CRITICALITY OF RARE EARTH ELEMENTS AND THEIR ENVIRONMENTAL IMPACTS: EXPLORING DEEPER INTO THE ENERGY TRANSITION

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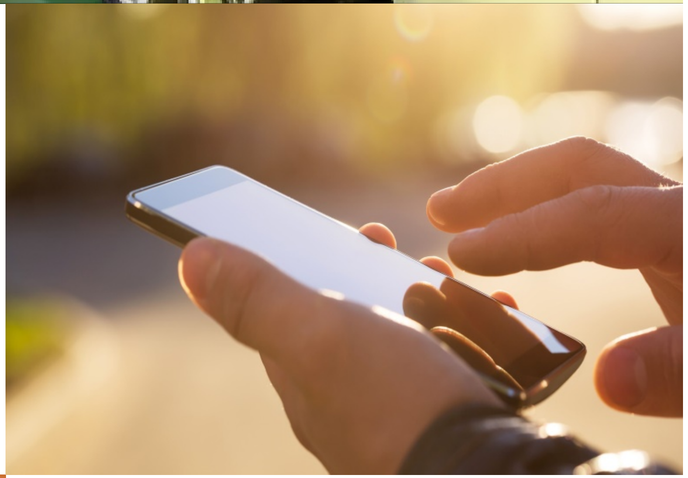
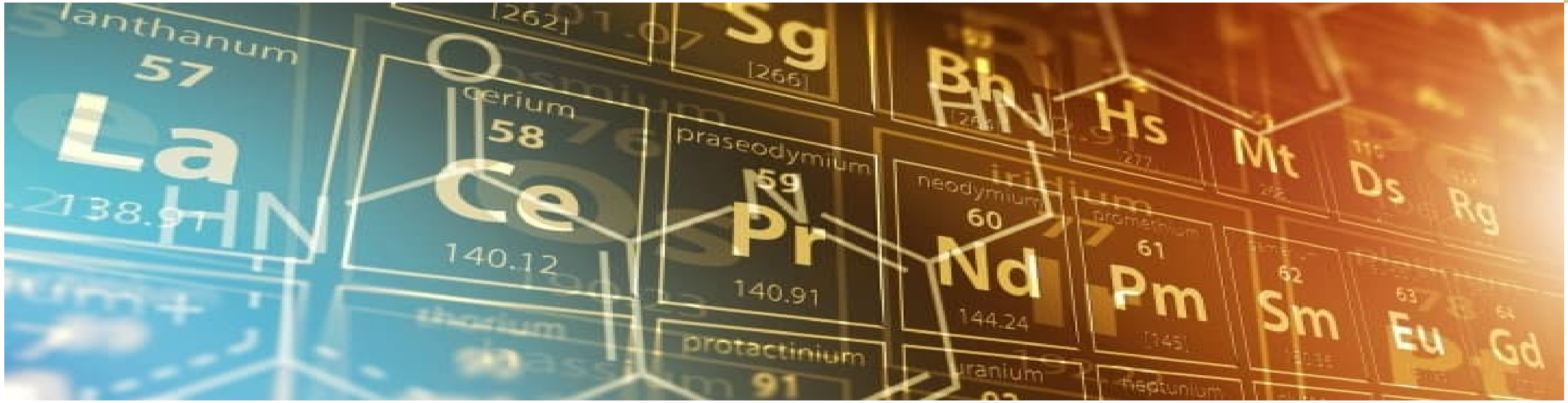


4TH AIEE ENERGY SYMPOSIUM ON ENERGY SECURITY
ROME, 2019



IFP Energies nouvelles

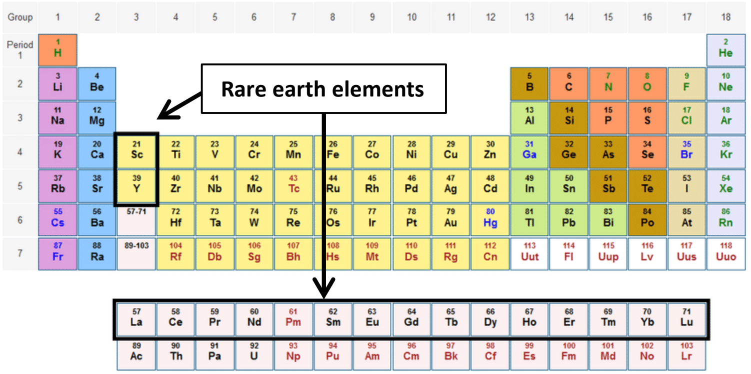
AGENDA

- **Context**
- **Objective**

- **Methods**
- **TIAM-IFPEN (Times Integrated Assessment Model-IFPEN)**
- **Scenarios description**

- **Results**
- **Conclusion**

CONTEXT



- Rare Earth elements (REE): group of seventeen chemical elements with similar properties (fifteen lanthanides, plus scandium and yttrium).

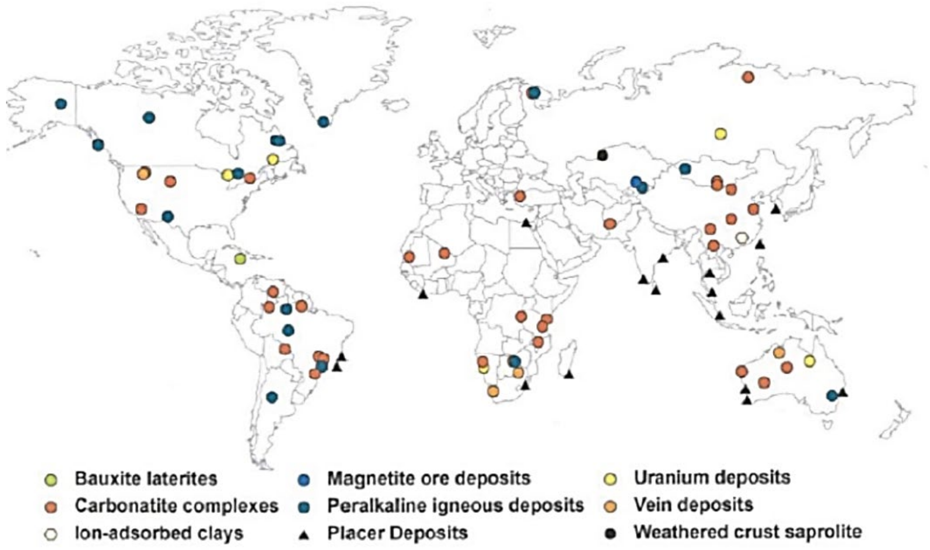
They are not so rare!

- Occurrences of REEs are scattered around the globe - many of the existing deposits may never reach the production stage due to issues as **labor costs, political instability, lack of infrastructure, environmental impact, social and political concerns and problems with metallurgical extraction** (APS, 2010).

- Until the 1980s - main producer of rare earths → **Unites States** → mine of **Mountain Pass** (Southern California).

