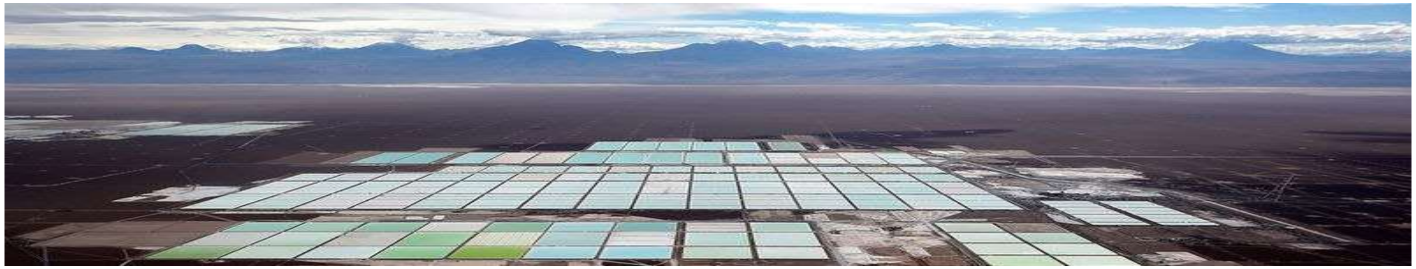

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A CRITICALITY ANALYSIS ON LITHIUM, COPPER, COBALT, NICKEL AND ALUMINIUM FOR LOW-CARBON TECHNOLOGIES

A DETAILED BOTTOM-UP ANALYSIS

Dr. Emmanuel HACHE, Dr. Gondia-Sokhna SECK, IFP Énergies nouvelles

OUTLINE

- ✓ Review of literature
- ✓ TIAM Model Methodology
- ✓ Results
- ✓ Conclusion

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, 2019), Seck et al. (2020)

- ✓ An extensive part of the first literature was devoted to rare-earth elements or to green metals 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)

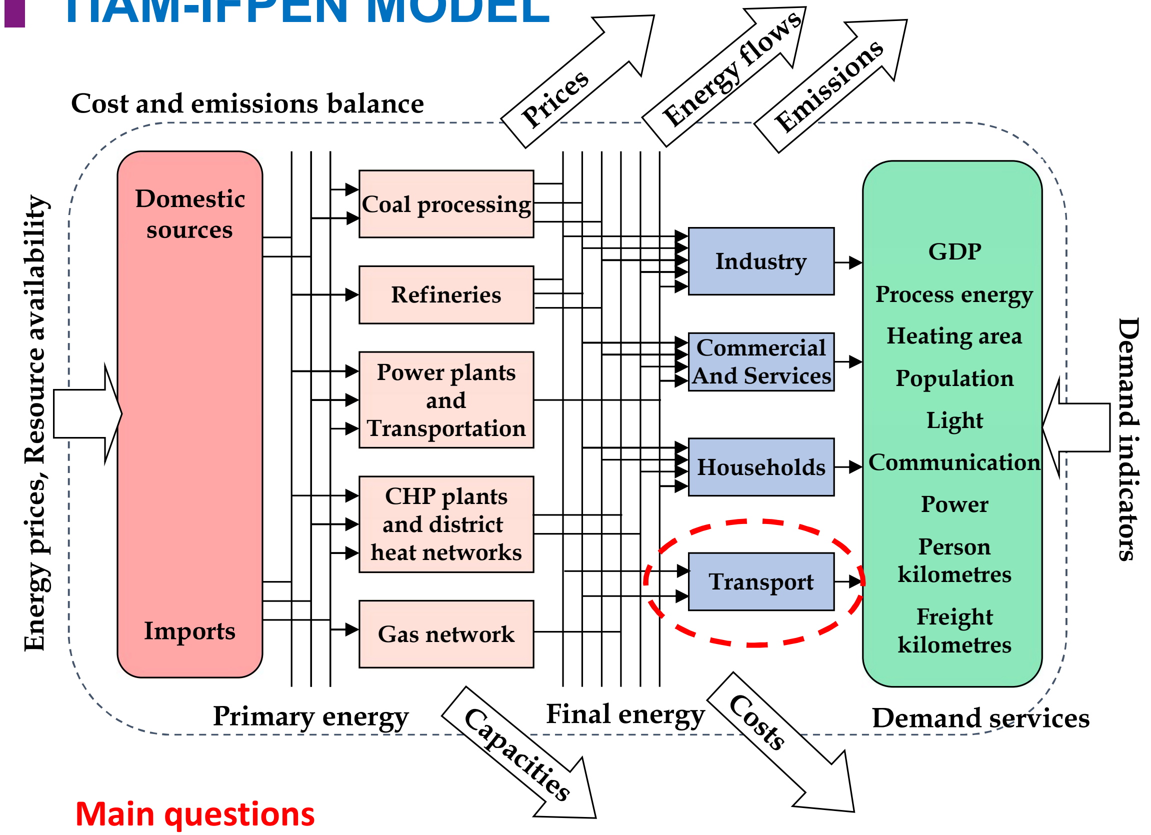
- ✓ One of the major challenges is the development of criticality assessment methods

- ✓ 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



- **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

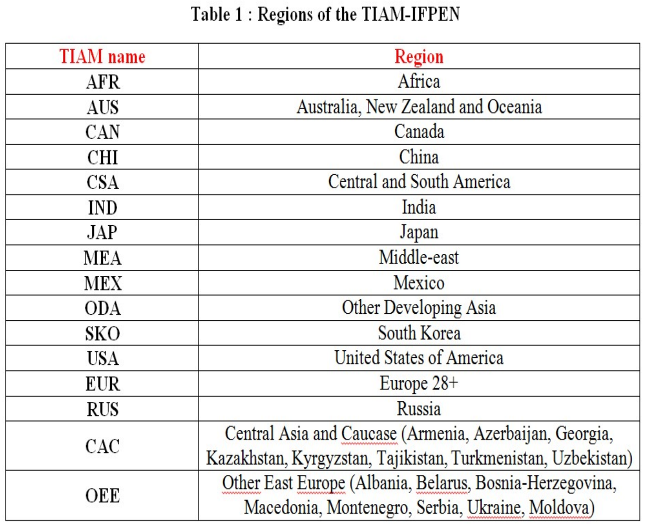
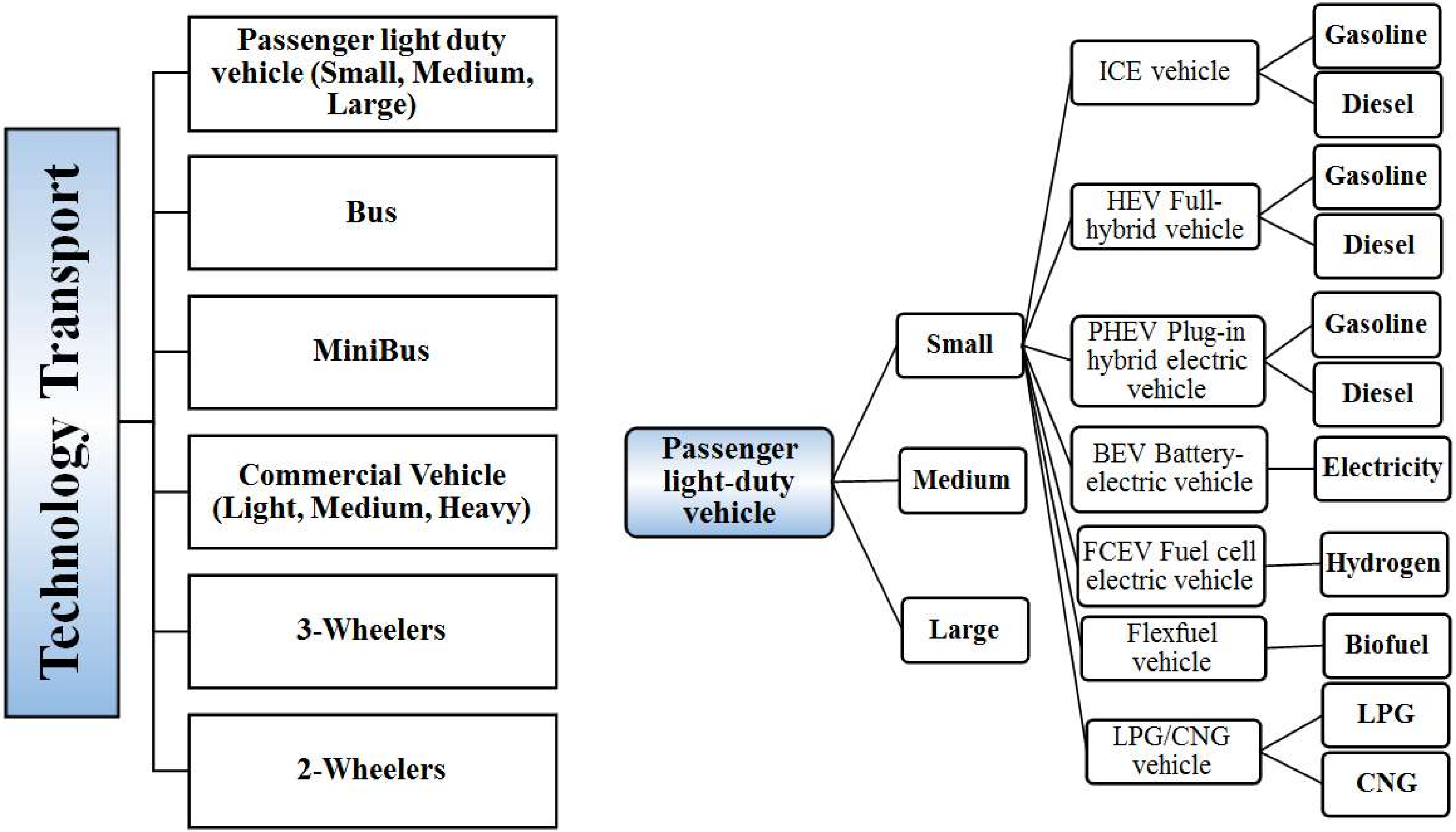


