PRESENTATION
SWOT ANALYSIS - CRITICAL RAW MATERIALS FOR THE EUROPEAN ENERGY TRANSITION

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PROJECT DETAILS

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TABLE OF CONTENTS

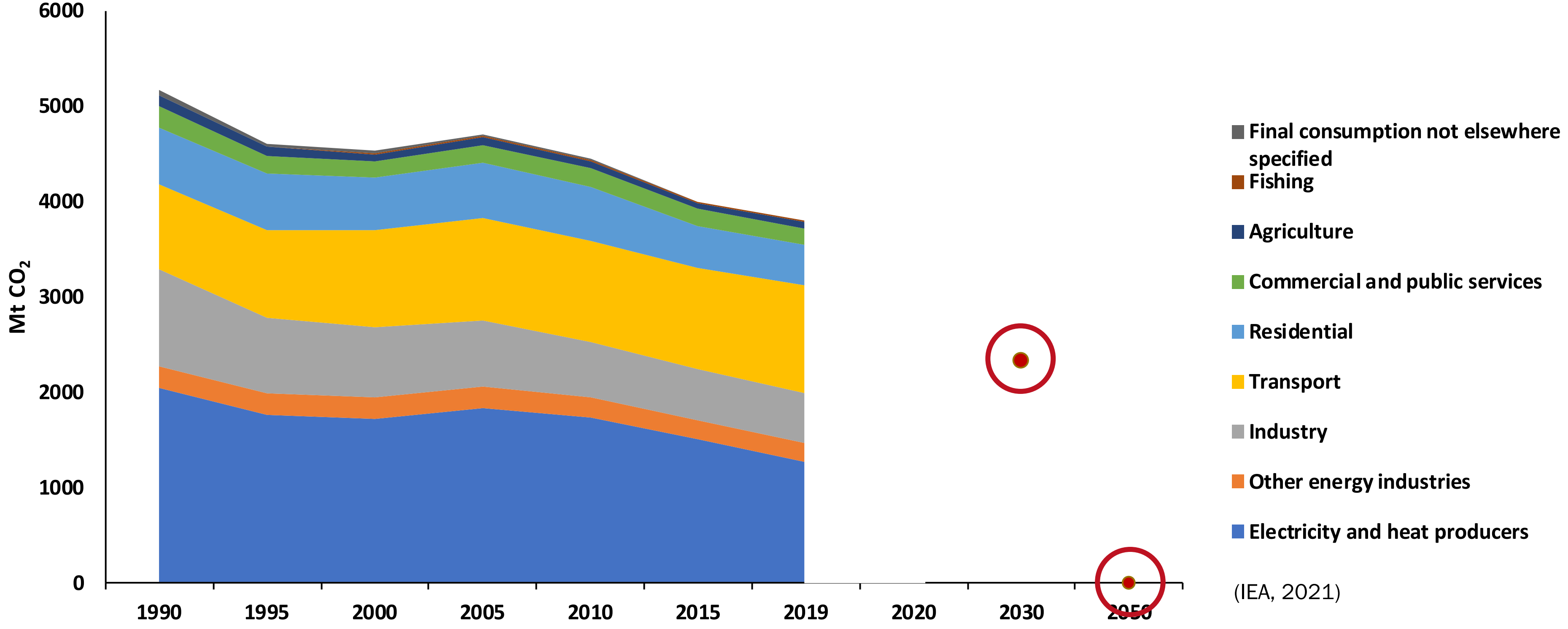
TNO innovation for life

ABBREVIATIONS

Abbreviation	Description
APS	Announced Policies Scenario
CRMs	Critical Raw Materials
CSP	Concentrated Solar Power
HREEs	Heavy Rare Earth Elements
LREEs	Light Rare Earth Elements
NZE	Net Zero Emissions Scenario
PMGs	Platinum Metals Group
PV	Photovoltaics
R&D	Research and Development
REE	Rare Earth Elements
SDS	Sustainable Development Scenario
STEPS	Stated Policies Scenario

INTRODUCTION

- Unless deep GHG emission reductions are attained, temperature rise will continue in the upcoming years and possibly exceed 1.5 °C to 2 °C by the end of the 21st-century compared to pre-industrial levels



(IEA, 2021)

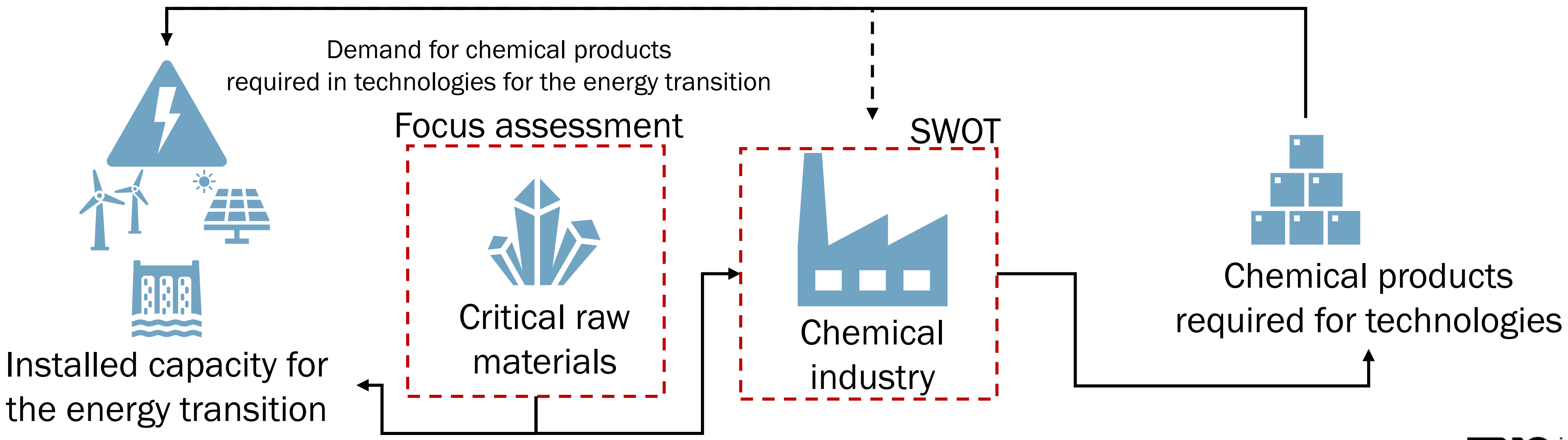
- Achieving deep GHG emissions reduction requires a wide deployment of renewable energies across all sectors and therefore, a considerably increase in the demand for materials to deploy such technologies is expected

PROJECT PLAN

HOW MUCH CRITICAL RAW MATERIALS (CRM) ARE NECESSARY TO MAKE THE (EUROPEAN) ENERGY SYSTEM FUTURE-PROOF TO STAY BELOW THE EMISSION TARGET OF 1.5°C IN 2050?

Project plan

- Identify the installed capacity of different technologies required to stay below the 1.5 °C degree.
- Identify the critical raw materials intensity of use in the different energy transition technologies.
- Assess the critical raw materials required for the energy transition based on the future technologies deployment.
- Carry out a SWOT analysis to identify the current strengths and weaknesses (SW) and future opportunities and threats (OT). The SWOT analysis focuses on the European chemical sector.



UNDERSTANDING THE ENERGY TRANSITION (4 SCENARIOS)

INTERNATIONAL ENERGY AGENCY (IEA) WORLD ENERGY OUTLOOK AND ENERGY TRANSITION SCENARIOS

	NZE	APS	STEPS	SDS
	Net Zero Emissions by 2050 Scenario	Announced Policies Scenario	Stated Policies Scenario	Sustainable Development Scenario
Definitions	A scenario which sets out a narrow but achievable pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. It doesn't rely on emissions reductions from outside the energy sector to achieve its goals.	A scenario which assumes that all climate commitments made by governments around the world, including Nationally Determined Contributions (NDCs) and longer-term net zero targets, will be met in full and on time.	A scenario which reflects current policy settings based on a sector-by-sector assessment of the specific policies that are in place, as well as those that have been announced by governments around the world.	An integrated scenario specifying a pathway aiming at: ensuring universal access to affordable, reliable, sustainable and modern energy services by 2030 (SDG 7); substantially reducing air pollution (SDG 3.9); and taking effective action to combat climate change (SDG 13).
Objectives	To show what is needed across the main sectors by various actors, and by when, for the world to achieve net zero energy related and industrial process CO_2 emissions by 2050 while meeting other energy-related sustainable development goals.	To show how close do current pledges get the world towards the target of limiting global warming to 1.5 °C, it highlights the "ambition gap" that needs to be closed to achieve the goals agreed at Paris in 2015.	To provide a benchmark to assess the potential achievements (and limitations) of recent developments in energy and climate policy.	To demonstrate a plausible path to concurrently achieve universal energy access, set a path towards meeting the objectives of the Paris Agreement on climate change and significantly reduce air pollution.