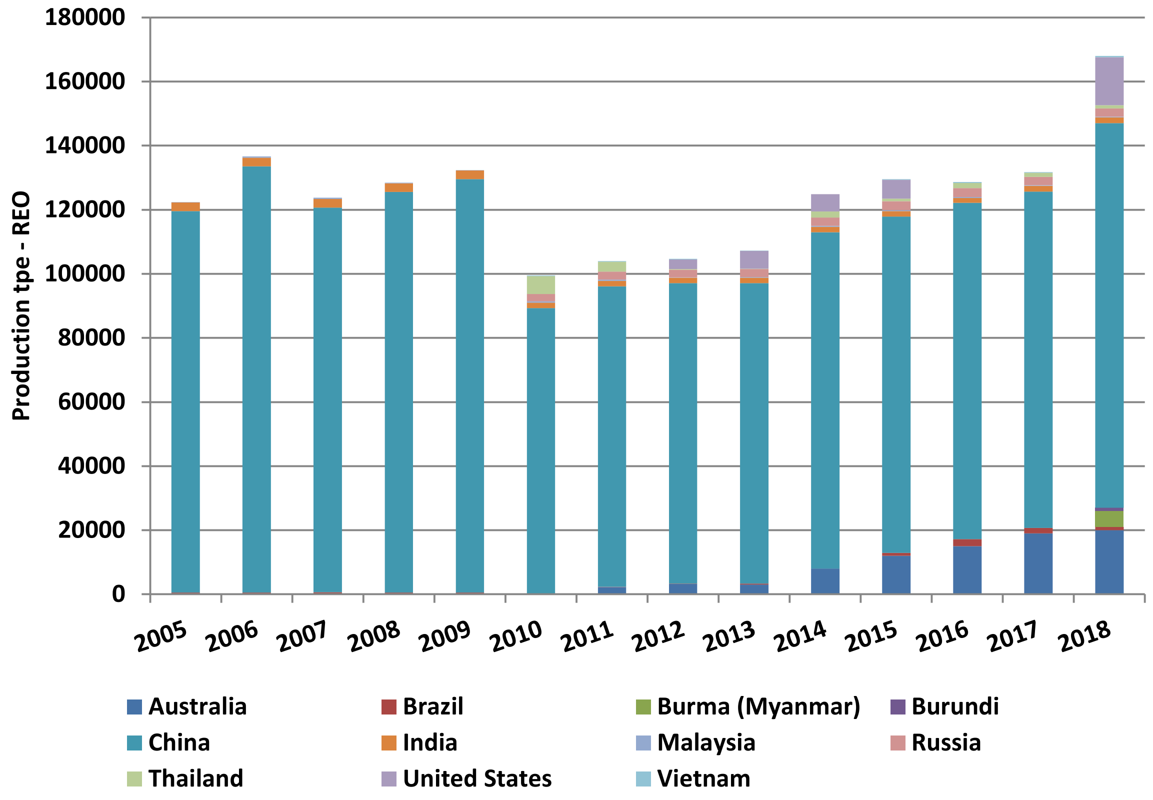
- Since 1985, the share of the US production in world production has gradually dropped to an average of about a third of world production between 1985 and 1992 and finally to 5% in 2002: fall of US competitiveness compared to REE imported from **China**.

- For the last two decades, **China** has been the world's largest producer of rare earths.



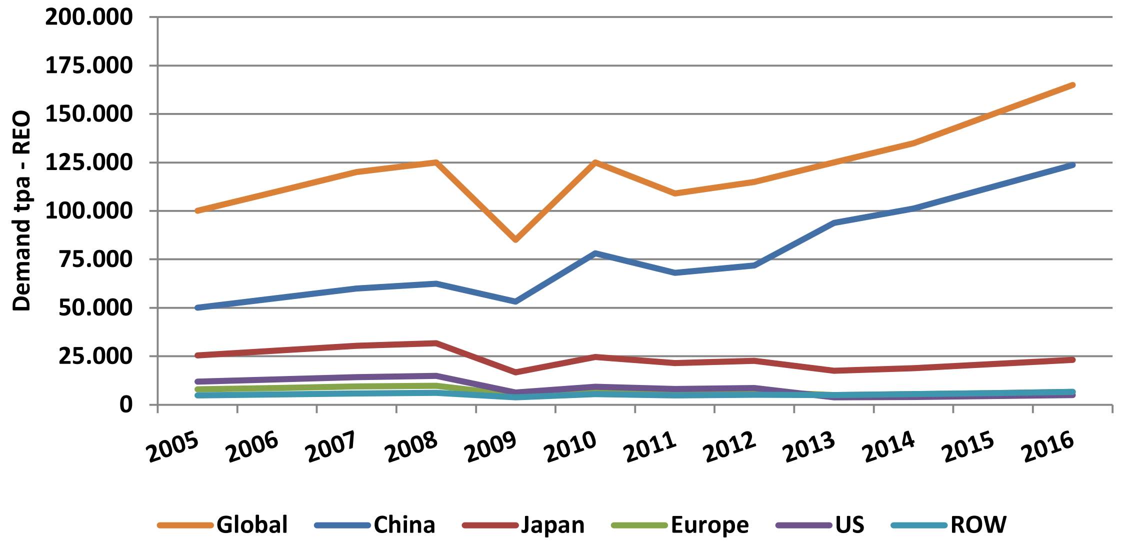
CONTEXT

REO production (2005 – 2018)



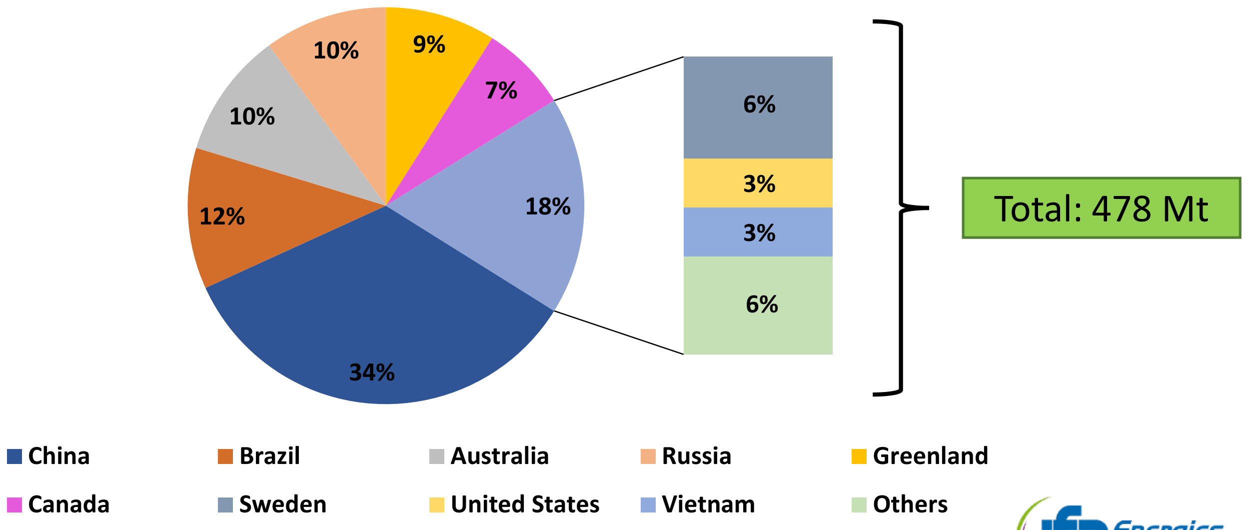
Source: USGS (2006; 2007; 2008; 2009; 2010; 2011; 2012; 2013; 2014; 2015; 2016; 2017; 2018; 2019)

REO demand (2005-2016)



Source: USGS (2009; 2011; 2013); Europeran Comission (2017)

