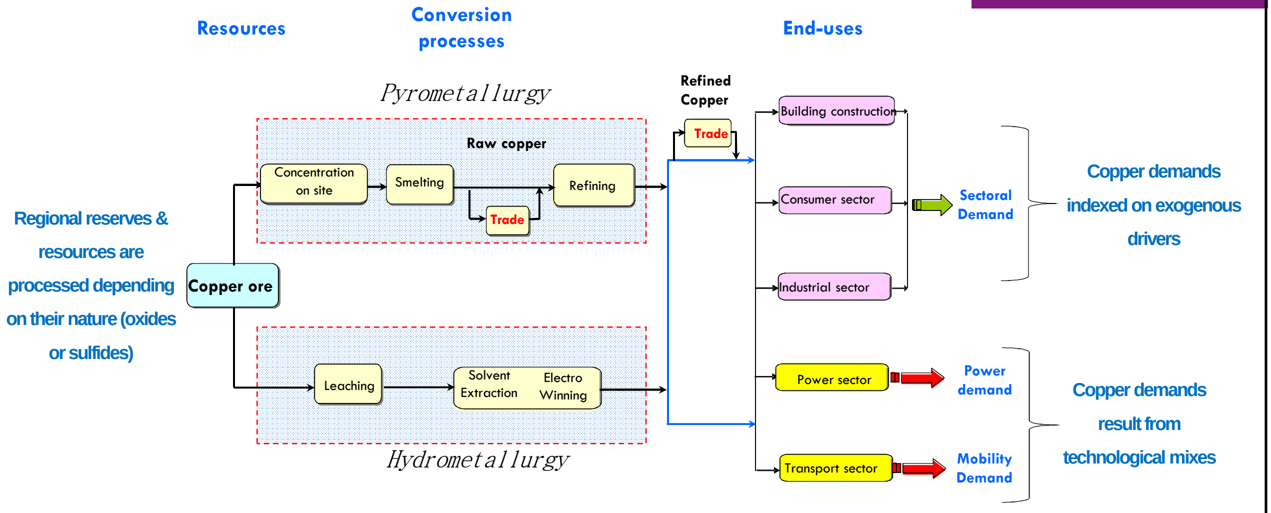


Profile of regionalized lithium imports from the Central and South America (CSA) region



THE COPPER SUPPLY CHAIN IN THE TIAM MODEL

ENERGY MODELLING



Resources

Conversion processes

End-uses

Regional reserves & resources are processed depending on their nature (oxides or sulfides)

Copper ore

Pyrometallurgy

Raw copper

Concentration on site

Smelting

Refining

Trade

Hydrometallurgy

Leaching

Solvent Extraction

Electro Winning

Refined Copper

Trade

Building construction

Consumer sector

Industrial sector

Power sector

Transport sector

Sectoral Demand

Power demand

Mobility Demand

Copper demands indexed on exogenous drivers

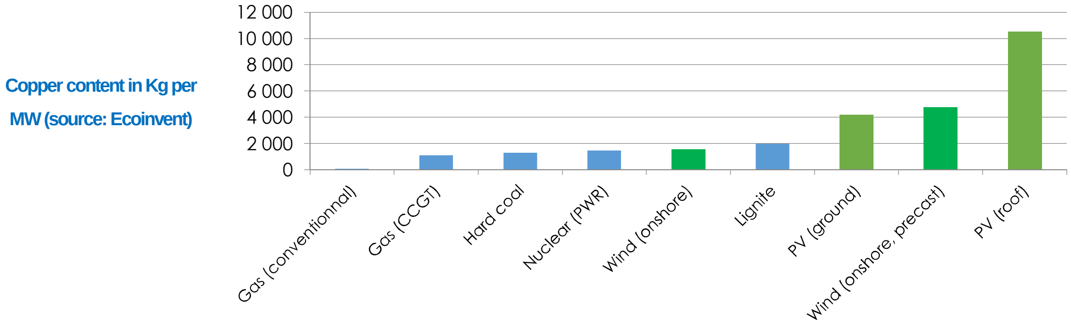
Copper demands result from technological mixes

- Ore grades are assumed to be constant over time.

COPPER IN THE ENERGY TRANSITION CONTEXT

INTRODUCTION

- Copper is widely used in the production of a broad set of low-carbon technologies.