Table 1 : Regions of the TIAM-IFPEN

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.**

TIAM-IFPEN MODEL : TRANSPORT SECTOR



Technology Transport

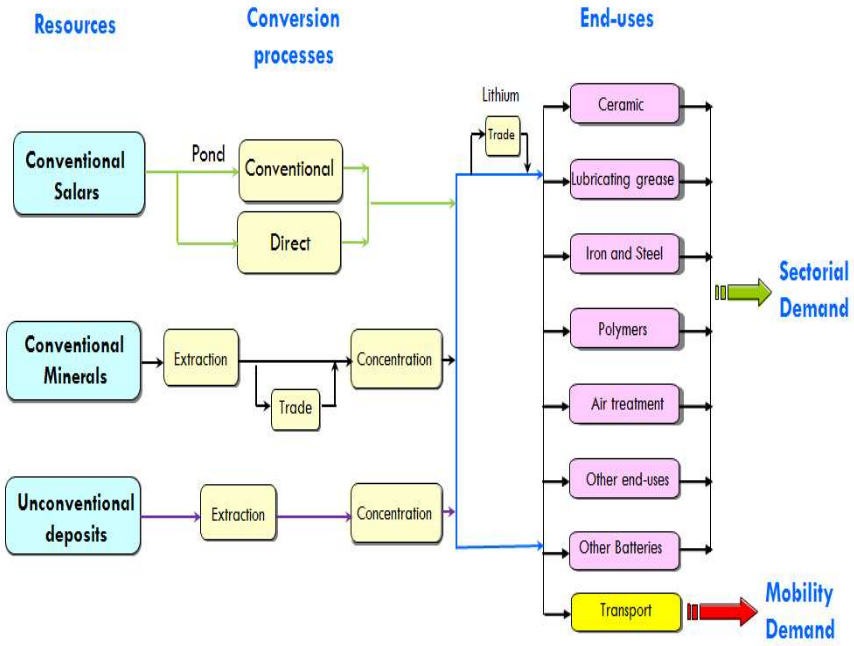
- **Passenger light duty vehicle (Small, Medium, Large)**
- **Bus**
- **MiniBus**
- **Commercial Vehicle (Light, Medium, Heavy)**
- **3-Wheelers**
- **2-Wheelers**

Passenger light-duty vehicle

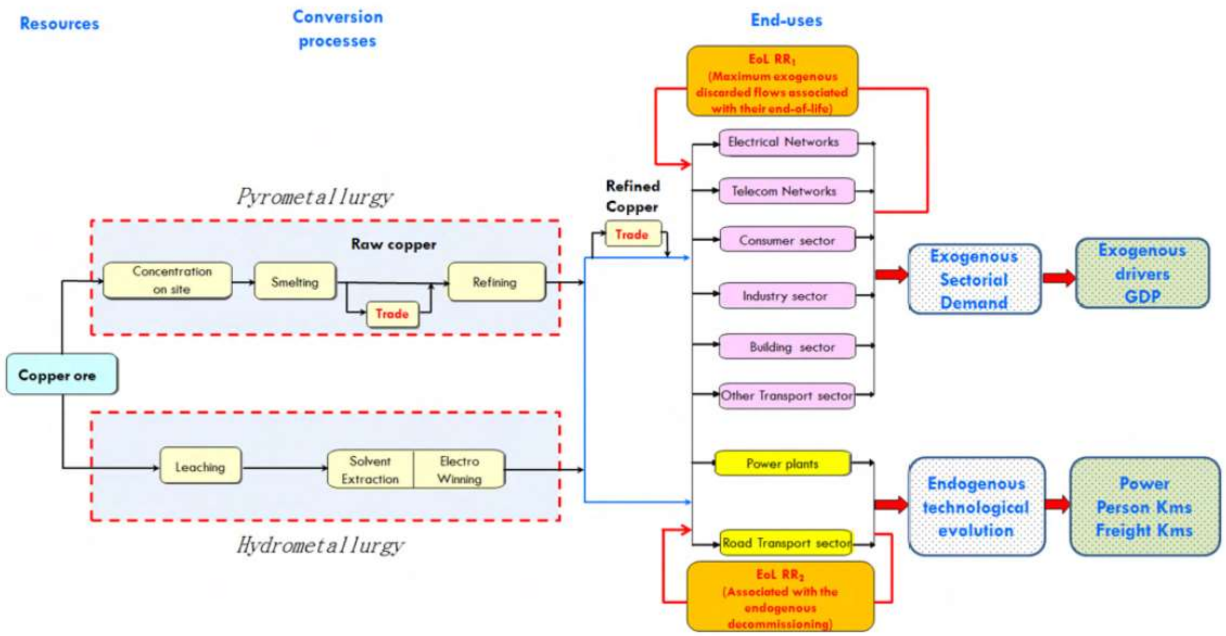
- **Small**
  - ICE vehicle
    - **Gasoline**
    - **Diesel**
  - HEV Full-hybrid vehicle
    - **Gasoline**
    - **Diesel**
  - PHEV Plug-in hybrid electric vehicle
    - **Gasoline**
    - **Diesel**
  - BEV Battery-electric vehicle
    - **Electricity**
  - FCEV Fuel cell electric vehicle
    - **Hydrogen**
  - Flexfuel vehicle
    - **Biofuel**
  - LPG/CNG vehicle
    - **LPG**
    - **CNG**
- **Medium**
- **Large**

DETAILED DESCRIPTION OF METALS SUPPLY CHAIN IN EACH TIAM REGION

Lithium



Copper



- ✓ It allows to evaluate the consumption of materials with regard to the deployment of low-carbon technologies
- ✓ It allows to evaluate trades of these materials between countries at different points of the value chain
- ✓ It is necessary to implement the material intensities for each of the low-carbon technologies

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.