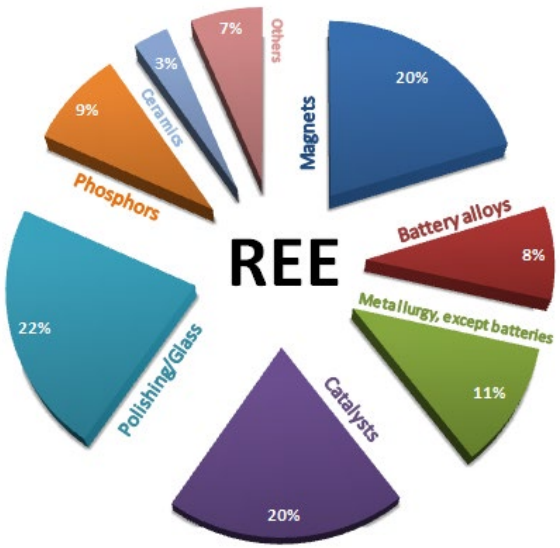
REO resources share as of 2017, by country

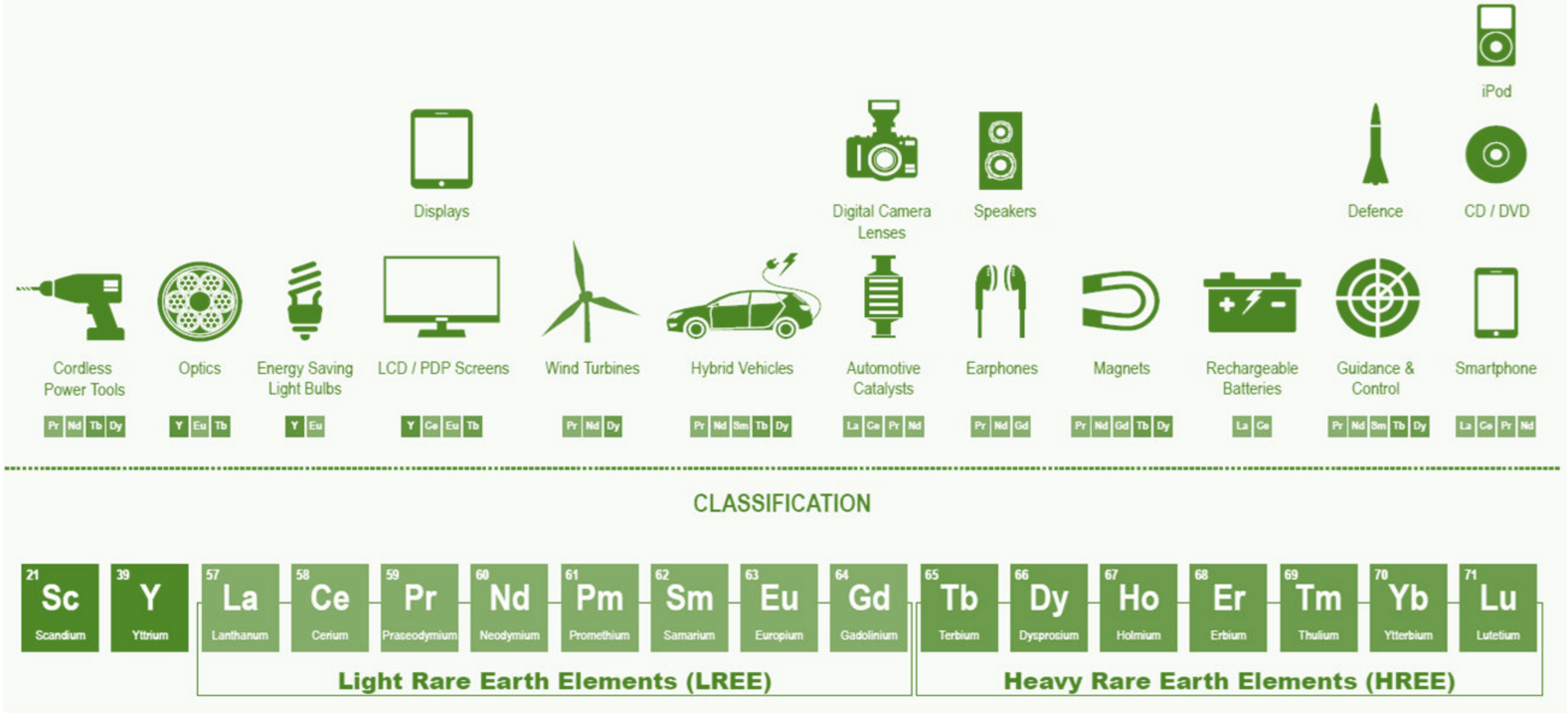


Source: Zhou et al. (2017)

CONTEXT

Rare earth applications





[1]Electronics, audio systems, fiber optics, crystal displays, lasers, x-ray.

Source: Roskill Information Services; USGS (2011); Du and Graedel (2011); Hart (2013); IMCOA (2013); China Water Risk (2016); Zhou et al. (2017); Ganguli and Cook (2018)

Rare earth applications

Neodymium and dysprosium

- The use of rare earths in the ***renewable energy production sectors*** → mainly based on the use of *permanent magnets* for certain segments of the wind energy markets (ADEME, 2019).

No other renewable energy conversion technology uses rare earths significantly.

- The use of rare earths in ***renewable energy storage devices*** → The most widely deployed technologies in the use of renewable energy storage today are *Lithium-ion (Li-ion), sodium-sulfur batteries (NaS) and lead-acid (PbA)*. The rare earths do NOT enter, or in very SMALL quantities (possibly as additive), in the composition of these batteries. Of the commonly used batteries, only *nickel metal hydride (NiMH) batteries* include a rare earth alloy at the cathode. These batteries have mostly been used in hybrid vehicles and in power-operated equipment, but their use for renewable energy storage will remain very **marginal**, particularly because of their high cost compared to Li-ion batteries, whose characteristics and performance is more suitable for this purpose (ADEME, 2019).

- ***Rare earths recycling*** → estimated at less than 1% of the waste produced and concerns mainly manufacturing waste (Binnemans *et al*., 2013; ADEME, 2019). ***Main causes***: inefficient collection, quantities often very low or intimately mixed with impurities in the final products, technological problems.