- **APS** and **STEPS** are exploratory, in that they define a set of starting conditions, such as announced and stated policies and targets, and then see where they lead based on model representations of energy systems, including market dynamics and technological progress.
- The **NZE** is normative, in that it is designed to achieve an emissions trajectory consistent with limiting the global temperature rise to 1.5 °C without a temperature overshoot (with a 50% probability), universal access to modern energy services and major improvements in air quality – and shows a pathway to reach it.
- The **SDS** is also normative, mapping out a pathway consistent with the "well below 2 °C" goal of the Paris Agreement, while achieving universal access and improving air quality.

(IEA, 2021)

UNDERSTANDING THE ENERGY TRANSITION (SCENARIOS)

KEY ASSUMPTIONS

Scenarios selection

- The **STEPS** provides a more conservative benchmark for the future, because it does not take it for granted that governments will reach all announced goals. Instead, it takes a more granular, sector-by-sector look at what has actually been put in place to reach these and other energy-related objectives, taking account not just of existing policies and measures but also of those that are under development (e.g., “Green deal”).

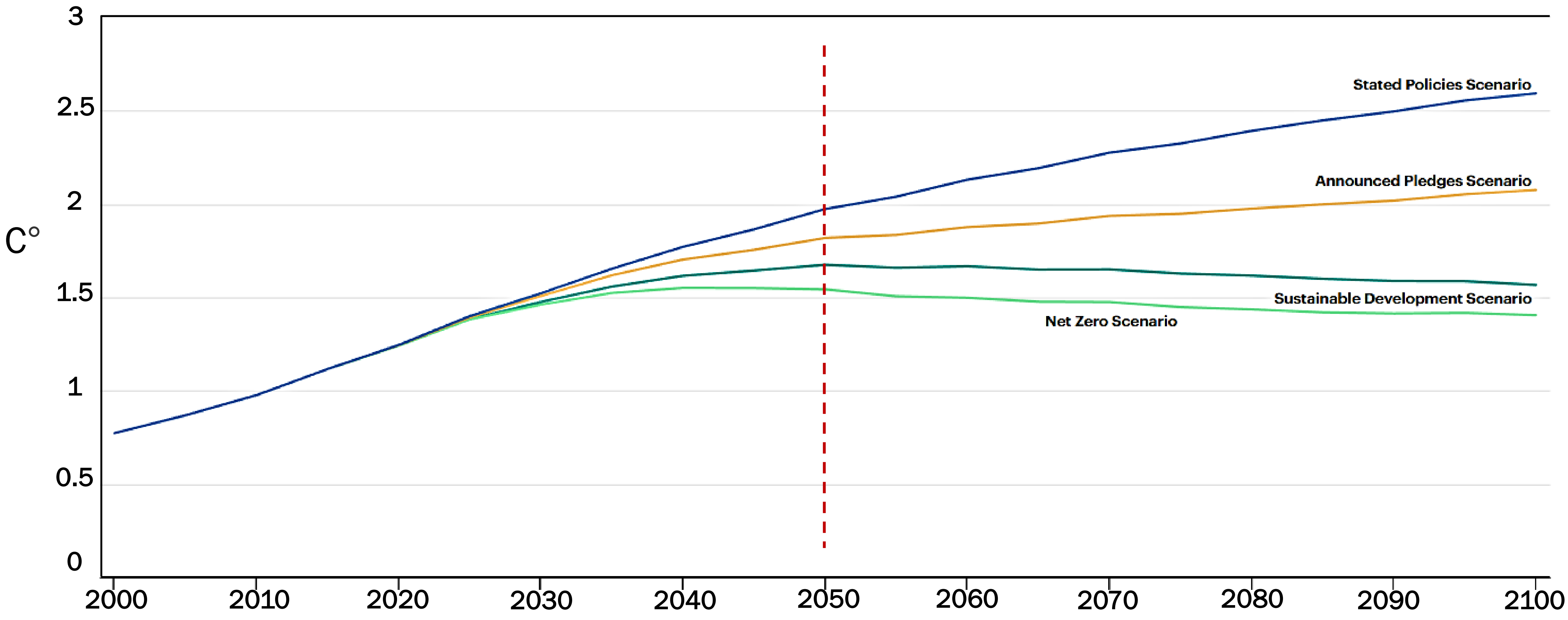
- On a global basis, the **NZE** scenario is the only one that limits global temperature rise to 1.5 °C (without temperature overshoot) before 2050. However, no regional data is available.

- The **SDS** scenario provides a good approximation to **NZE** scenario as it aims to keep temperature rise to “well below 2 °C” as specified in the Paris Agreement. It provides regional data.

(IEA, 2021)

UNDERSTANDING THE ENERGY TRANSITION (SCENARIOS)

TEMPERATURE TRAJECTORIES



(IEA, 2021)

PROJECT CHARACTERISTICS

IUPAC KEY ASSUMPTIONS

Scenarios selection

- Considering the projects goal, scope and data availability, the assessment is carried out as following:

1. Regional assessment of CRM required for the energy transitions in Europe.
   - Considered scenarios: STEPS (benchmark) and SDS (well below 2 °C)
2. Global assessment of CRM required for the energy transitions
   - Considered scenarios: STEPS (benchmark), SDS (well below 2 °C) and NZE (limits to 1.5 °C)
3. Considered technologies:

Technology	Assumption
Solar (PV)	Specific technology capacity (GW) for each point in time derived from regional (and global) generation (TWh) and capacity (GW) projections
Wind	
Hydropower	
Nuclear	
Geothermal	
Concentrated Solar Power (CSP)	
Electrolysers	Capacity derived from energy use for Hydrogen production, considering average facility of 5000 h/years and only green Hydrogen production

PROJECT CHARACTERISTICS

THE FOURTH LIST OF CRITICAL RAW MATERIALS FOR THE EU

Antimony		Fluorspar		Magnesium	✓ (green)	Silicon Metal	✓ (green)
Baryte		Gallium	✓ (green)	Natural Graphite	✓ (red)	Strontium	
Bauxite		Germanium	✓ (green)	Natural Rubber		Tantalum	✓ (green)
Beryllium		Hafnium	✓ (green)	Niobium	✓ (green)	Titanium	✓ (green)
Bismuth		HREEs	✓ (green)	PGMs	✓ (green)	Vanadium	✓ (green)
Borates	✓ (green)	Indium	✓ (green)	Phosphate rock		Tungsten	✓ (green)
Cobalt	✓ (red)	Lithium	✓ (red)	Phosphorus			
Coking Coal		LREEs	✓ (green)	Scandium			

Symbol	Explanation
✓ (green)	CRM present in the technologies assessed in this report according to specific references (see MS Excel tool for references)
✓ (red)	CRM present in Li-on batteries, not assessed in this report

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

Note: This is the current list. However, in the next years other material such as aluminium can become critical due to logistics, geopolitics, etc.