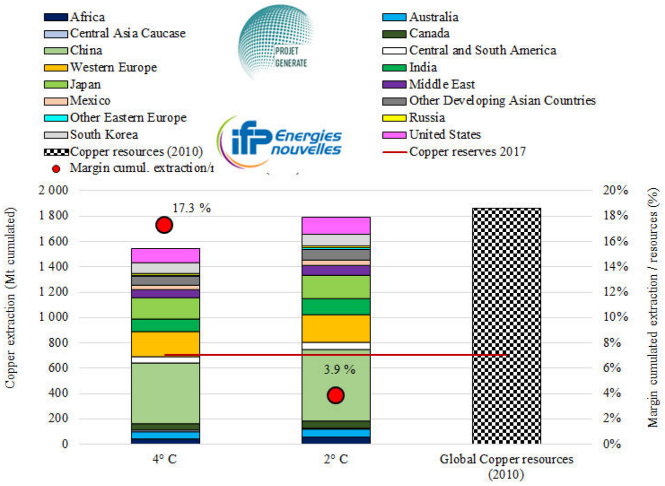
- Copper availability can impede the diffusion of building-mounted solar PV technologies.
  - Cu contents range from 10 to 14,5 tons per MW (estimates for 16 building-mounted PV installations).
- Wind power turbines with precast concrete towers have a much more higher copper content than conventional turbines.
- They are expected to be widely used as they allow reaching higher installed capacity per turbine.

IMPACT OF THE ENERGY TRANSITION ON COPPER CONSUMPTION: 4℃ VS. 2℃

RESULTS

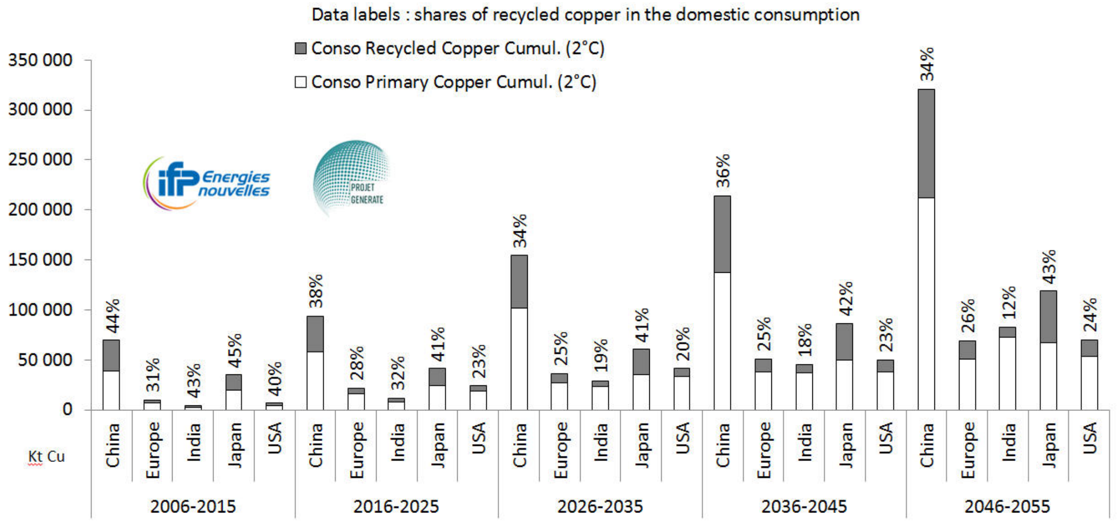
✓ The energy transition decreases by around 15 points the available copper resources in 2050.
✓ Copper reserves need to be multiplied by 2,7 between 2010 and 2050 in a 2°C scenario.
✓ It is plausible compared to the historical evolution of copper reserves
(2,25-fold between 1996 and 2015)