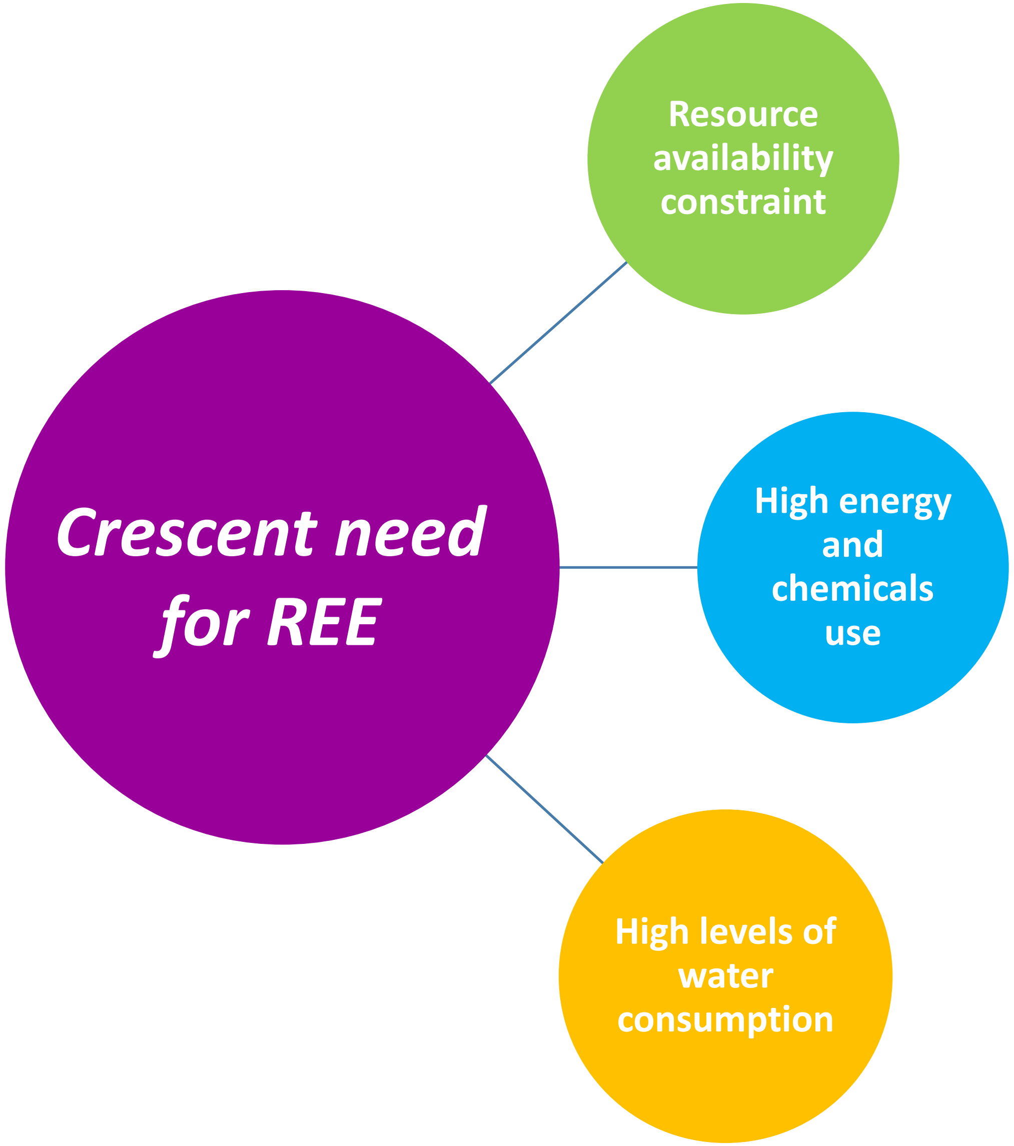
CONTEXT

Context

Energy transition

Economic growth

Stringent environmental constraints

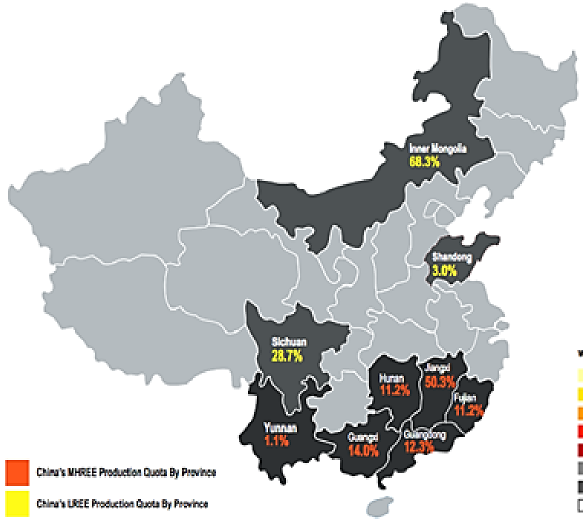


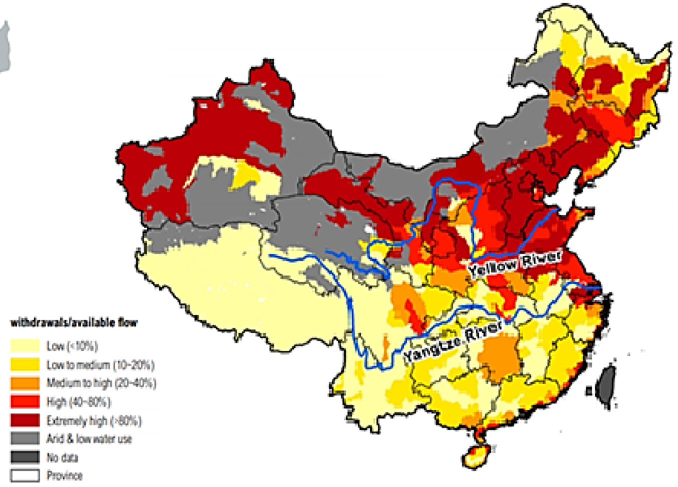
CONTEXT

<u>China</u>

World's largest producer of REE

High water stress measured by the WRI





Bayan Obo (Inner Mongolia) → the largest rare earth reserve of the world is located in an area of "Extremely high" water stress, and the others rare earths production sites are all located in areas that have at least a "Low to medium" water stress level.

OBJECTIVE

Analyze, through prospective climate scenarios (4°C and 2 °C) run on TIAM-IFPEN (Times Integrated Assessment Model-IFPEN), the evolution of the REE criticality with the energy transition, their impact on water consumption and whether or not these impacts can be overcome by the current water supply at REE production sites.

METHODS

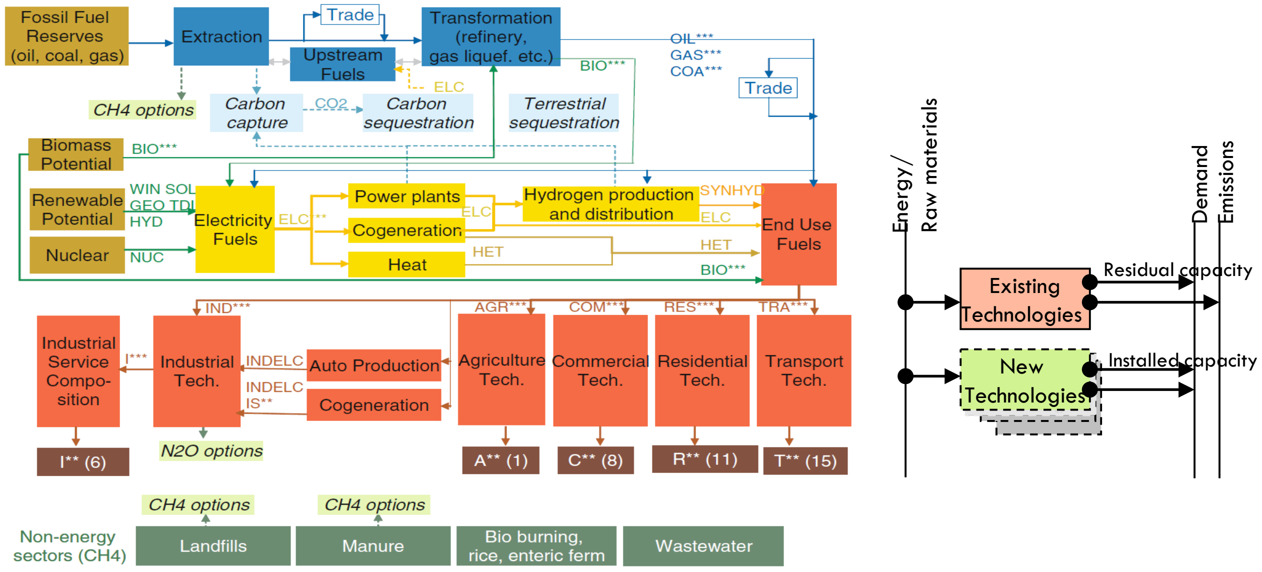
1. Development of a consistent REE database (resources, production, demand, process characteristics, processing and capital costs , etc)
2. Input the database information in TIAM-IFPEN
3. Run the climate scenarios (4°C and 2°C) over the period 2005-2050
4. Analyze the impact on water consumption caused by expected growths in REE production, and whether or not these impacts can be overcome by the current water supply at REE production sites