PROJECT CHARACTERISTICS

CRITICAL RAW MATERIALS FOR THE EU ACCORDING TO TECHNOLOGY TYPES

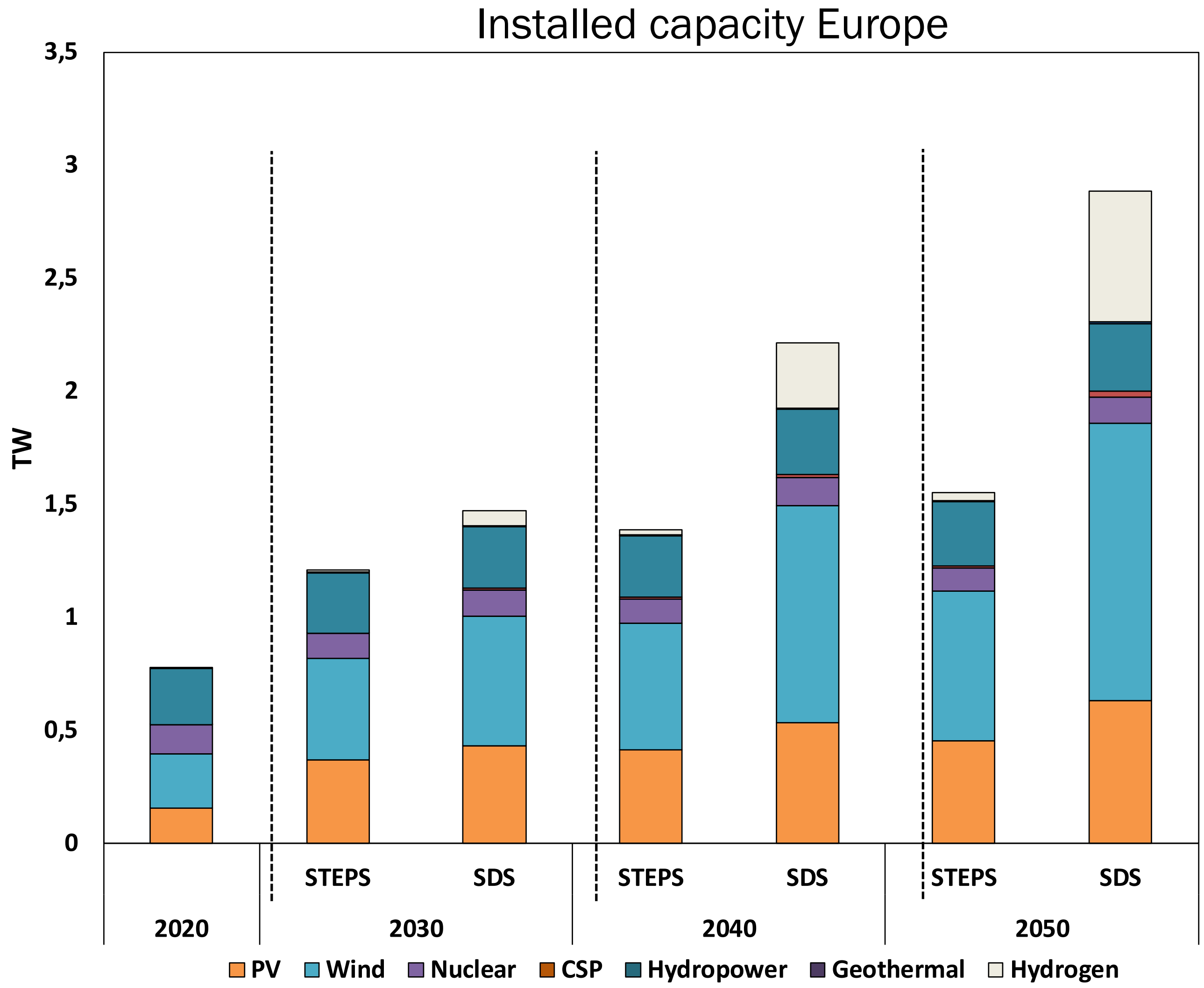
PV	CSP	Wind	Hydro	Geo	Nuclear	Hydrogen
Gallium	Magnesium	Borate	Magnesium	Niobium	Hafnium	Iridium (PGM)
Germanium	Niobium	Dysprosium (HREE)	Titanium	Tantalum	Indium	Platinum (PGM)
Indium	Titanium	Neodymium (LREE)		Titanium	Tungsten	Titanium
Silicon Metal	Vanadium	Praseodymium (LREE)			Vanadium	
		Terbium (HREE)			Yttrium (HREE)	

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

For more information about material intensities and references please see **Annex 2**

RESULTS: EUROPE (1)

UNDERSTANDING THE TECHNOLOGIES ROLE. PROJECTIONS REQUIRED INSTALLED CAPACITIES

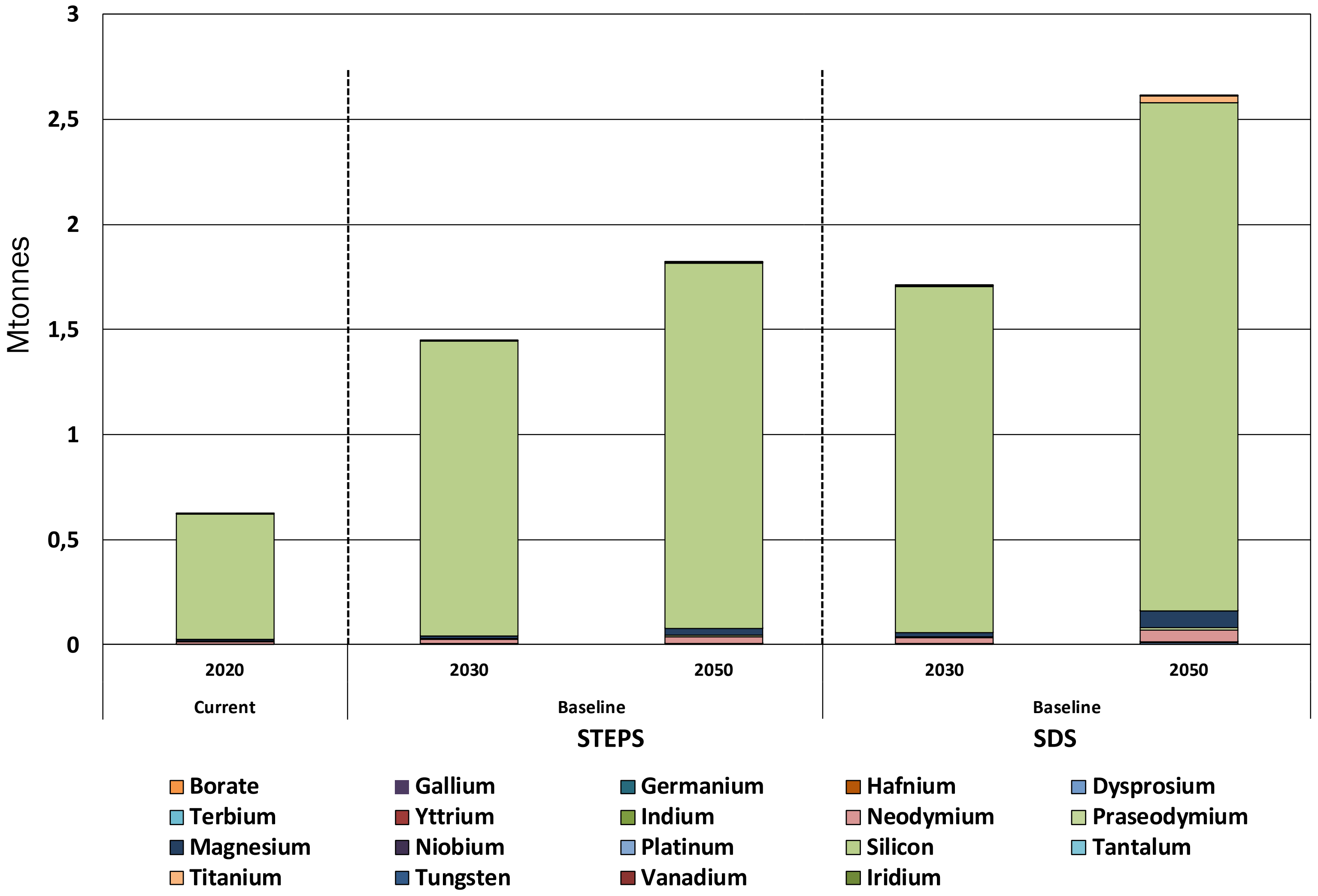


1. For 2050, following the current trends (STEPS), the overall installed capacity increases in 100%. To "stay well bellow 2 °C" (SDS) the overall installed capacity by 2050 has to increase by 270%
2. The technologies share is dominated by Wind, PV, Hydro, and the appearance of hydrogen in the latter years
3. Nuclear is expected to decrease given the projected decommissioning of several nuclear plants. In addition, nuclear fusion is left out of the picture because of uncertainty for installed capacity after 2050.
4. It will takes a few decades to increase the installed capacity substantially

Note: The installed capacity is cumulative

RESULTS: EUROPE (2)