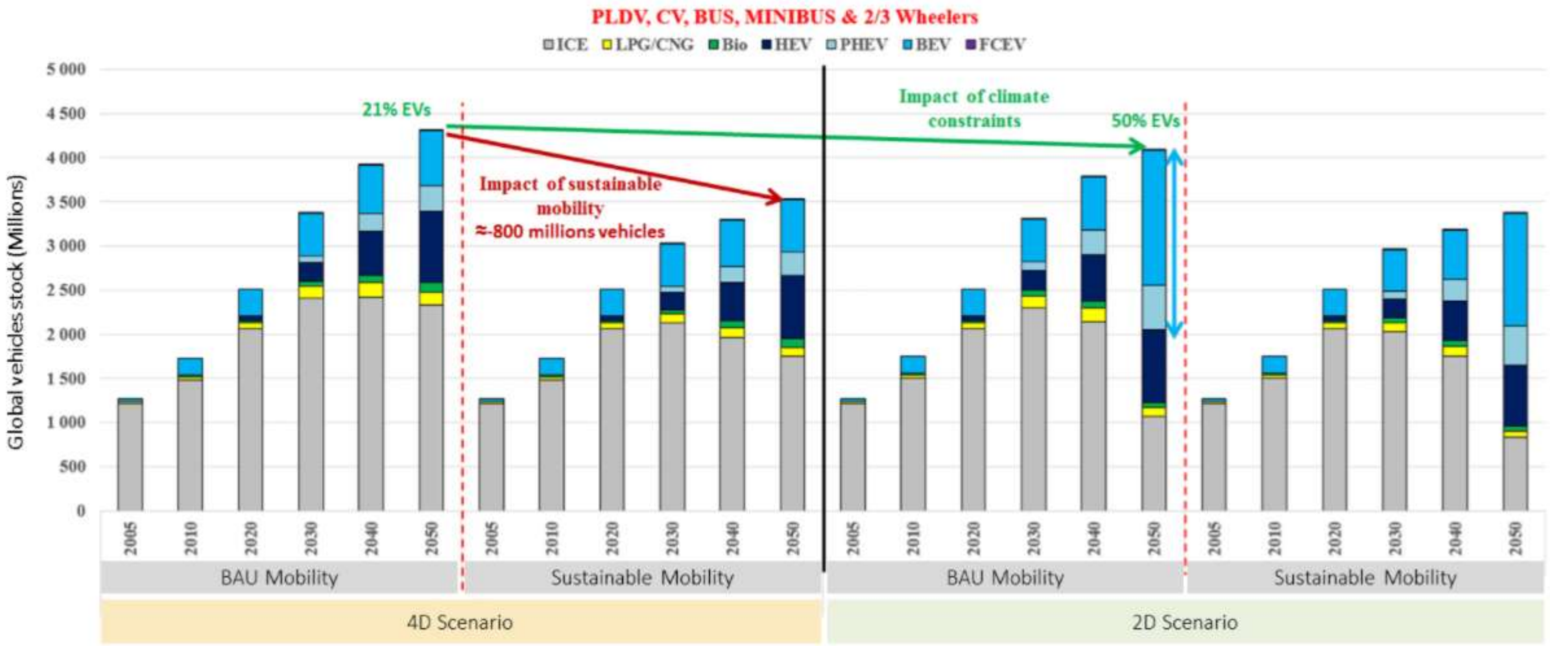
✓ In each climate scenario, two shape of mobility have been considered as abovementioned:
(1): Hypothesis of a High mobility (BAU) where we assume the impact of urban dispersal, a worldwide phenomenon,
on mobility and travel as well as the influence of urban land coverage on travel where we keep on having
a huge car dependency and usage.
(2): Hypothesis of a sustainable 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.

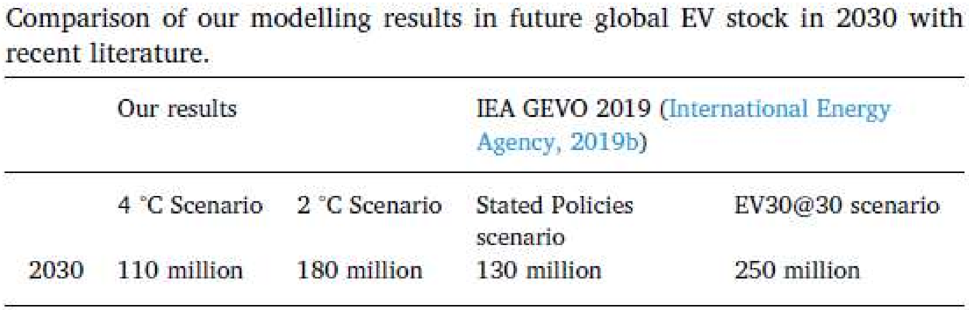
OUTLINE

- ✓ Context, Review of literature and question
- ✓ TIAM Model Methodology
- ✓ **Results**
- ✓ Conclusion

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

EVOLUTION OF THE GLOBAL VEHICLE FLEET BETWEEN 2005 AND 2050

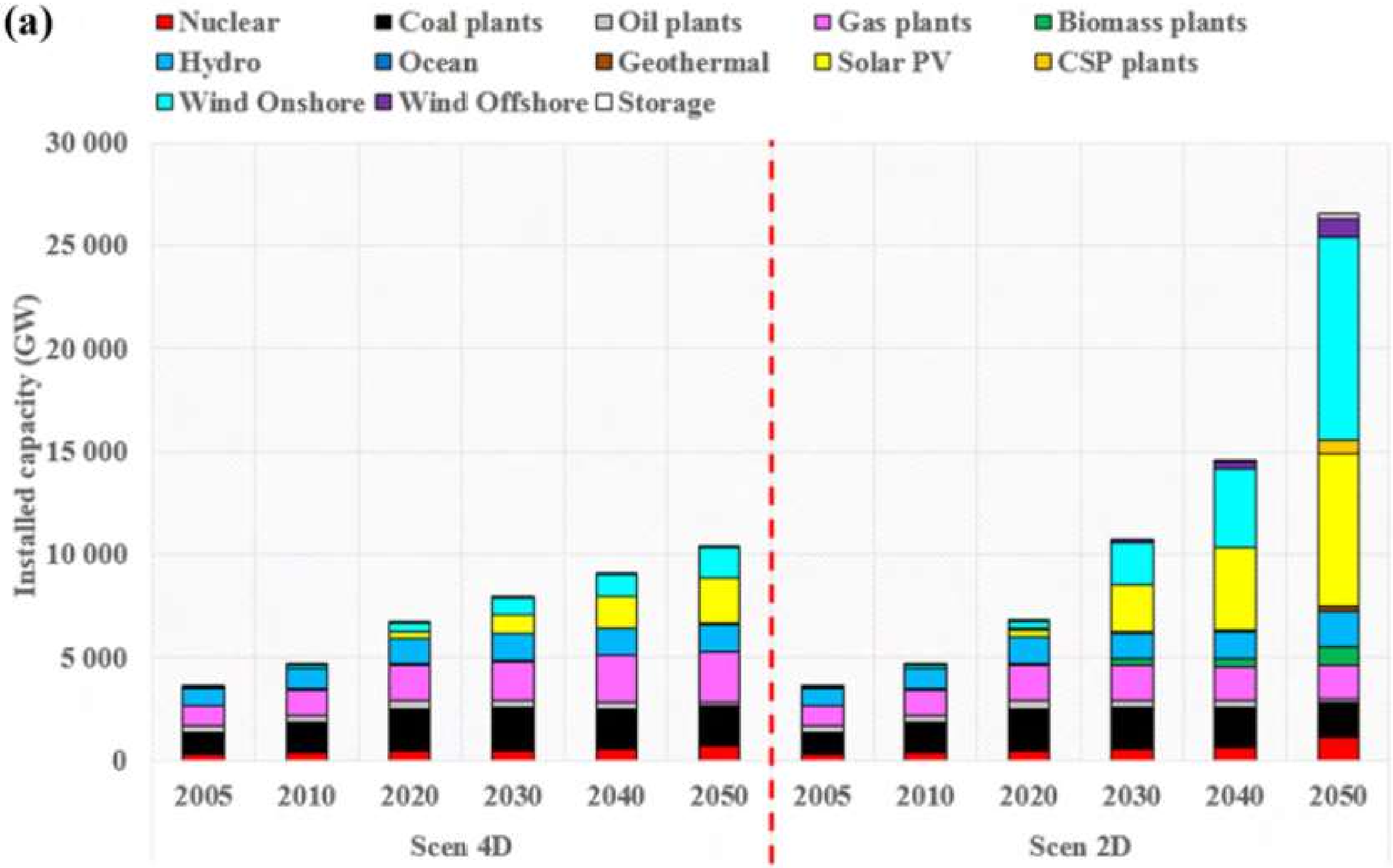




Comparison of our modelling results in future global EV stock in 2030 with recent literature.