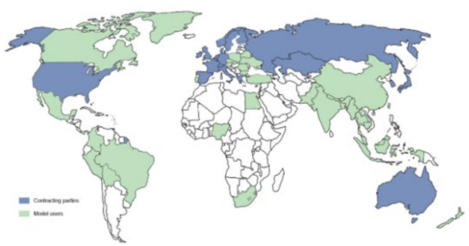
TIAM-IFPEN (TIMES INTEGRATED ASSESSMENT MODEL- IFPEN)

- **Developed as part of the IEA-ETSAP (International Energy Agency – Energy Technology Systems Analysis Program)**
- **Aims at exploring possible energy futures based on contrasted scenarios**
  - **A detailed technology-rich modeling paradigm from the primary resources to the end-uses (16 regions)**
  - **Main driver: Exogenous final energy services demand**
  - **Provide options to decision makers regarding energy systems over medium to long-term time horizons**
  - **Design of least-cost pathways for sustainable energy systems**
- **At a Local, National or Multi-regional level**
  - **Micro-measures: Technology portfolios, targeted subsidies to groups of technologies, etc.**
  - **Broader policy targets: General carbon tax, fuel taxes, or targeted capital subsidies, etc.**

Technology considered: *Renewable energy technologies (RETs) (solar PV and CSP, wind onshore and offshore, hydro, biomass), fossil-based technologies (coal, natural gas, oil) and nuclear*

Data sources: *World Energy Outlook (IEA), IRENA, European Commission, National Renewable Energy Laboratory (NREL), PLATTS database, BP Statistics, US Geological Survey (USGS), Specialized literature*

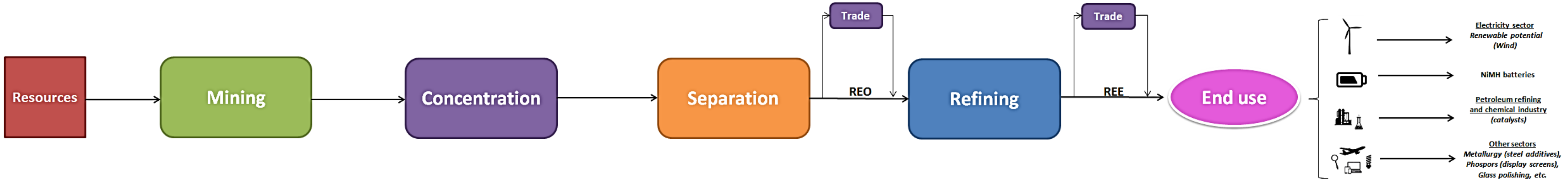




TIAM name	Region
AFR	Africa
AUS	Australia, New Zealand and Oceania
CAN	Canada
CHI	China
CSA	Central and South America
IND	India
JAP	Japan
MEA	Middle-east
MEX	Mexico
ODA	Other Developing Asia
SKO	South Korea
USA	United States of America
EUR	Europe 28+
RUS	Russia
CAC	Central Asia and Caucase (Armenia,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

TIAM-IFPEN (TIMES INTEGRATED ASSESSMENT MODEL-IFPEN)

The Model structure : Detailed description of Rare earth element supply chain



Water consumption for the production of 1 kg of RE oxide

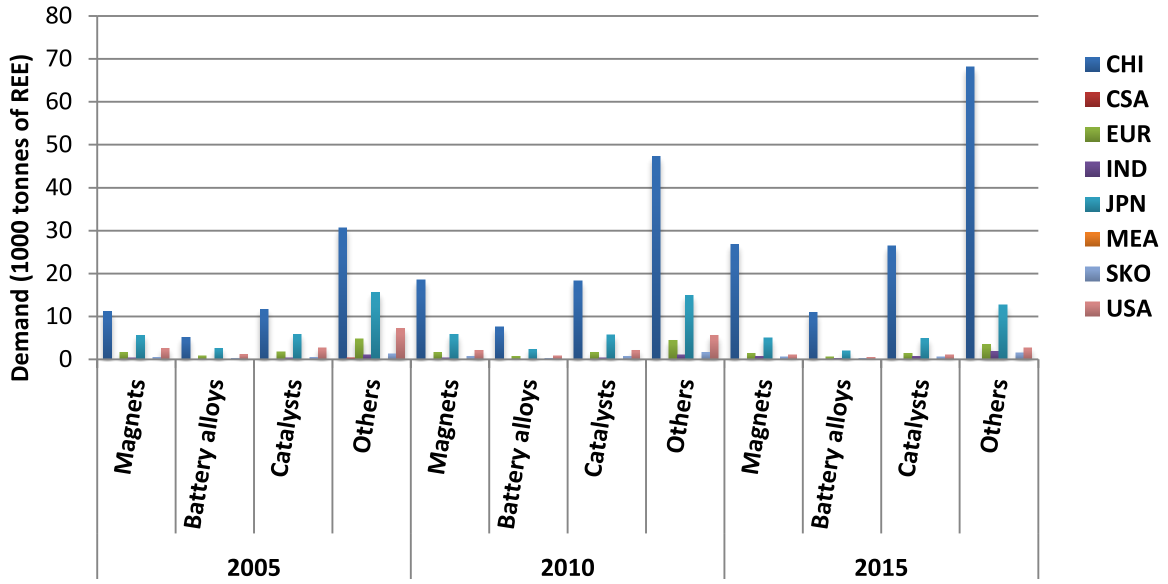
REE Classification	Water consumption (kL)
Light	41.06
Medium	40.64
Heavy	49.00

Source: Koltun and Tharumarajah (2010), Zhou et al. (2016)

REO consumption intensity in the production of wind turbines

Turbine Capacity (MW)	Total REO consumption (Kg)	REO consumption intensity (Kg/MW)	Source
3	560	186.67	AMEC (2014)
3.3	616	186.67	AMEC (2014)
4	696	174.00	IMA (2018)
5	874	174.80	Venås (2015)
6	1120	186.67	AMEC (2014)
7	1306	186.57	AMEC (2014)
8	1493	186.63	AMEC (2014)