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX

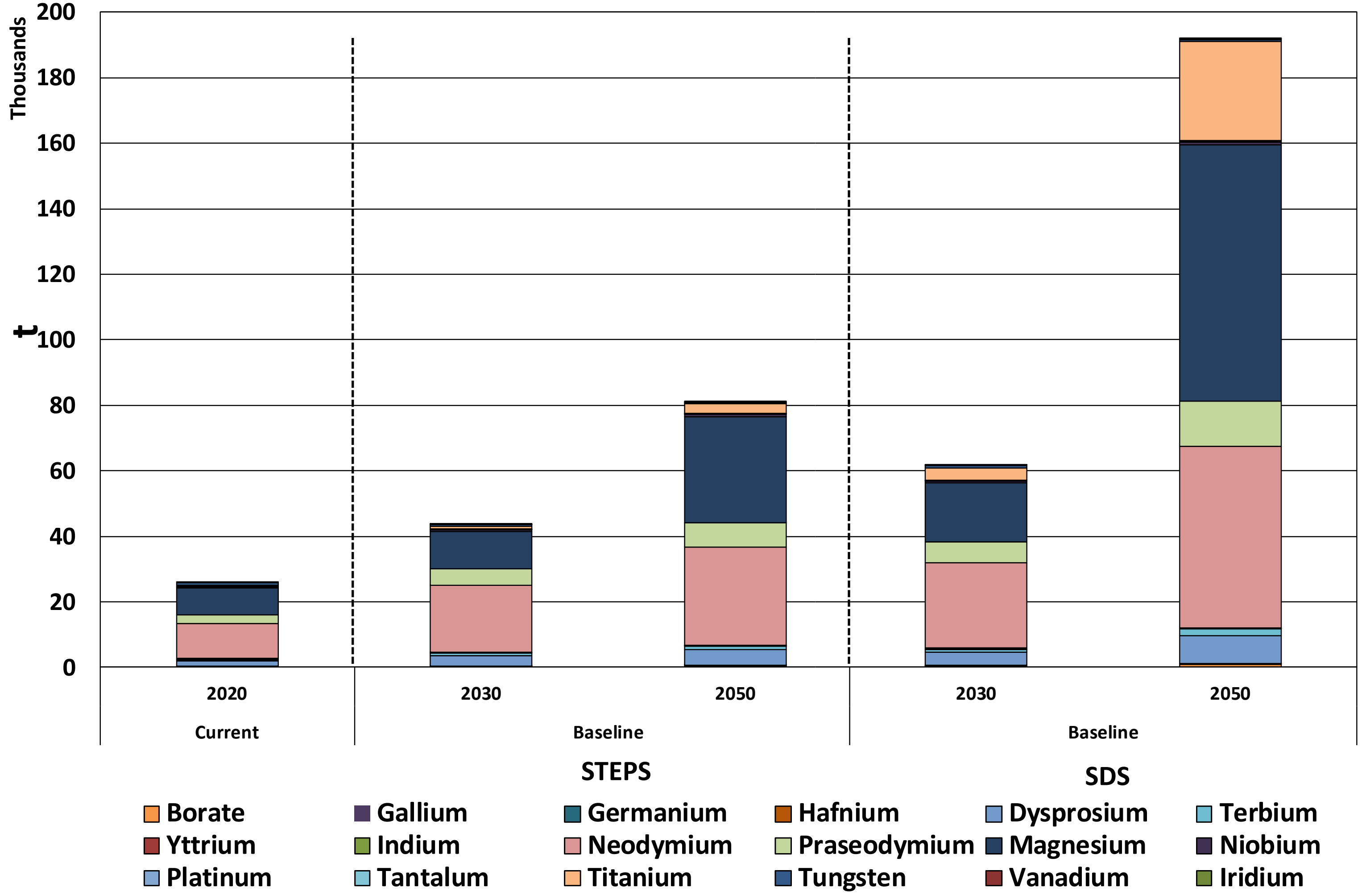


1. For 2050, following the current trends (STEPS), the overall demand of CRM is 1,8 million tons. To “stay well bellow 2 °C” (SDS) the overall demand of CRM is 2,6 million tons by 2050.
2. The largest demand for CRM is related to the large deployment of PV and Wind technologies.
3. Silicon (Si) is the CRM required the most, followed by Magnesium (Mg) and Neodymium (Nd).

Note: See next slide for graph without silicon

RESULTS: EUROPE (2)

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX **WITHOUT SILICON**



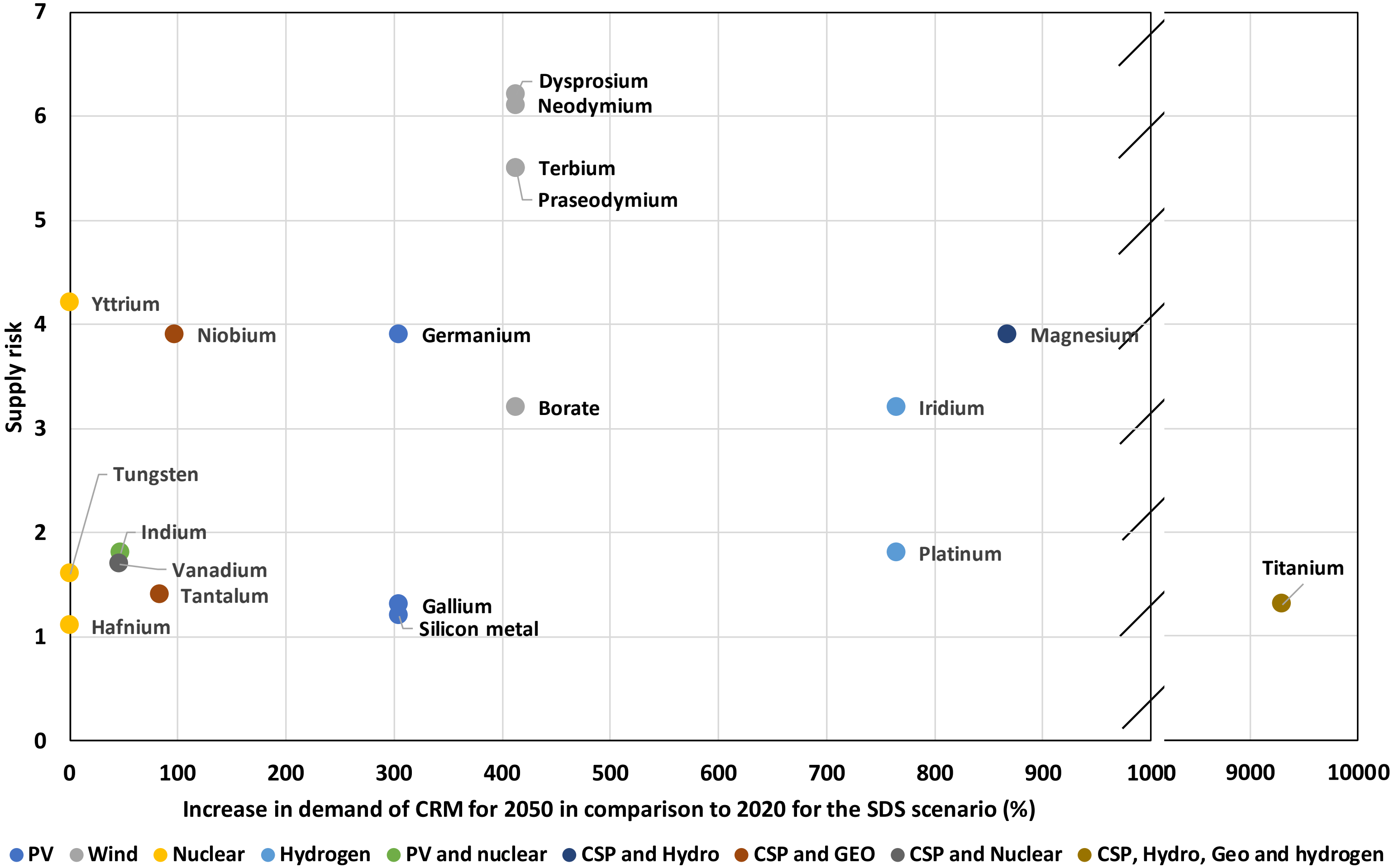
RESULTS: EUROPE (3)

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX

1. Silicon for PV is required the most given that the material intensity usage is considerably higher than any other. Approximately 4000 t (see **Annex 2**) are required for each GW of installed capacity. This material intensity usage for PV is 2 order of magnitude higher compared to the material intensity usage of most CRM materials in other technologies. Even higher amounts (above 6000 t(Silicon)/GW) are reported in other studies such as Tokimatsu et al., 2018 and Carrara et al., 2020. However, Silicon material intensity usage is expected to decline in the upcoming years. Currently (2020), Silicon usage averaged 3100 t/GW (PVPS, 2021). For more information about Silicon see **Annex 1**
2. Magnesium is required for CSP and Hydropower. Mg intensity usage in CSP is considerable high (3000 t/GW) while for hydropower it is 1,9 t/GW (See **Annex 2**).
3. Neodymium is mainly required for Wind. However, the material intensity usage 28-180 t/GW (See **Annex 2**) is low compared to other materials such as Silicon. Still, large quantities of Neodymium are required given the great deployment of Wind to meet climate targets.
4. Towards 2050, large quantities of Titanium are also required. Despite that the material intensity usage of Titanium is low compared to other CRM, it is required in several technologies: CSP, Hydropower, Geothermal, Nuclear and Hydrogen.