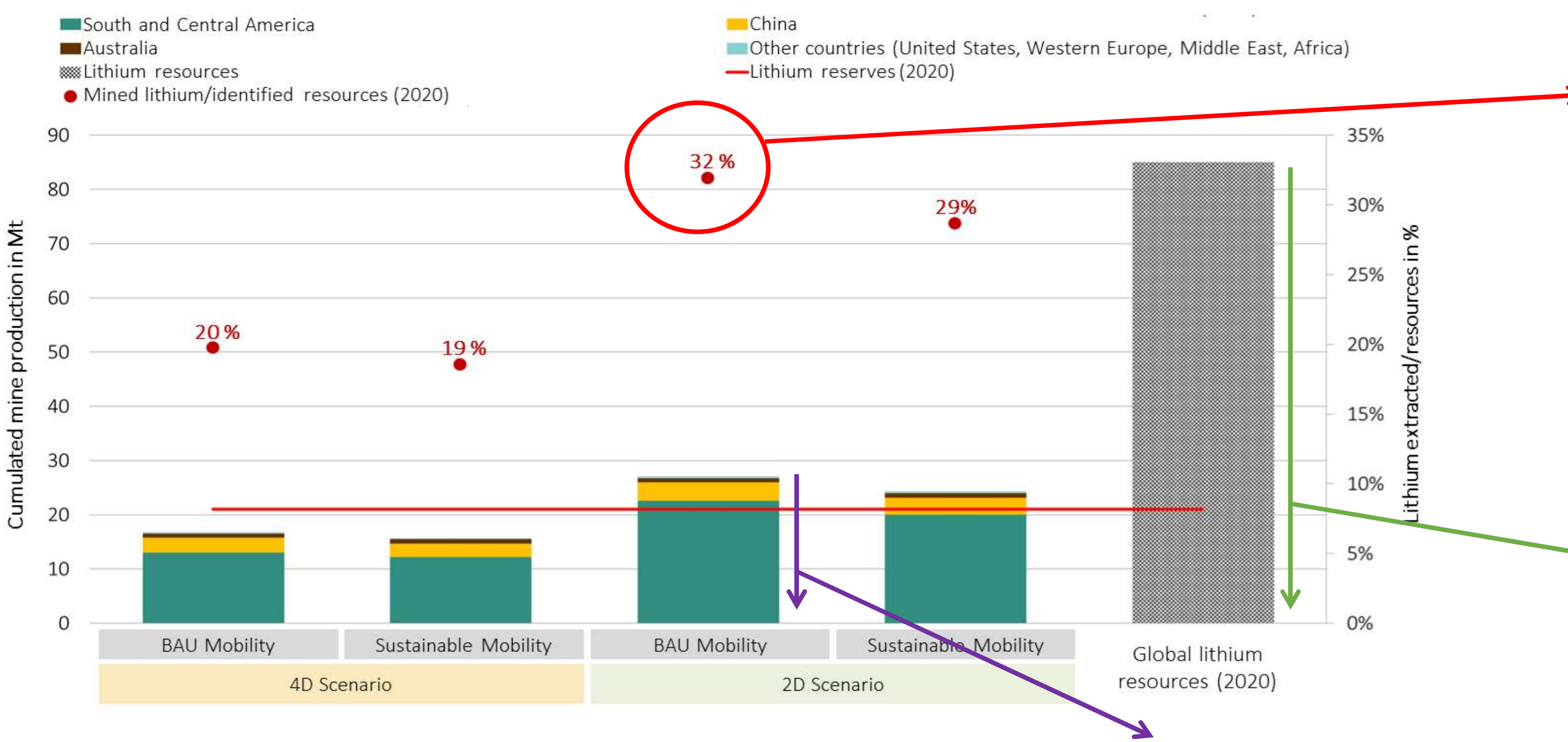
	Our results		IEA GEVO 2019 (International Energy Agency, 2019b)	
	4 °C Scenario	2 °C Scenario	Stated Policies scenario	EV30@30 scenario
2030	110 million	180 million	130 million	250 million

EVOLUTION OF WORLD POWER INSTALLED CAPACITY WITH CLIMATE CONSTRAINTS



IMPACT OF THE GLOBAL EV EVOLUTION ON THE LITHIUM DEMAND

COMPARISON BETWEEN CUMULATED LITHIUM MINE PRODUCTION (2005 - 2050) AND IDENTIFIED RESOURCES AND RESERVES IN 2020



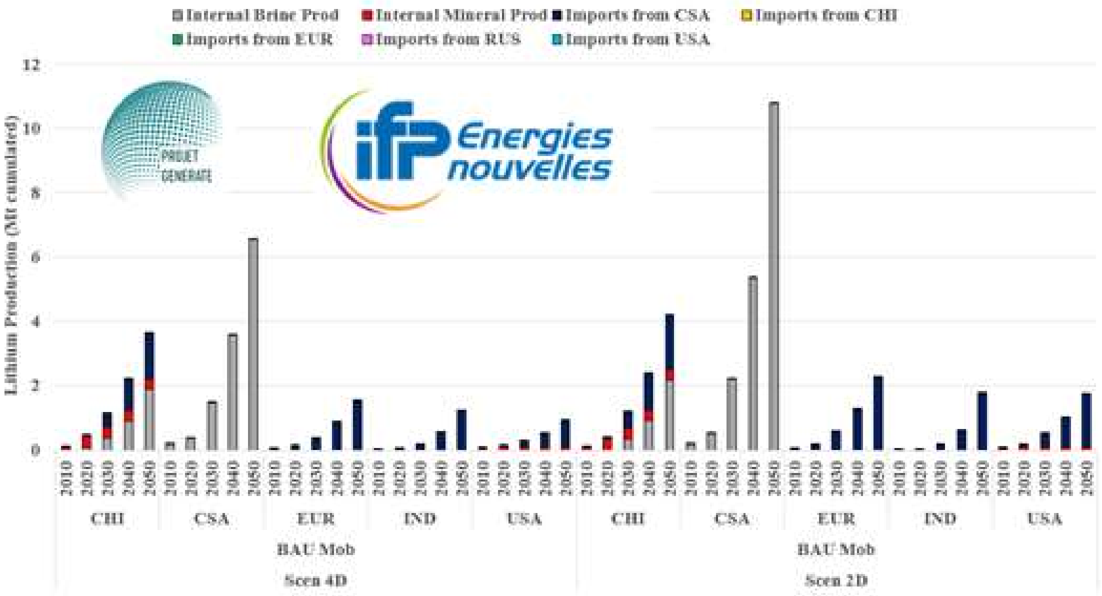
Cumulative Production (2005-2050) / Global Lithium Resources in %