REE Demand by use per TIAM-IFPEN region



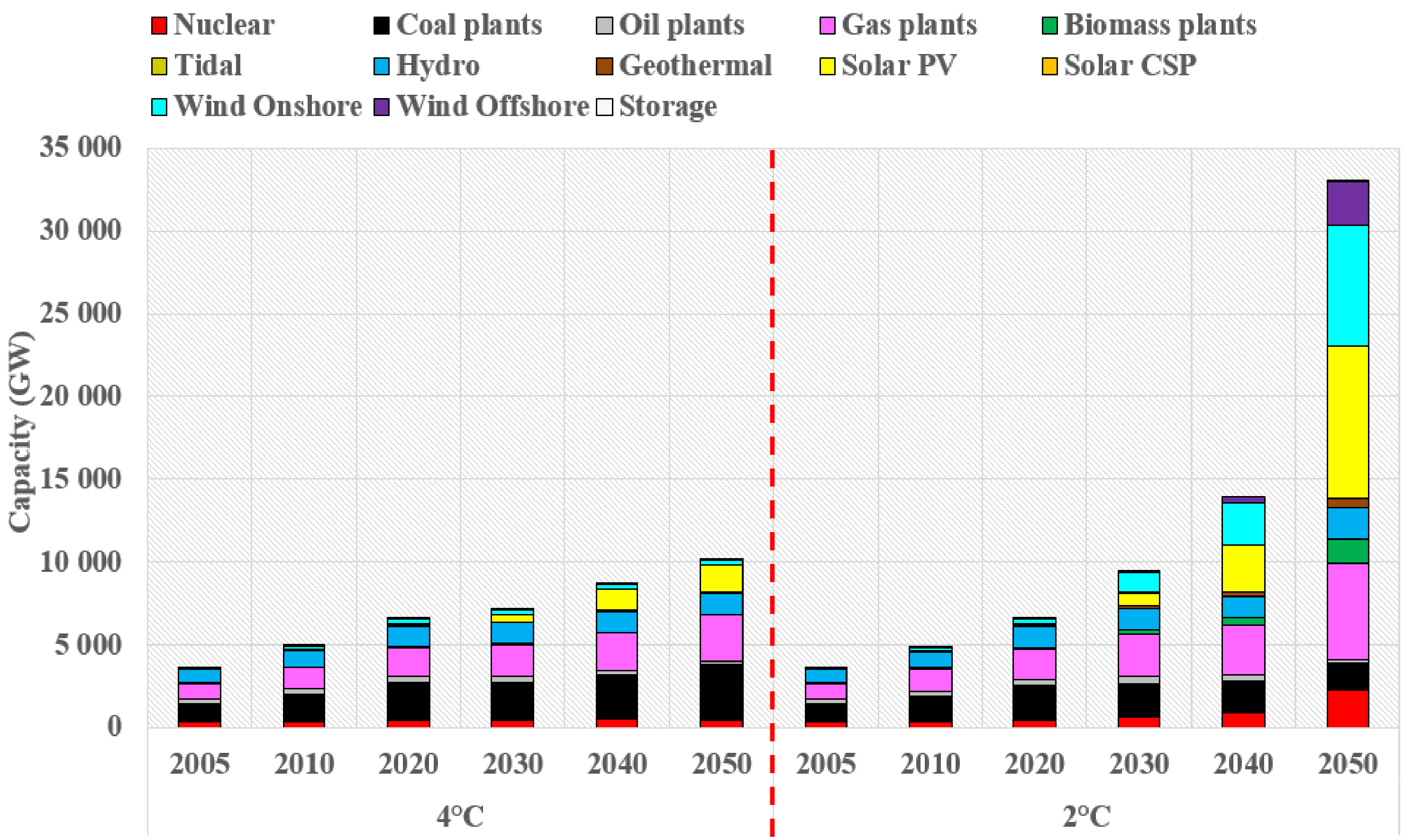
SCENARIOS DESCRIPTION

- ✓ For the purpose of the present study, **we examined two climate scenarios** to assess the impact on the rare earths market with the penetration of Renewable Energy Sources, mainly wind energy technologies:
  - ❑ Scen 4D which is consistent with limiting the expected global average temperature increase to 4°C above pre-industrial levels by 2100.
  - ❑ Scen 2D which is a more ambitious scenario, which translates the climate objectives of limiting global warming to 2°C by 2100.
- ✓ Study horizon: 2005-2050 (Subdivided in 6 periods)
- ✓ Annual growth rate assumptions for Rare earths end-use sectors
  - ❑ Since 2011, the share of certain sectors in total consumption has decreased.
  - ❑ In batteries, the emergence of large-scale use of lithium-ion batteries (without REE) has impacted the consumption of REE for metallurgical alloys previously used in NiMH (nickel metal hydride) batteries
  - ❑ In other sectors, despite a smaller share, volumes used increased. In particular, the oil and automotive catalysis, metallurgical alloys and polishing powders sectors benefited from low prices and the abundance of some lower unit value elements (lanthanum and cerium) with a greater diversity of uses

	Annual growth rates		
End-use sectors	**2005-2016**	**2016-2030**	**2030-2050**
Battery alloys	-2.6%	**-1.9%**	**-1.0%**
Catalysts	3.7%	**2.8%**	**1.9%**
Others	3.7%	**2.7%**	**2.2%**
Magnets	9%	**Driven by new installed capacity of Wind energy technologies**	

RESULTS

Evolution of the installed capacity of the world power sector between 2005-2050

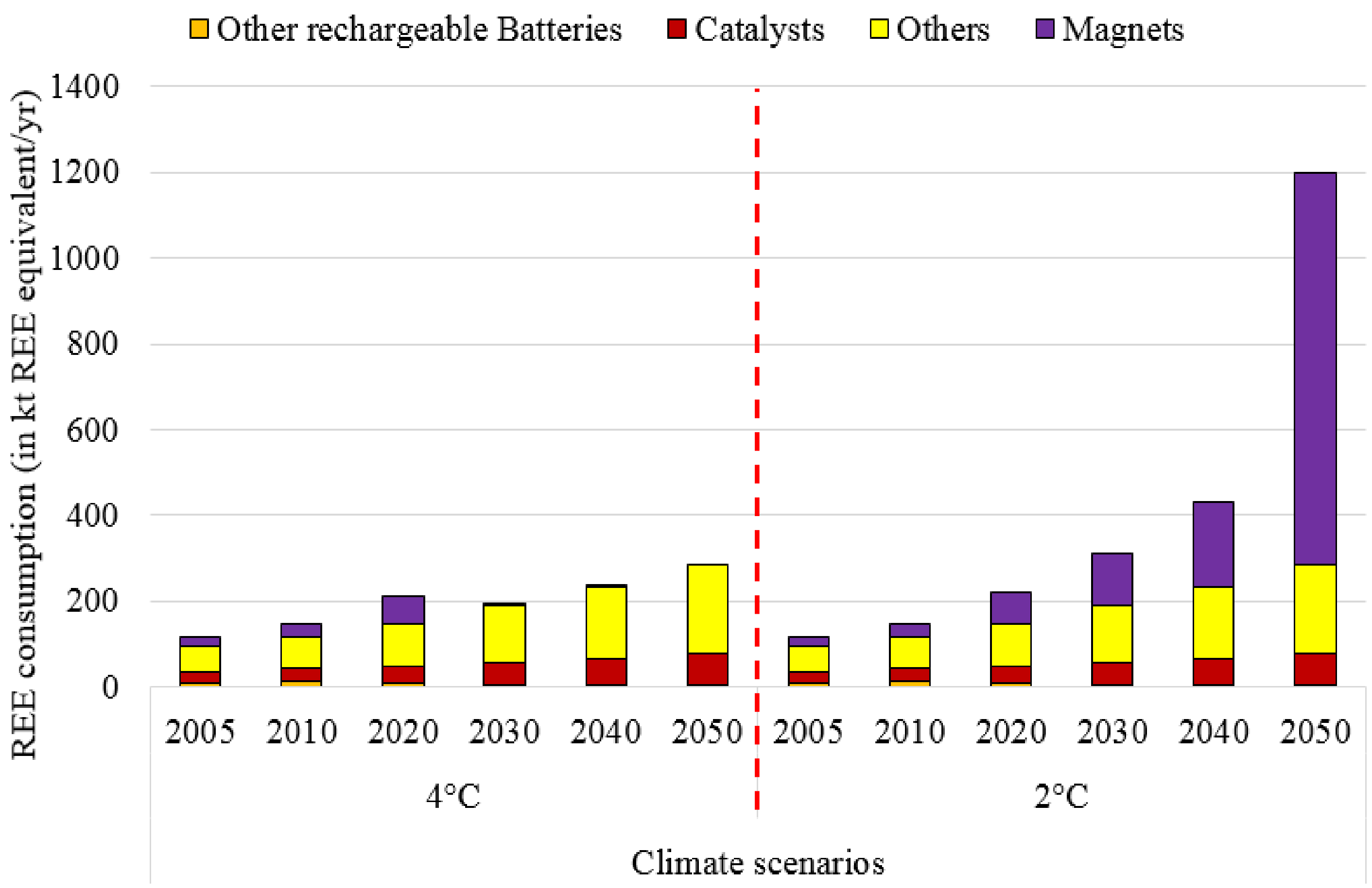


High penetration of Renewable Energy Sources with stringent climate scenario:

- Scen 4D: 41 GW new installed capacity of wind technology between 2020-2050
- Scen 2D: In a more ambitious scenario, 9540 GW of new wind capacity have been installed between 2020-2050
- An installed capacity of around 7300 GW Onshore Wind and 2600 GW Offshore Wind have been achieved by 2050 in the 2°C scenario

RESULTS

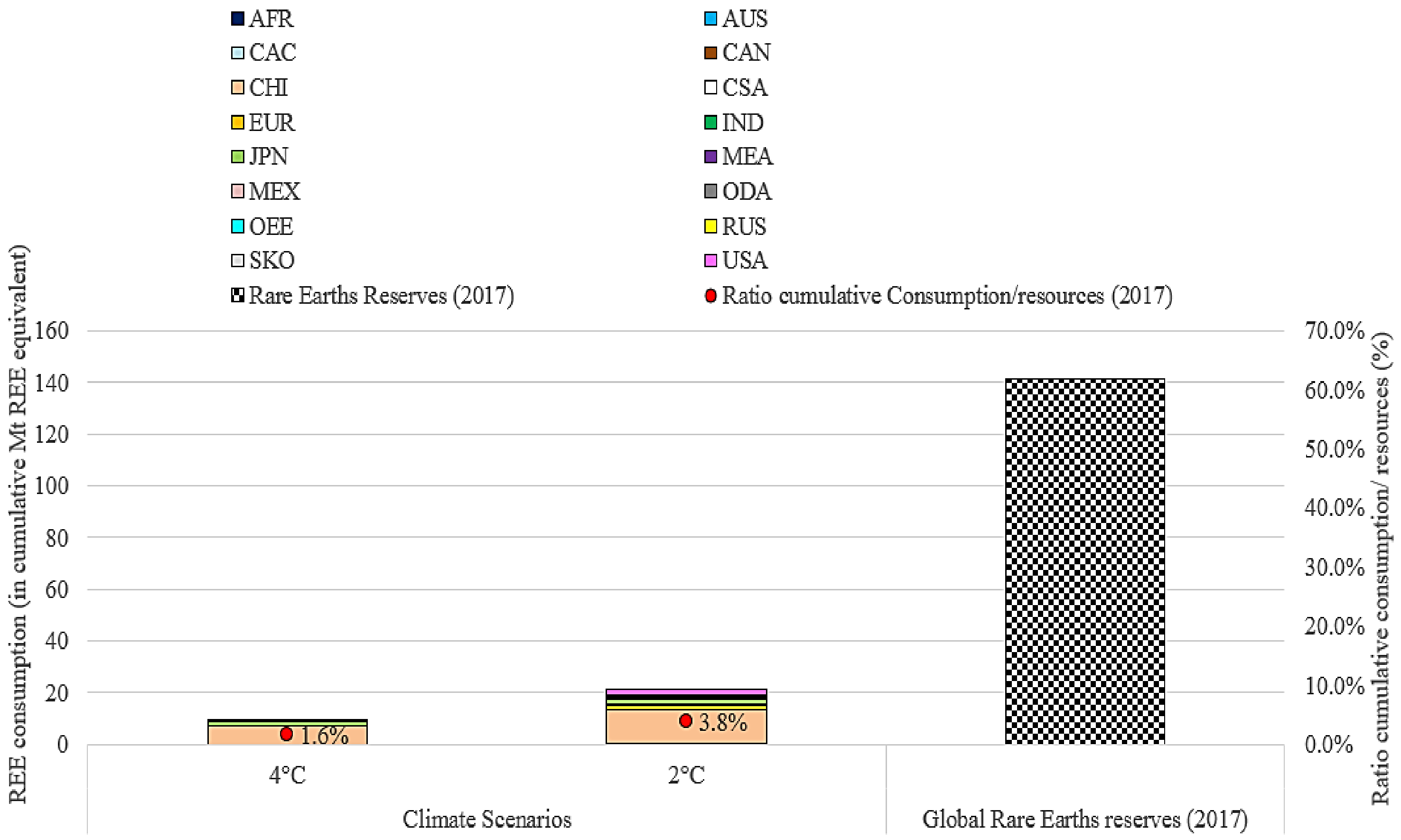
Evolution of the REE consumption between 2005-2050



- **Scen 4D:**
  - Total consumption increases by 142% between 2005-2050
  - Demand reduction for magnets use between 2005-2040/ By 2050 it is zeroed - linked to reduced investment in new wind technology capacities
- **Scen 2D:**
  - Total consumption increases by 921% between 2005-2050
  - REE consumption for magnets reaches 916 kt equivalent/year in 2050 – compared to 22.4 kt in 2005

RESULTS

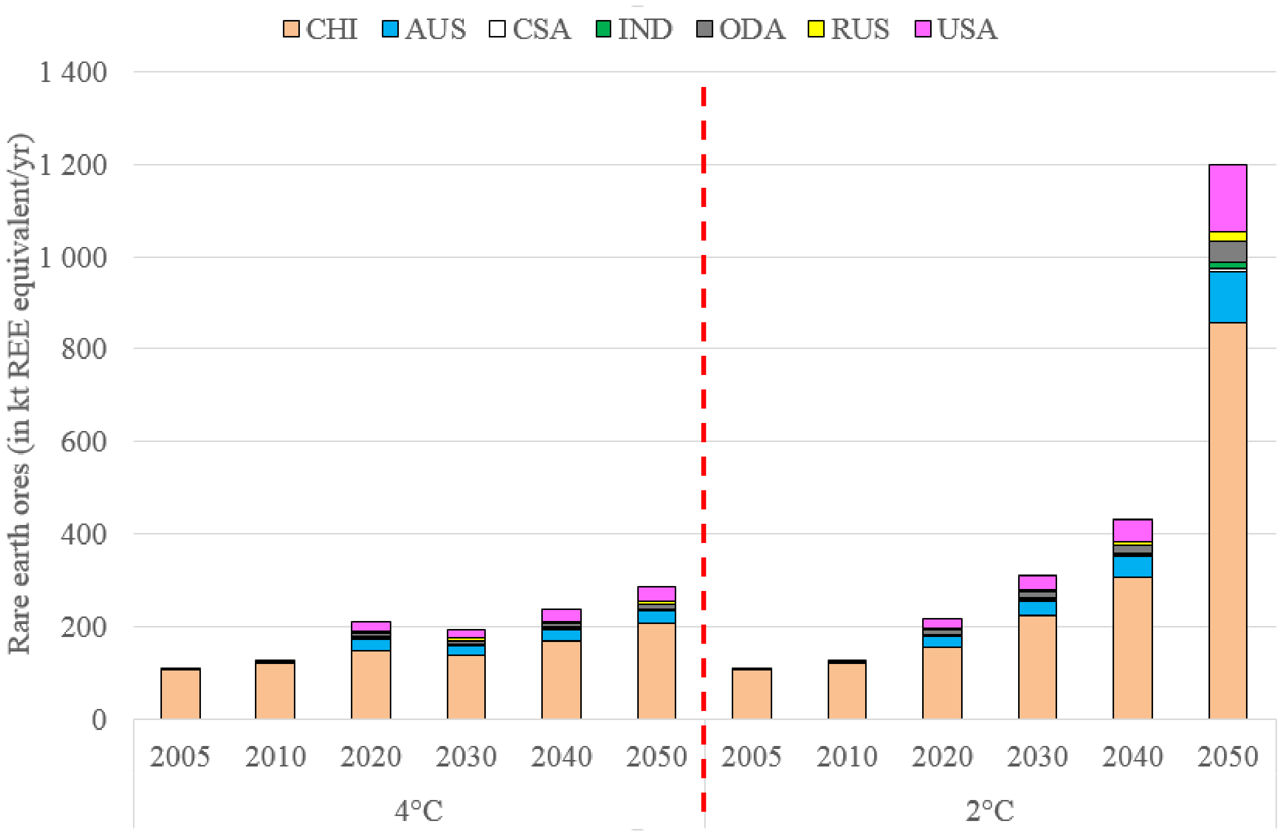
Evolution of the REE consumption between 2005-2050