RESULTS: EUROPE (4)

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX COMPARED TO SUPPLY RISK



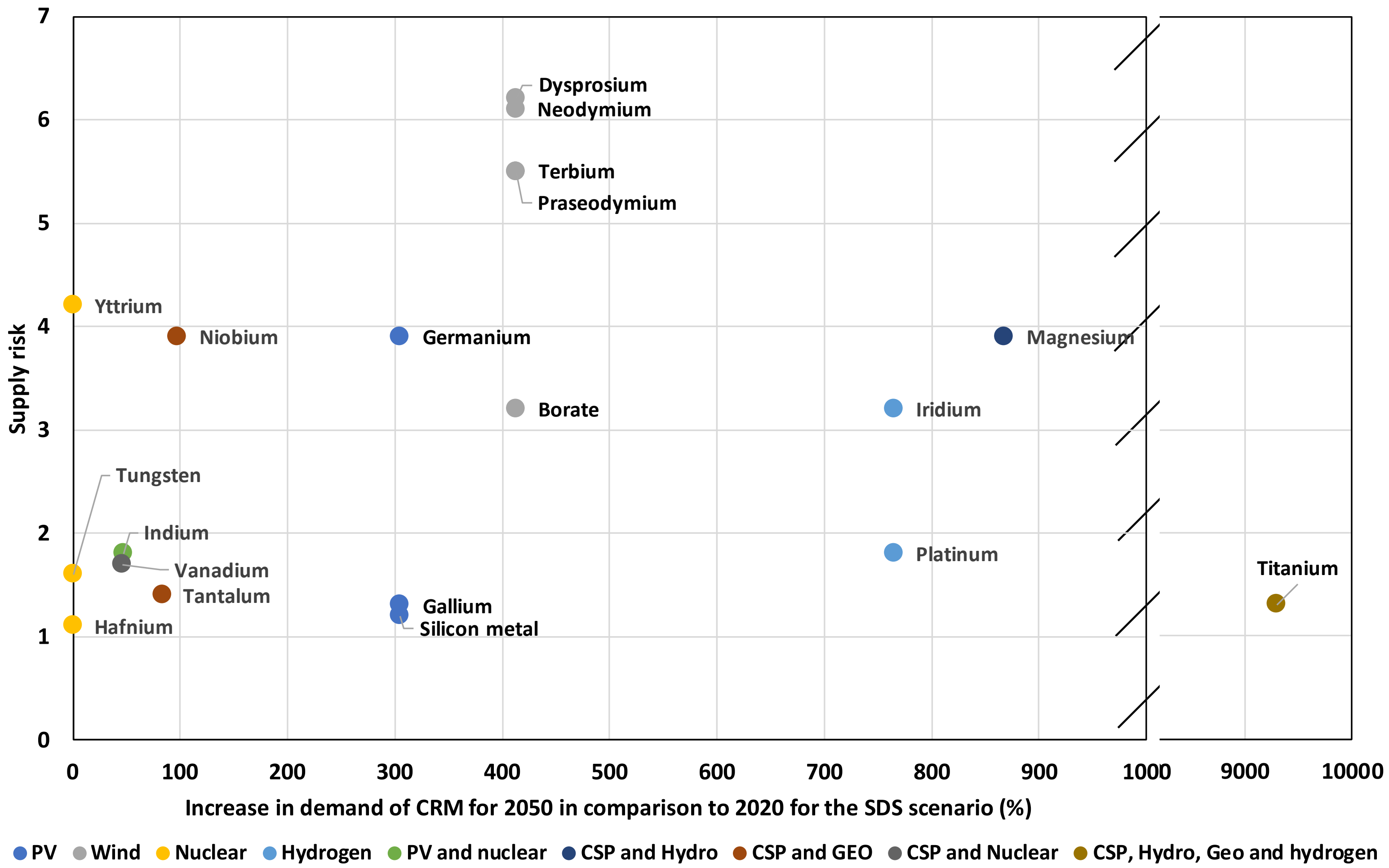
1. In 2050, the demand for the majority of CRM increases in over 100%.
2. The demand increase is the highest in CRMs used in several technologies, mainly Titanium. Similarly, the demand for Platinum and Iridium, related to Hydrogen production, increases considerable.
3. The demand for REEs such as Neodymium and Dysprosium, mainly related to Wind, increases by more 400%.

REEs = Rare Earth Elements

Note: Check the slide notes for information about the supply risk indicator

RESULTS: EUROPE (4)

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX COMPARED TO SUPPLY RISK



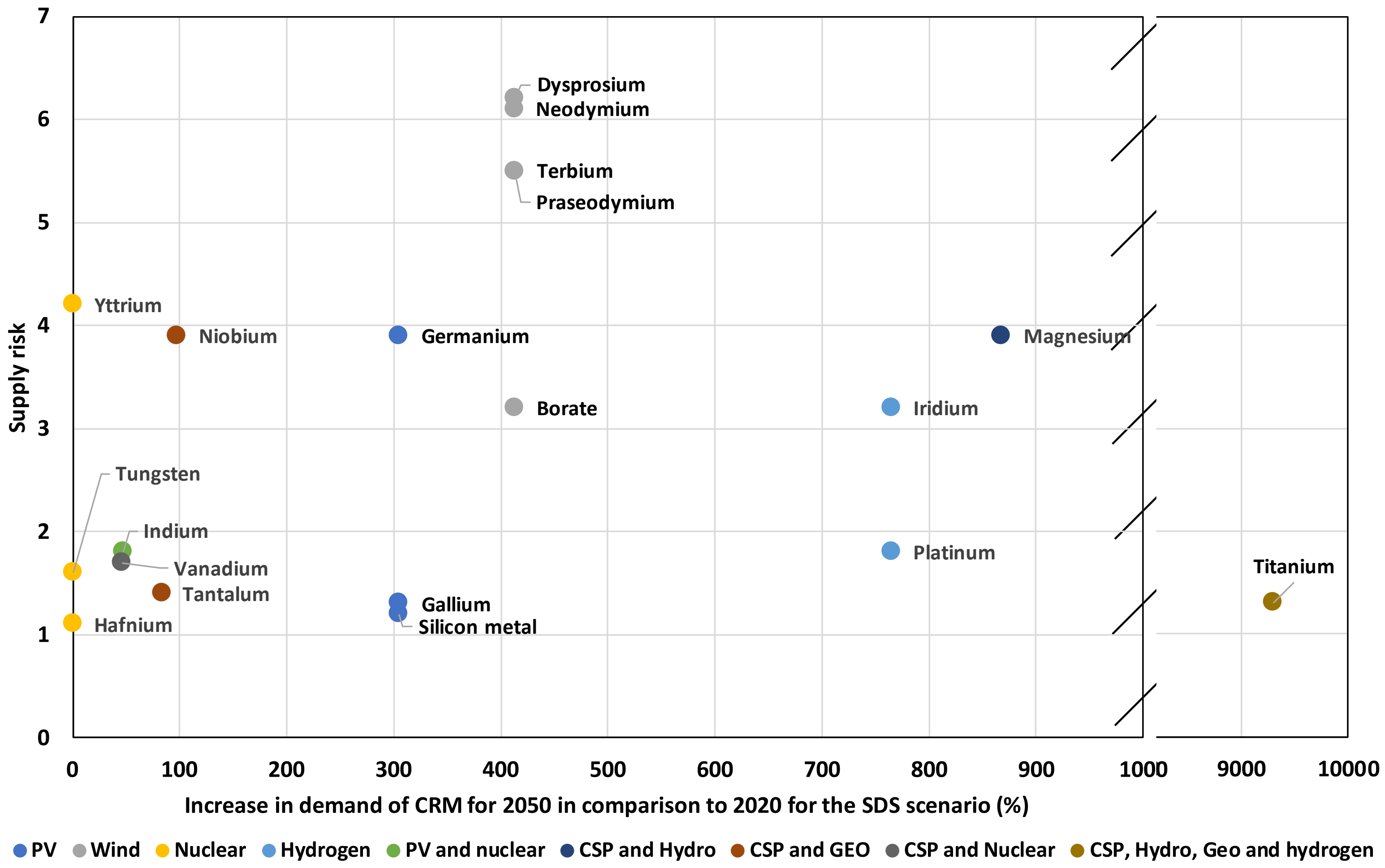
REEs = Rare Earth Elements

Note: Check the slide notes for information about the supply risk indicator

1. The demand for CRM (Iridium and Platinum) in Hydrogen is high given that for 2020 no green Hydrogen production is considered, while for 2050 the capacity increases considerably.
2. The demand for Magnesium is also high. This is driven mainly by the high intensity usage of Magnesium in CSP.
3. The demand for Hafnium, Yttrium and Tunsgten decreases by 9%. This demand reduction is related to the decommissioning of Nuclear facilities in Europe. However, in the graph, the % increase has been set to 0 for displaying purposes.