Global Lithium Resources

Cumulative production (2005-2050) in a 2° Scenario

LITHIUM TRADE

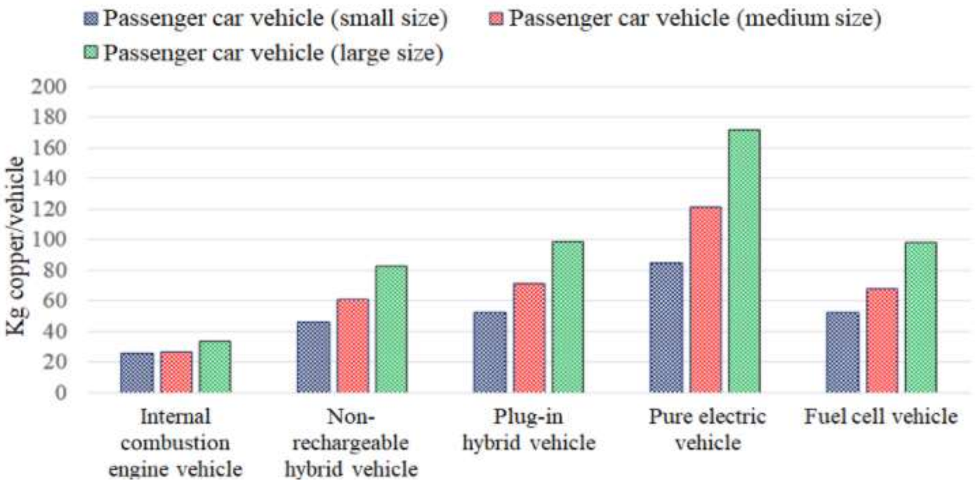
Internal production and imports in five major regions: China (CHI), Central and South America (CSA), India (IND), Europe (EUR) and United States of America (USA)



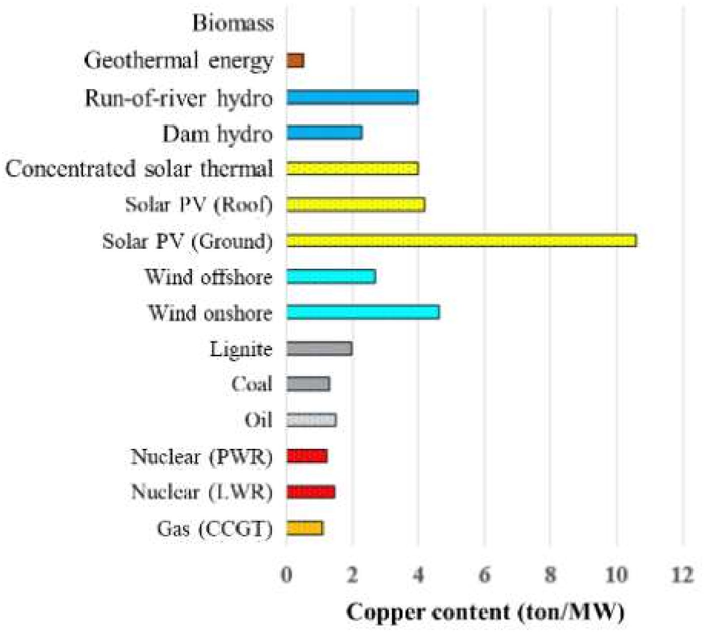
Profile of regionalized lithium imports from the Central and South America (CSA) region

COPPER IN THE ENERGY TRANSITION CONTEXT

COPPER CONTENT OF DIFFERENT TYPES OF VEHICLES (in Kg)



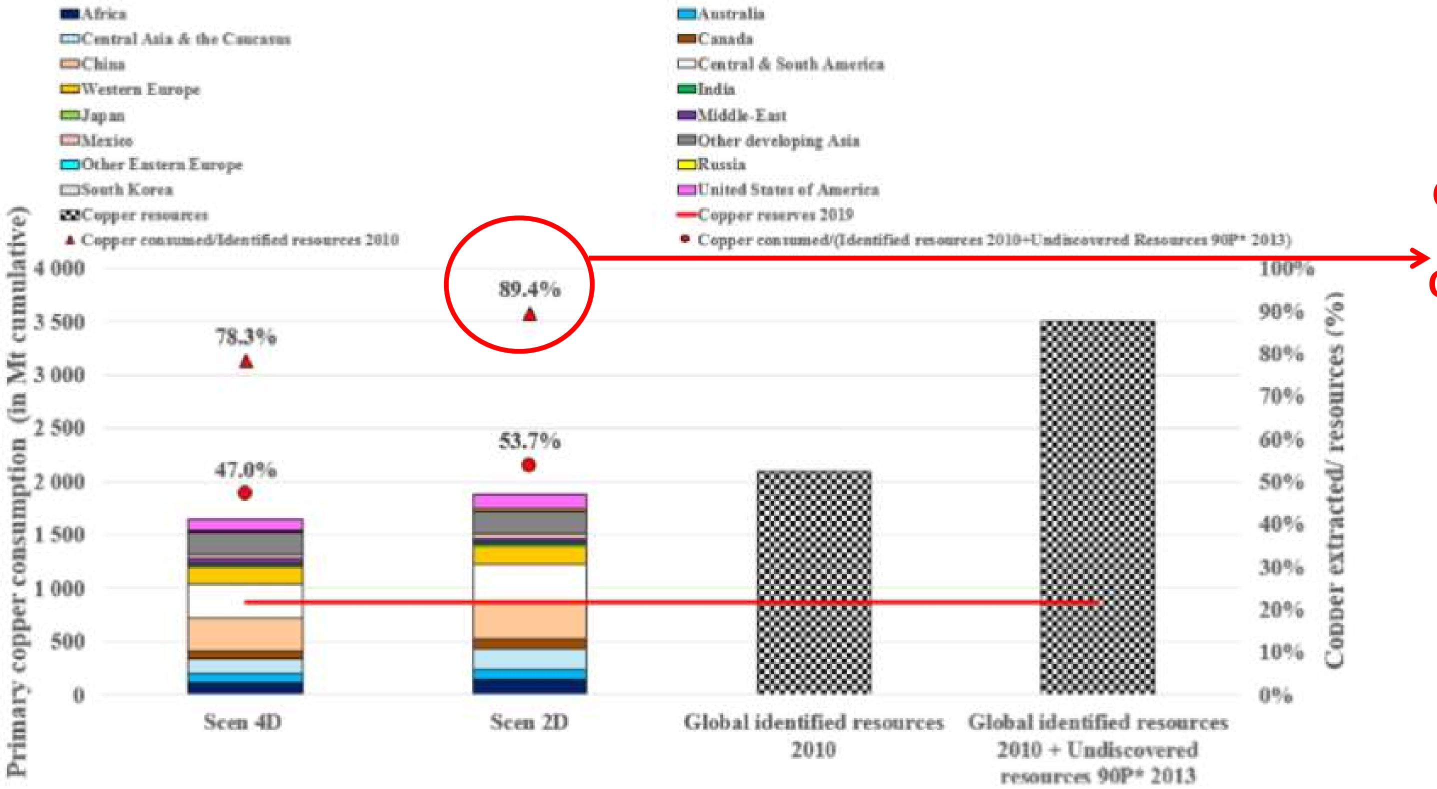
COPPER CONTENT OF THE MAIN MEANS OF ENERGY PRODUCTION (in tons of copper per MW)



CCGT: Combined Cycle Gas Turbine; *LWR*: Light Water Reactor; *PV*: Photovoltaic; *PWR*: Pressurized Water Reactor