✓ Vulnerabilities: Water, production strategy



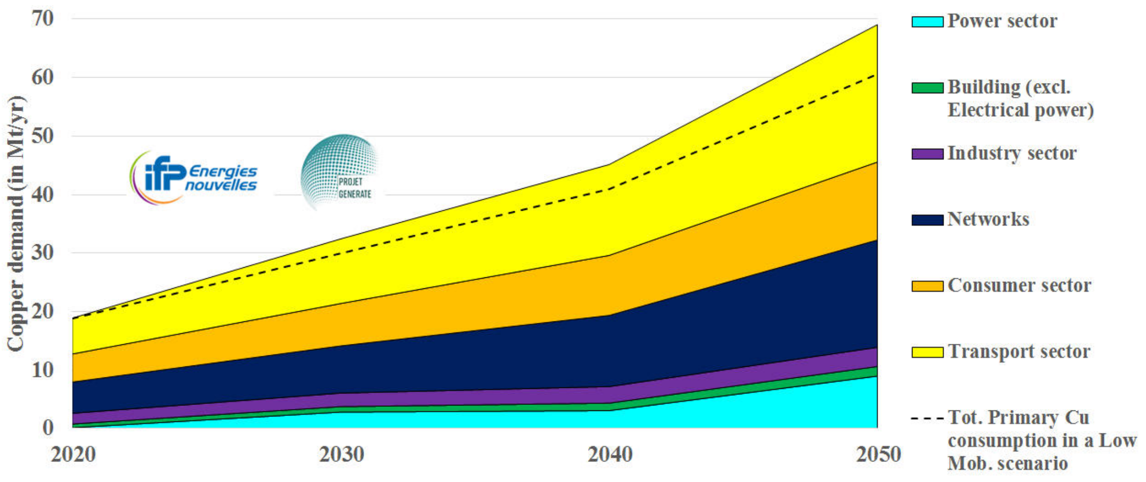
RECYCLING ISSUE

RESULTS



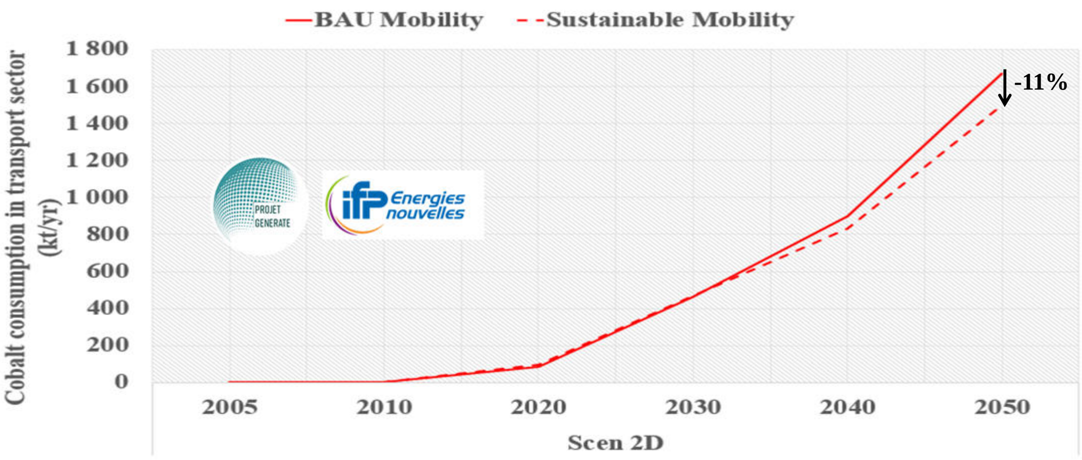
SUSTAINABLE MOBILITY IS A KEY ISSUE

RESULTS



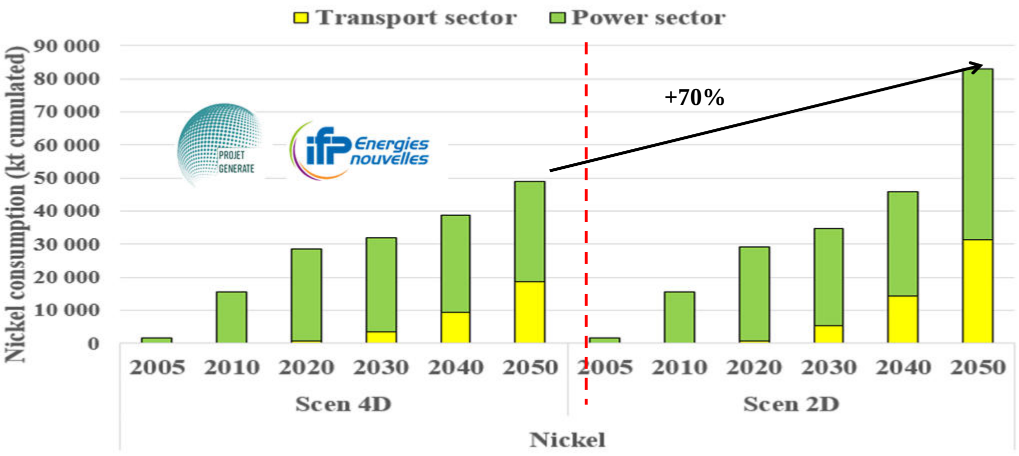
RESULTS

COBALT CONSUMPTION



RESULTS

NICKEL CONSUMPTION



CONCLUSION

- ✓ The scenarios developed in this article tend to show that energy transition dynamic could lead to a decrease in the metal safety margin in the 2°C, the most stringent climate scenario, and an hyper mobility.
- ✓ Long-term equilibrium dynamics in commodity markets tell us that the absence of geological criticality of reserves and resources does not hide different forms of vulnerability, whether economic, industrial, geopolitical or environmental
- ✓ Structural metals versus strategic metals
- ✓ Public Policy is a key issue
  - ✓ Recycling
  - ✓ Sustainable Mobility

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