RESULTS: EUROPE (4)

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX COMPARED TO SUPPLY RISK



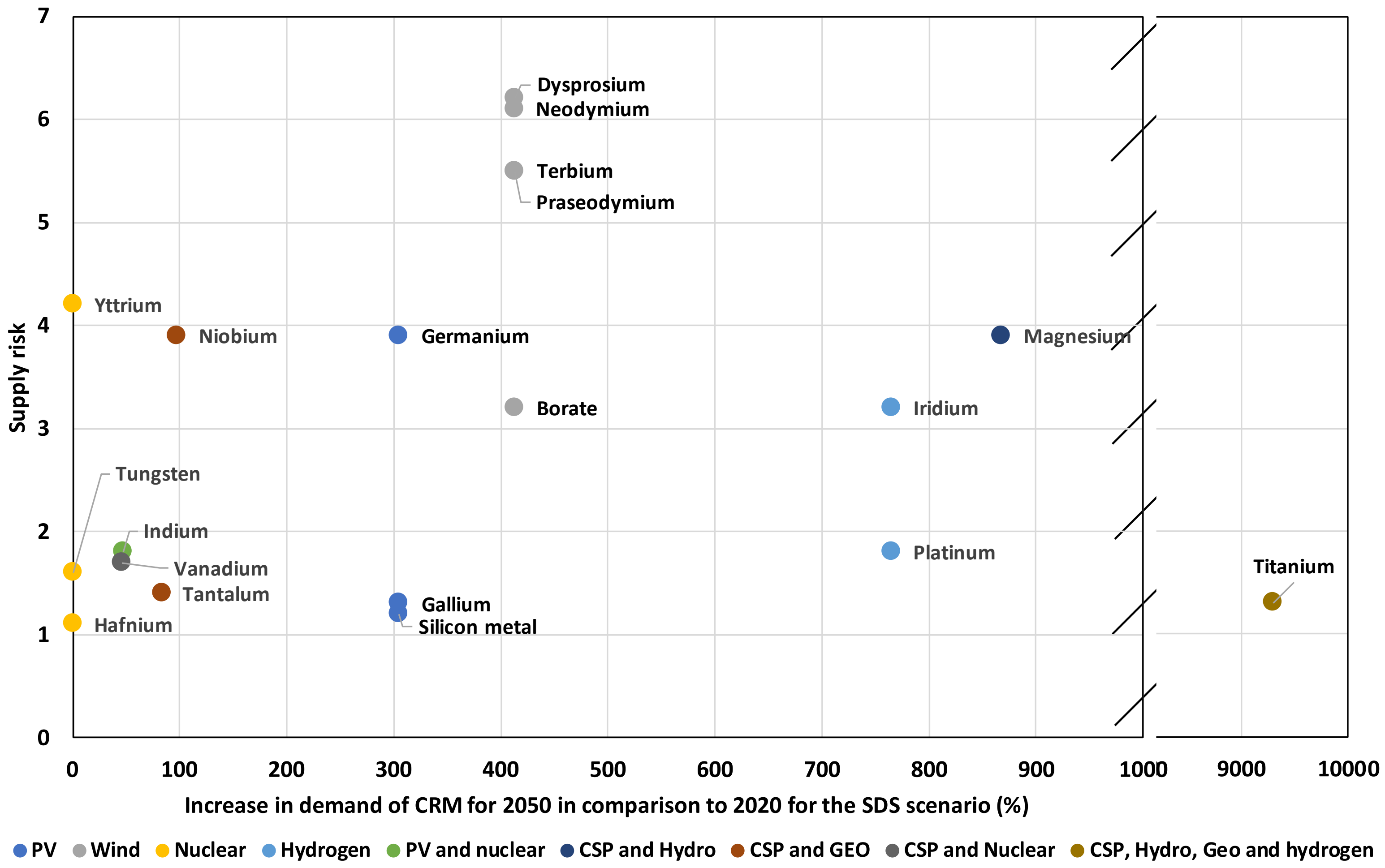
REEs = Rare Earth Elements

Note: Check the slide notes for information about the supply risk indicator

1. The highest supply risk is for CRMs used in wind; Dysprosium, Neodymium, Terbium and Praseodymium.
2. Yttrium supply risk is also high, however there is no demand increase because of the future decommission of nuclear facilities.
3. The supply risk for CRMs used in PV is low. Only Germanium supply risk is high. However, Germanium is used only in Amorphous silicon thin-film PV technologies (a-SI), which currently represents only 0.3% of worldwide installed PV panels.

RESULTS: EUROPE (4)

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX COMPARED TO SUPPLY RISK



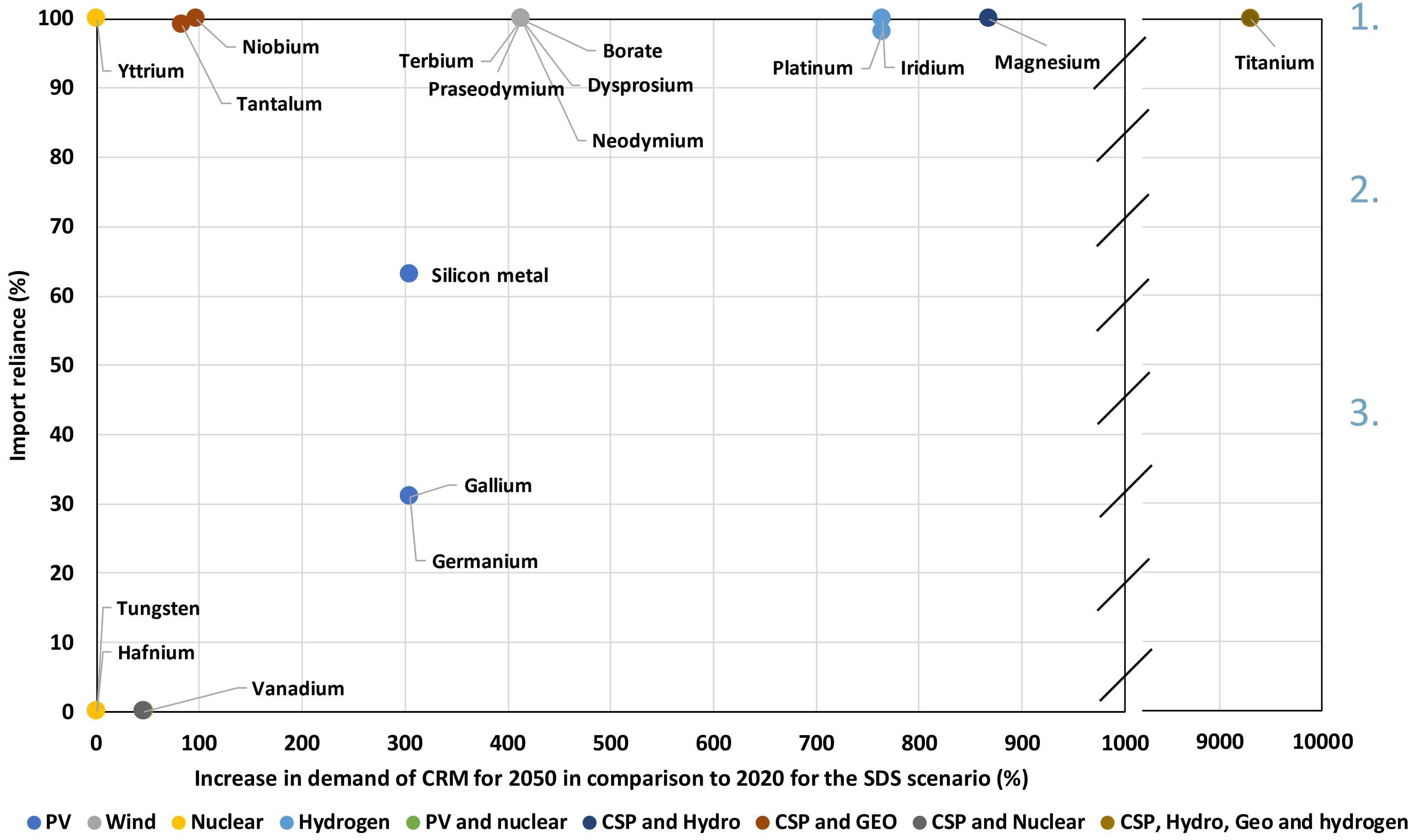
1. Some CRMs (Magnesium and Niobium) used in CSP are also characterized by a high supply risk. Contrarily, Vanadium (also used in Nuclear) represent a considerably lower supply risk.
2. Titanium, which is the CRM used in several technologies (CSP, Hydro, Geo and Hydrogen) represent a lower supply risk. However the expected demand is considerably high.