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

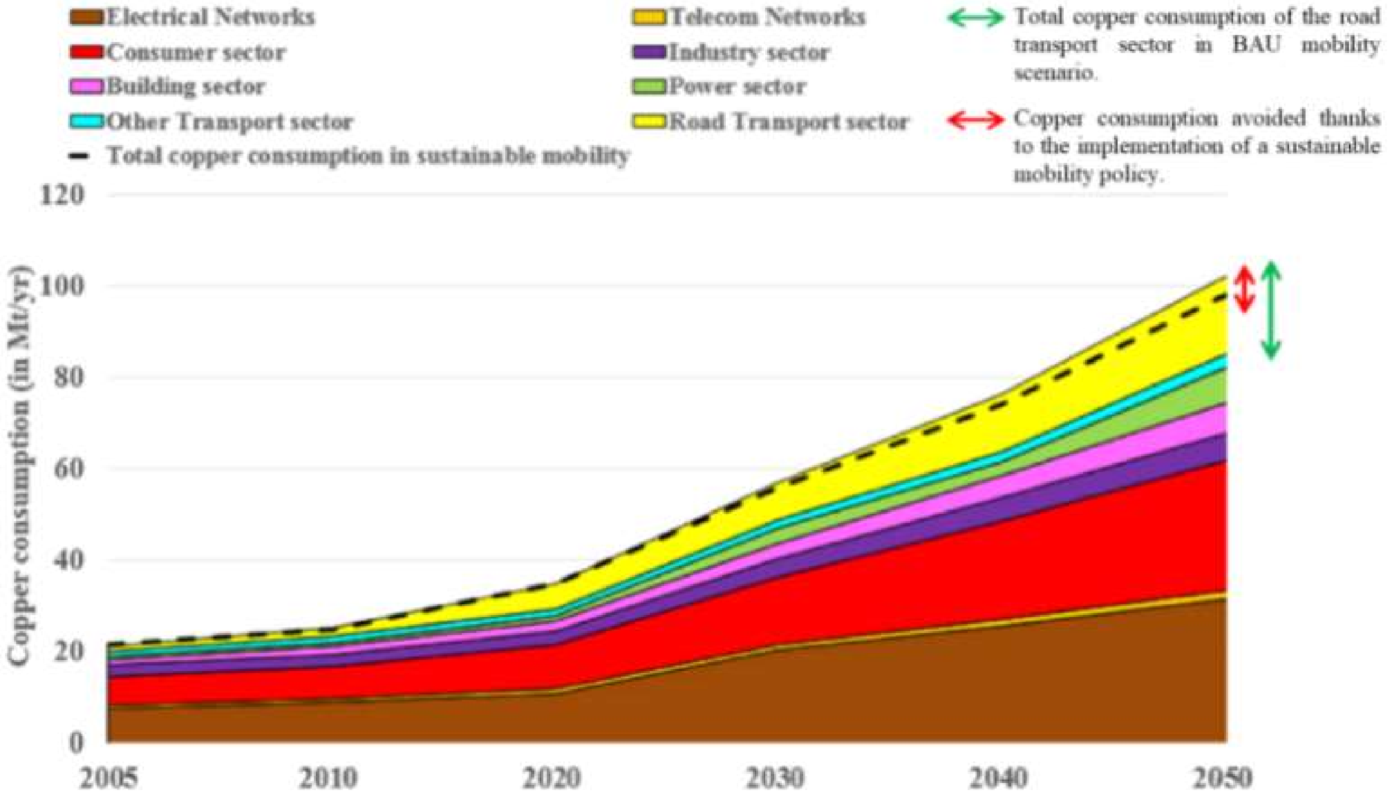
COMPARISON BETWEEN PRIMARY COPPER CUMULATIVE CONSUMPTION BY 2050 UNDER TWO CLIMATE SCENARIOS AND COPPER RESOURCES



Cumulative Primary Copper Consumption (2005-2050) / Global Copper Resources 2010 in %