- **Scen 4D:**
  - Cumulative REE consumption reaches 1.6% of global rare earth resources (2017)
  - The major consuming countries remain China, followed by Japan, United States and Europe.
- **Scen 2D:**
  - Cumulative REE consumption reaches 3.8% of global rare earth resources (2017)
  - The major consuming countries remain China, **followed by United States, Europe and Japan.**

RESULTS

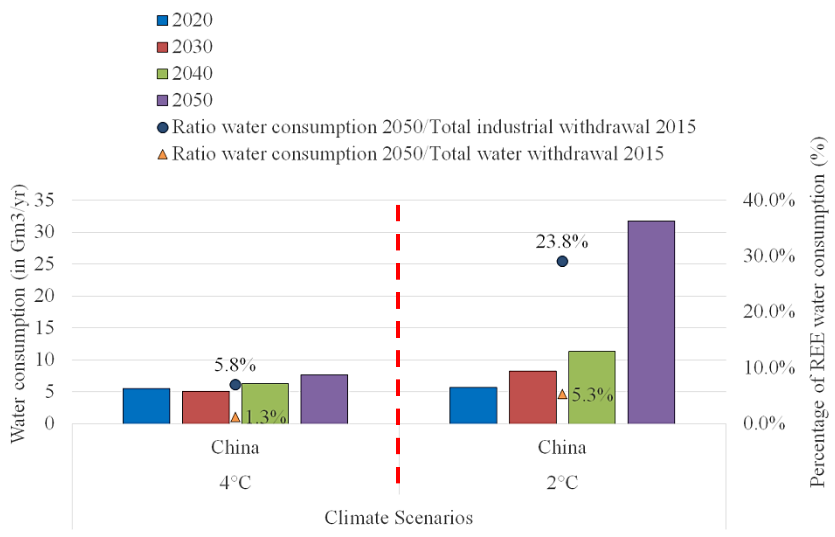
Evolution of the REO production (mining) between 2005-2050

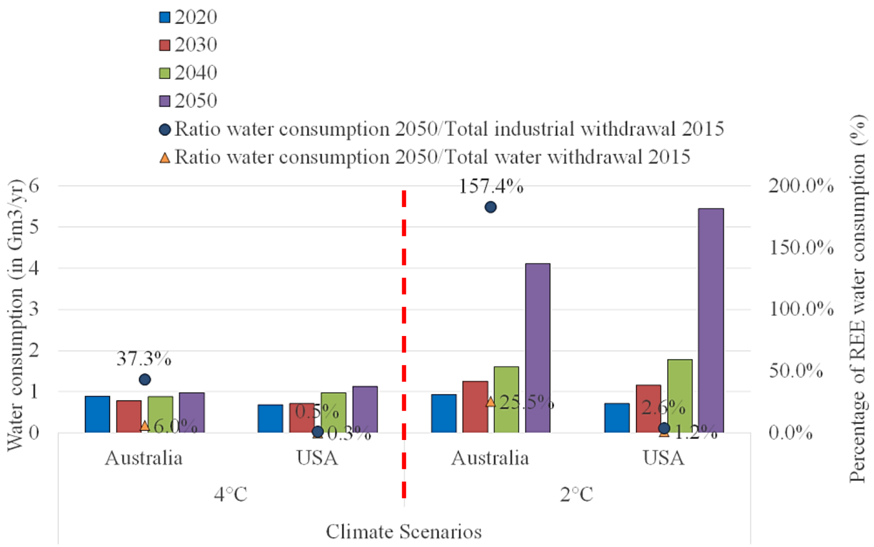


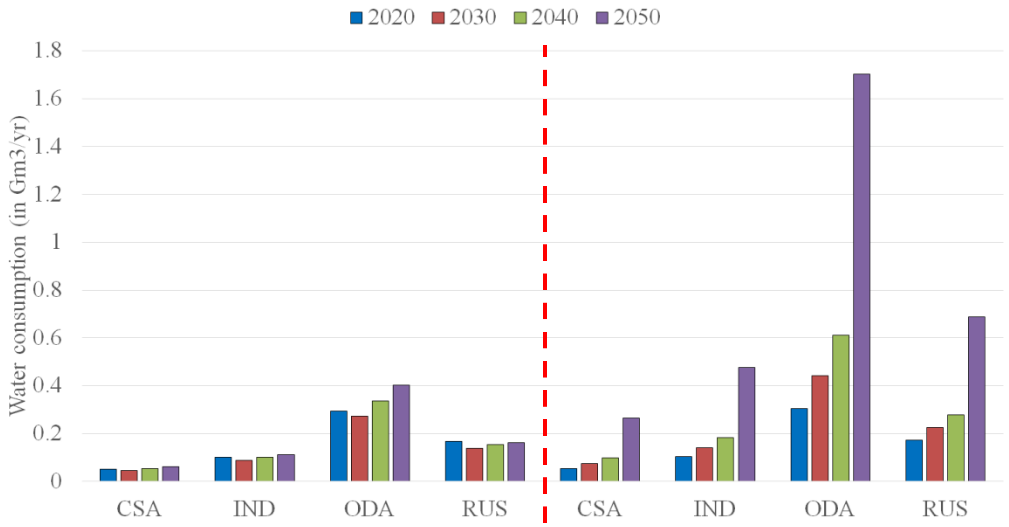
- **Scen 4D:**
  - China remains the main REO producer, but from 2020 Australia and USA begin to increase their production
  - In 2050:
    - China – 72.9%
    - United States – 10.8%
    - Australia – 9.3%
- **Scen 2D:**
  - Total production grows considerably and China continues to dominate, but with a lower share in 2050 than in the 4°C scenario
  - USA increases its production in a greater level than in the 4°C scenario
  - In 2050:
    - China – 71.4%
    - United States – 12.3%
    - Australia – 9.3%

RESULTS

- **Evolution of the water consumption in the REE production between 2005-2050**







Source for water withdrawal: Aquastat FAO (Year 2015)

CONCLUSIONS

- Demand for rare earth elements follows an upward trend in both scenarios, being more pronounced in the 2°C scenario than in the 4°C scenario, as expected.
- By 2050 the major producing countries remain China, followed by United States and Australia.
- Geopolitical problem: China will keep the monopoly, but will reduce its exports, directing the internal production for domestic consumption.
- Due to the increasing demand for REEs, water requirements also tend to increase, specially in the 2°C scenario. By 2050, water consumption of rare earth production in this scenario becomes critical for countries who are already under water supply stress such as China and Australia.
- ***The remaining question is: as water consumption and the development of decarbonizing technologies would certainly be closely intertwined in the future, could we continue to globally invest in low carbon innovations and alleviate water stress in REE production areas?***

Innovating for energy

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