REEs = Rare Earth Elements

Note: Check the slide notes for information about the supply risk indicator

RESULTS: EUROPE (5)

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX COMPARED TO IMPORT RELIANCE

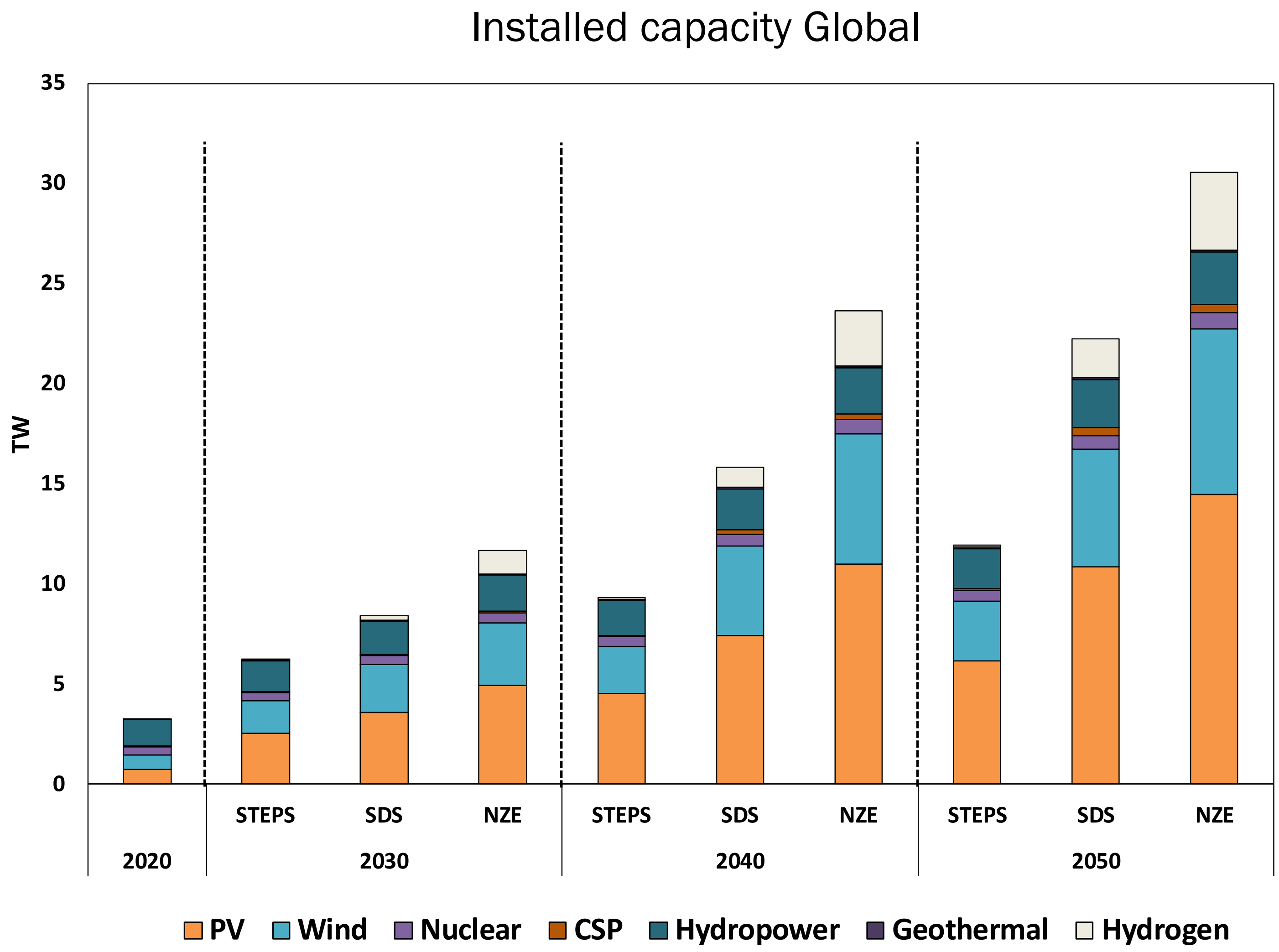


1. All CRMs required for wind and green hydrogen production have an import reliance of 100%.
2. The import reliance for most CRMs is 100% except for some CRMs used in PV technology, Nuclear and CSP.
3. Vanadium (for CSP and Nuclear) data is very limited. Still, the European Commission sets the import reliance at 0%. In addition, the increase in demand is low when compared to most CRMs.

Note: Check the slide notes for information about the importance reliance indicator. No data was applicable for Hafnium and Tungsten

RESULTS: GLOBAL (1)

UNDERSTANDING THE TECHNOLOGIES ROLE. PROJECTIONS REQUIRED INSTALLED CAPACITIES



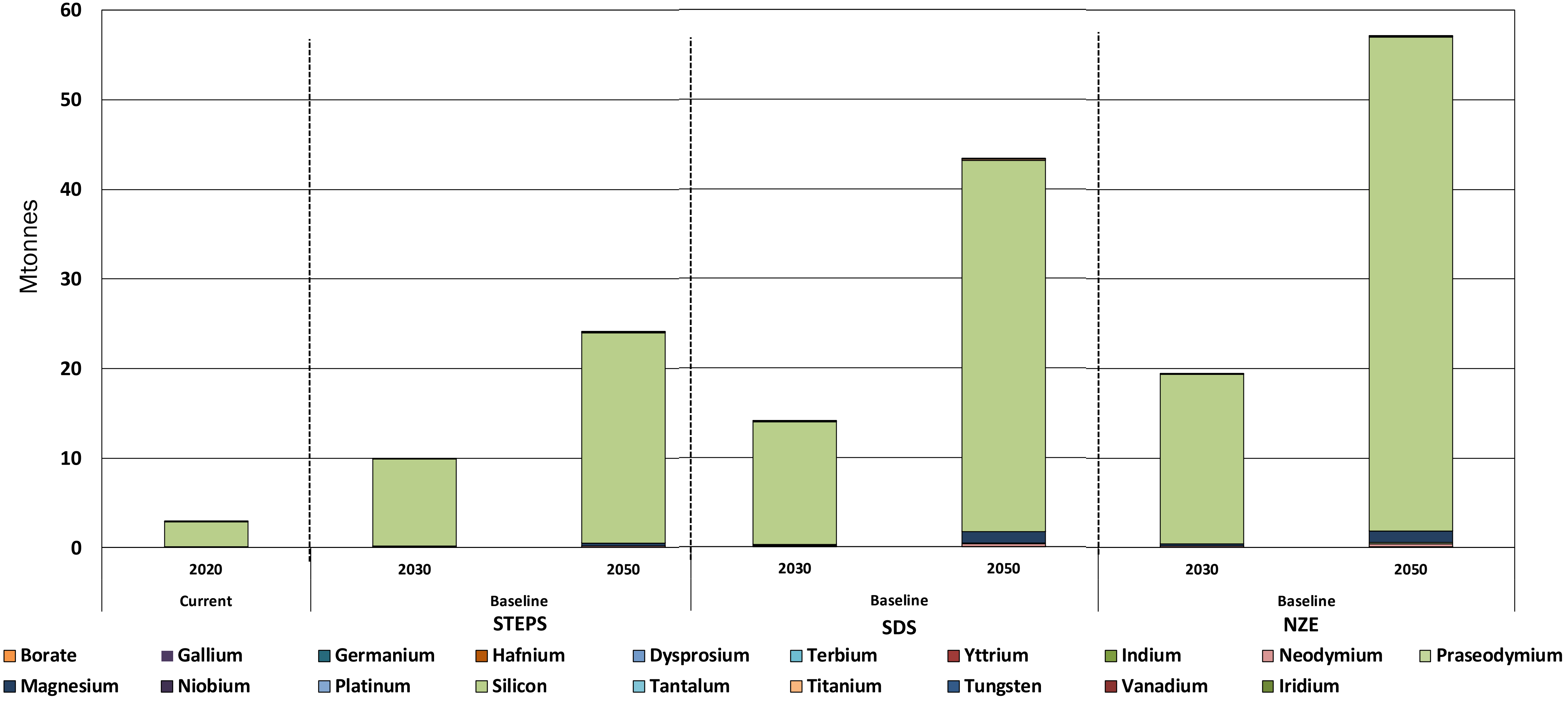
1. In order to limit global temperature rise to 1.5 °C (NZE) by 2050, the overall installed capacity needs to increase by 260% in 2030 and by 860% in 2050 compared to actual installed capacity (2020).