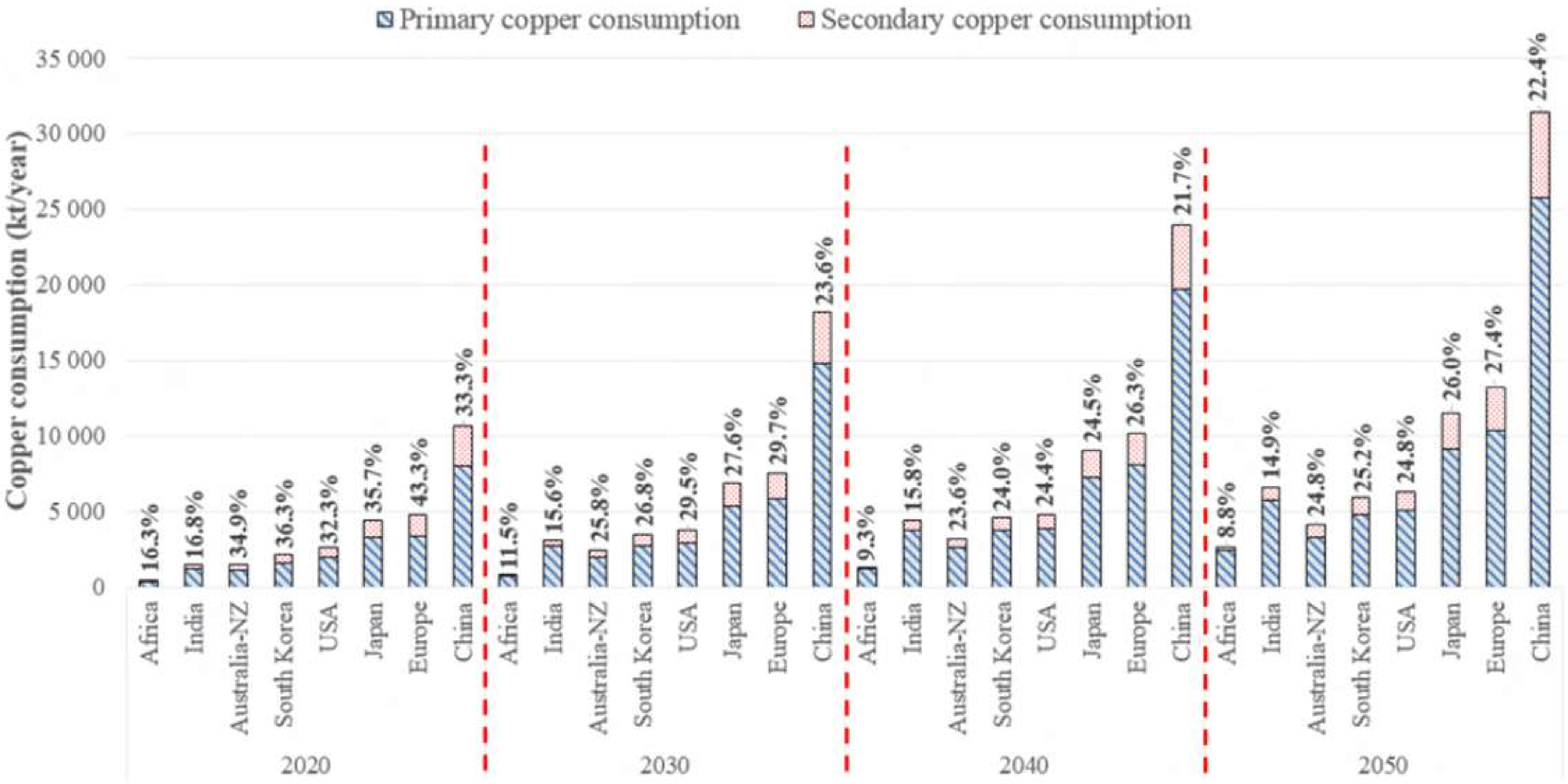
SUSTAINABLE MOBILITY IS A KEY ISSUE

EVOLUTION OF COPPER CONSUMPTION IN A 2°C SCENARIO: IMPACT OF THE TRANSPORT MOBILITY SHIFT



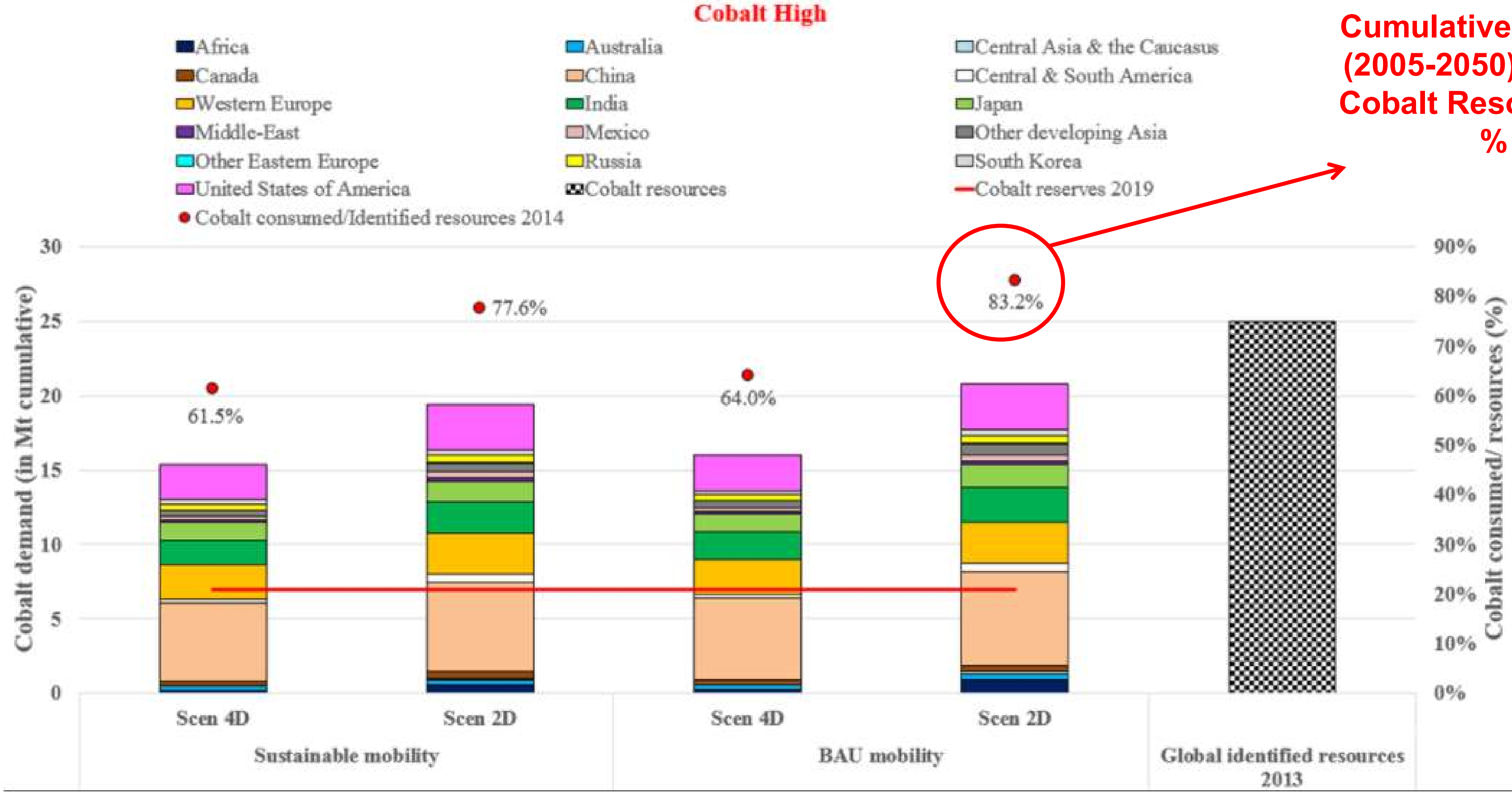
RECYCLING ISSUE

RESULTS



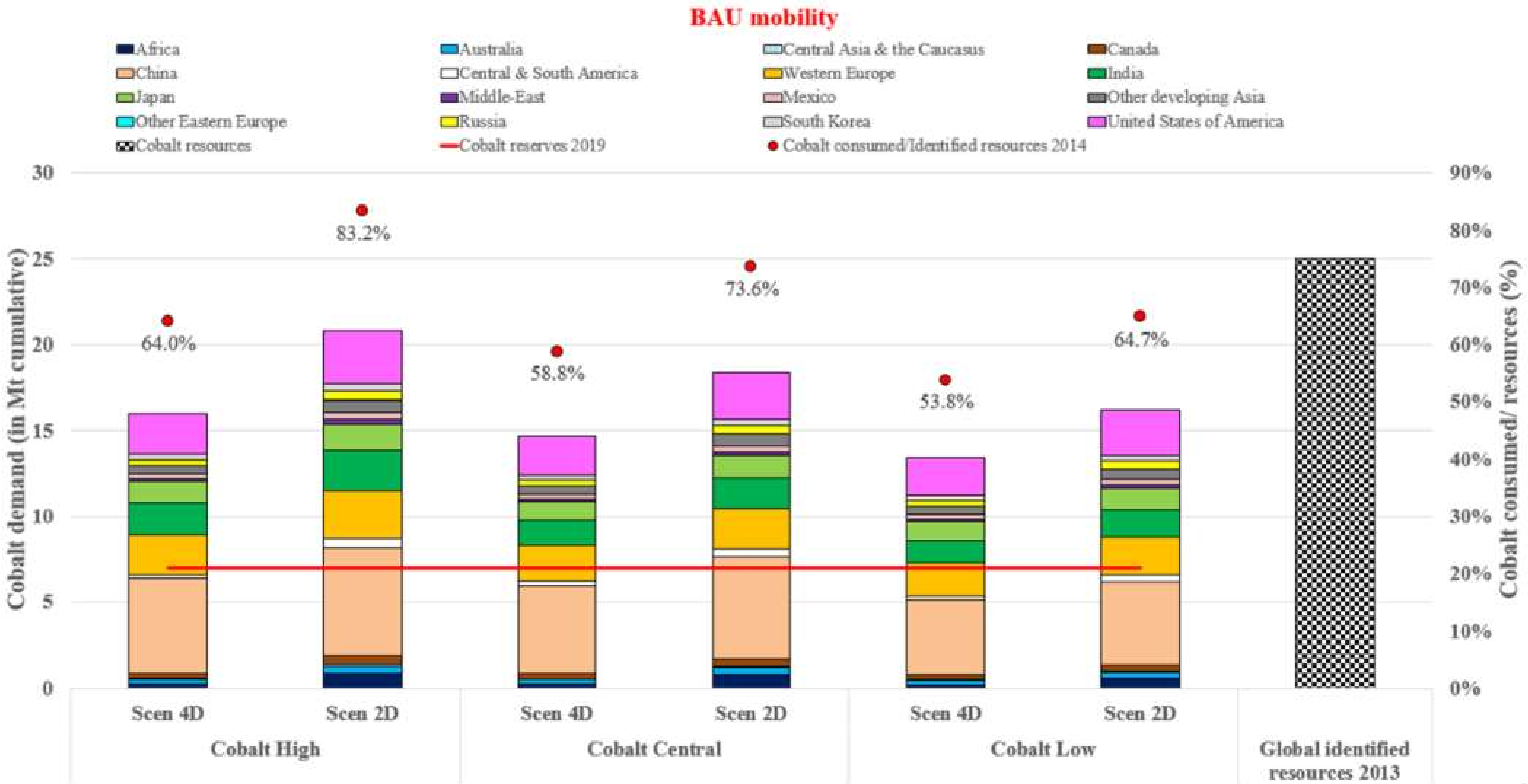
THE COBALT CASE

RESULTS



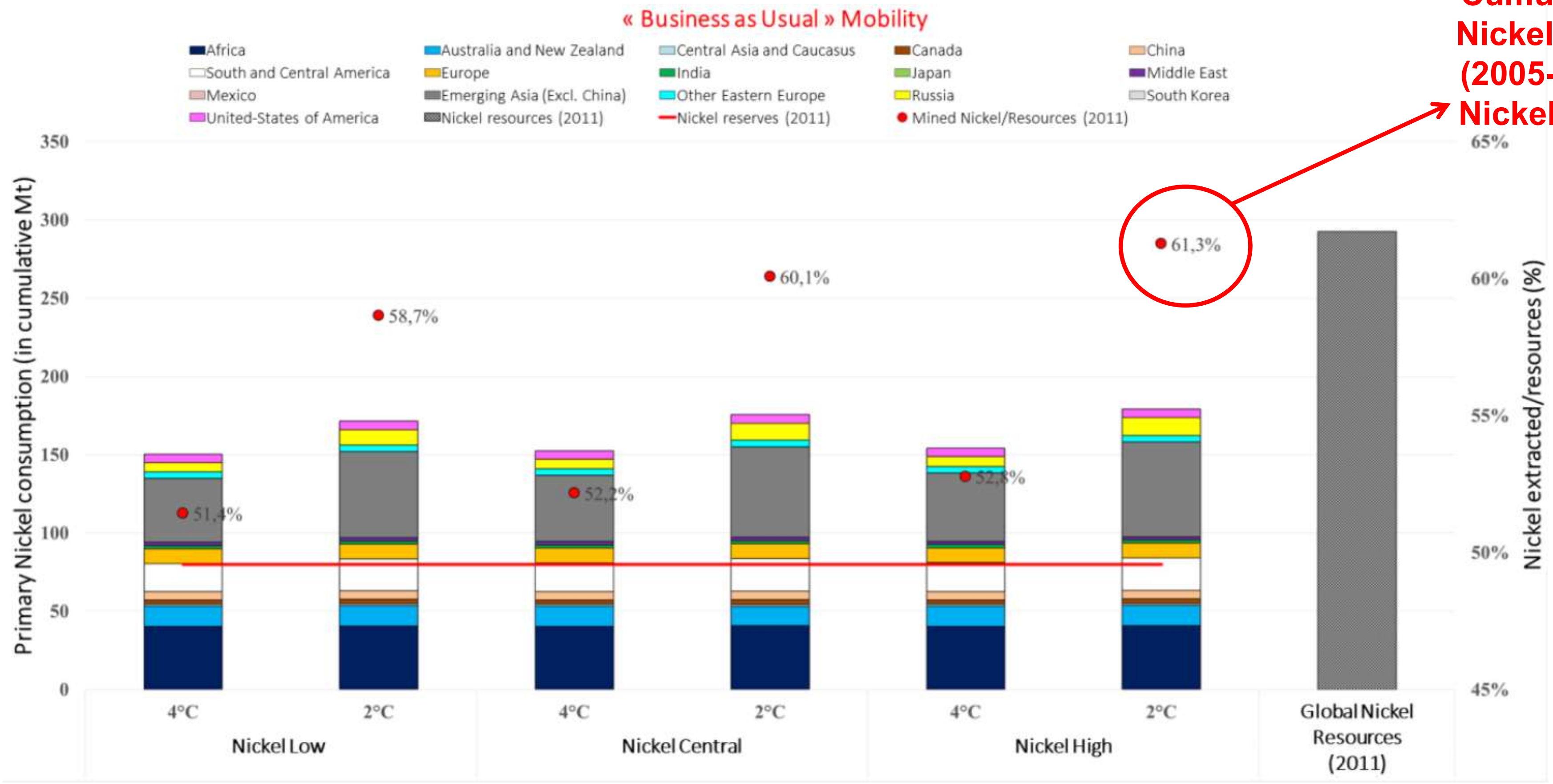
Cumulative Demand (2005-2050) / Global Cobalt Resources in %

BATTERY TECHNOLOGIES MATTER



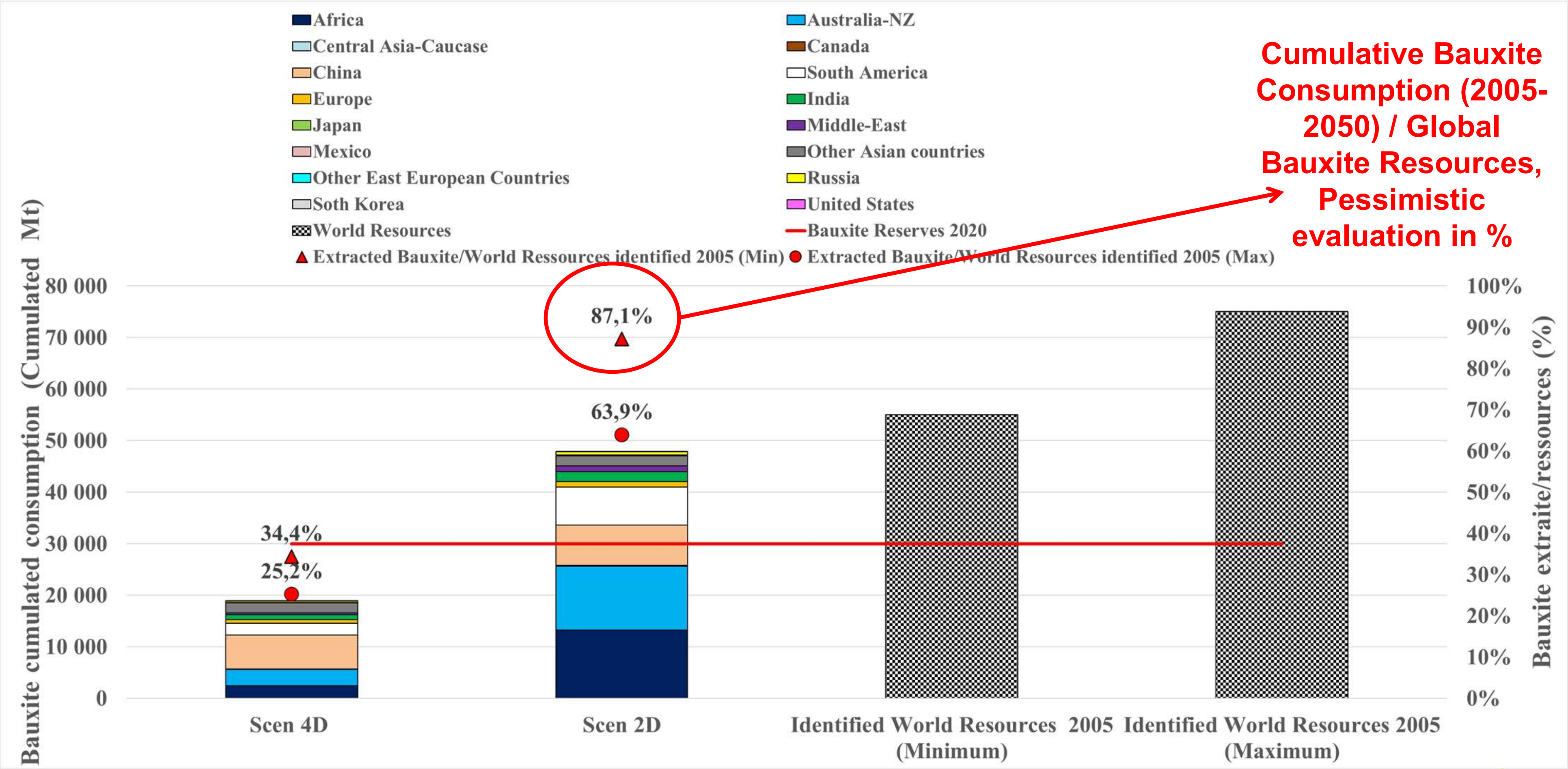
THE NICKEL CASE

RESULTS



Cumulative Primary Nickel Consumption (2005-2050) / Global Nickel Resources in %

BAUXITE CONSUMPTION



Cumulative Bauxite Consumption (2005-2050) / Global Bauxite Resources, Pessimistic evaluation in %

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, with a business as usual mobility.

- ✓ Structural metals versus strategic metals (Most constrained scenario- BAU mobility)

	2° Scenario	4° Scenario
Copper	89,4%	78,3%
Aluminium (Bauxite)	87,1%	34,4%
Cobalt	83,2%	64%
Nickel	61,3%	52,8%
Lithium	32%	20%
Rare Earths	3,8%	1,6%

- ✓ Other different forms of vulnerability, whether economic, industrial, geopolitical or environmental

- ✓ Public Policy is a key issue : Recycling and sustainable Mobility

- ✓ Next step: Carbon neutral scenario, Hydrogen intensity of raw materials assessment (Water, metals)

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