2. On a global basis, the share of technologies is dominated by PV, Wind, Hydro, and the appearance of hydrogen in the latter years. Most of the installed capacity for PV and Wind is expected to occur in Asia (China).

Note: The installed capacity is cumulative

RESULTS GLOBAL (2)

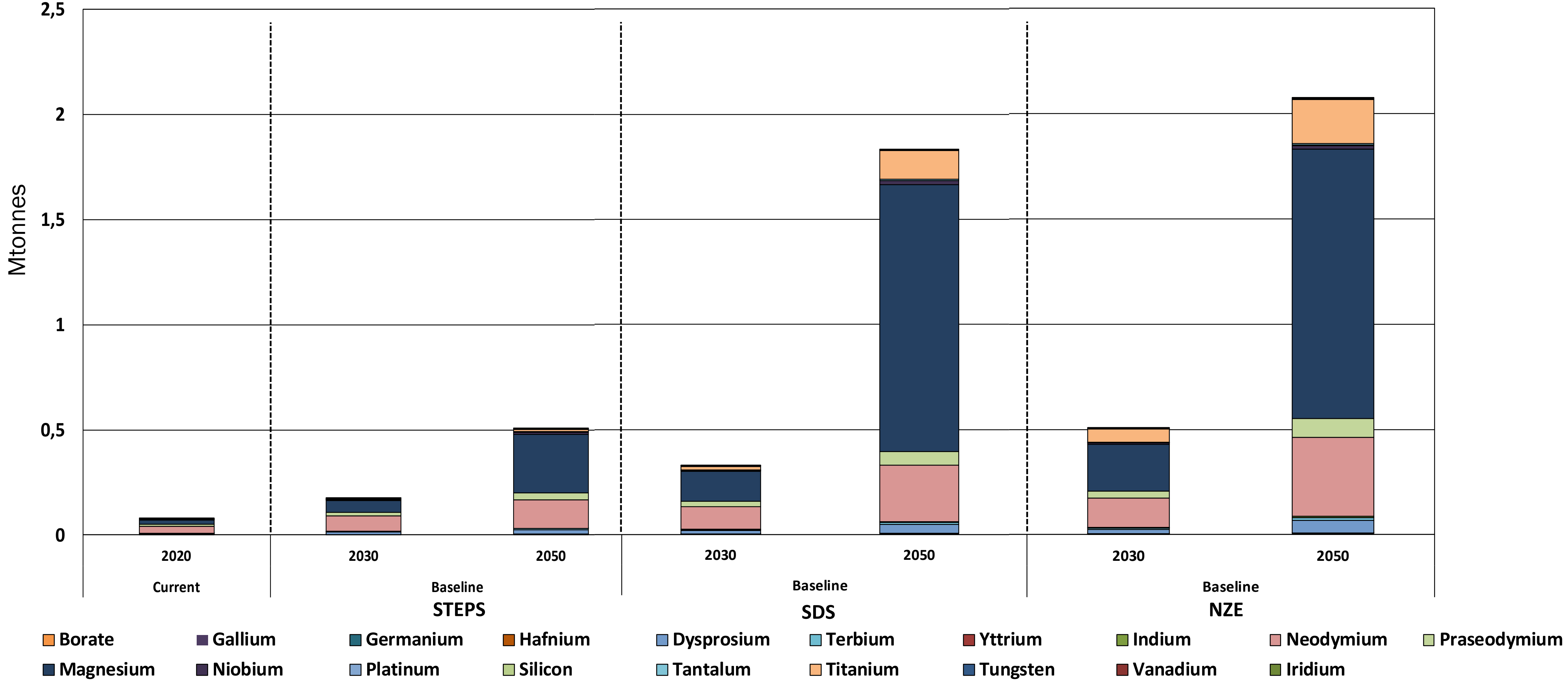
GLOBAL CRM DEMAND FOR TECHNOLOGIES MIX



The global CRM demand follows the same trend as with Europe. However the order of magnitude is considerably higher, resulting in almost 60 million tons of critical raw material required by 2050 in order to limit global temperature rise to 1.5 °C (NZE)

RESULTS GLOBAL (2)

GLOBAL CRM DEMAND FOR TECHNOLOGIES MIX **WITHOUT SILICON**



The global CRM demand follows the same trend as with Europe. However the order of magnitude is considerably higher, resulting in almost 60 million tons of critical raw material required by 2050 in order to limit global temperature rise to 1.5 °C (NZE)

DISCUSSION - FOCUS ON EUROPE (1/5)
UNDER SDS SCENARIO

1. Given the difference in scope and included materials, the comparison with similar exercises is challenging. Most relevant studies include efficiency improvements over time in terms of material intensity usage. In addition, some studies present the overall usage of CRM and other metals as a whole and not disregarded per element.
2. Batteries for transport and storage were not considered, but some studies estimate that by 2050 the demand for Lithium, Cobalt and Natural graphite (all CRM) can increase in almost 60 times for lithium and 15 for Cobalt and Natural Graphite when compared to current EU consumption (European Commission A, 2020). This can be one of the mayor bottlenecks for the energy transition.
3. The demand for other important metals used in the energy transition technologies such as Copper and Nickel (not considered CRM) is also expected to increase considerably.
4. This bottom-up assessment needs to be addressed with care given that demand trajectories are not included and energy transition scenarios are submitted to high policy uncertainties.

DISCUSSION - FOCUS ON EUROPE (2/5)
UNDER SDS SCENARIO

1. Similar studies (Tokimatsu et al., 2018, Kavlak., et al 2015, and European Commission A, 2020) also provide considerably large increase in silicon use for PV depending on scenario. However, other studies fail to include silicon. For most CRMs required for PV the supply risk is low except Germanium. Despite that CRMs imports for PV need to increase in order to meet 2050 cumulative demand, it appears that there are less challenges when compared to other technologies such as wind. However, note that China has near monopoly along all aspects of PV from production, to manufacturing and export. See Annex 1 for additional information on Silicon.

CRM in PV	Cumulative CRM demand for the energy transition by 2050 under the SDS scenario (t)	Supply risk	Main Eu supplier and share (%)	Current annual EU consumption in all applications (t)
Gallium	48.	1.3	Germany (35%)	50
Germanium	421.	3.9	Finland (51%)	30
Indium	181	1.8	France (28%)	200
Silicon Metal	2418222	1.2	Norway (30%)	400000

Note: For information on 2050 CRM cumulative demand and EU suppliers of CRM see Annex 3

DISCUSSION - FOCUS ON EUROPE (3/5)
UNDER SDS SCENARIO

1. As in similar reports (Leiden-Delft-Erasmus Centre for Sustainability Circular Industries Hub, 2022), the use of REEs for Wind is recognized as a major bottleneck for the European energy transition. Most CRMs for wind are characterized by a high supply risk, 100% import reliance and a demand increase in 2050 by more than 400% (cumulative) compared to 2020 under the SDS scenario. Major imports of REEs from China will be required to meet the cumulative 2050 REEs demand for wind. These characteristics pose a major challenge for large scale wind technology deployment in the EU.

CRM in wind	Cumulative CRM demand for the energy transition by 2050 under the SDS scenario (t)	Supply risk	Main Eu supplier and share (%)	Current annual EU consumption in all applications (t)
Borate	845	3.2	Turkey (98%)	36000
Dysprosium (HREE)	9693	6.2	China (98%)	200
Neodymium (LREE)	55425	6.1	China (99%)	4000
Praseodymium (LREE)	13651	5.5	China (99%)	1000
Terbium (HREE)	918	5.5	China (98%)	24

Note: For information on 2050 CRM cumulative demand and EU suppliers of CRM see Annex 3

DISCUSSION - FOCUS ON EUROPE (4/5)
UNDER SDS SCENARIO

1. Titanium demand for (mainly) green Hydrogen (and other technologies such as CSP) production in 2050 (under current circumstances) can reach 29 kt/year (cumulative) under the SDS scenario. Europe does not produce any titanium and imports it from all over the world. Platinum is one of the most scarce materials required in Proton Exchange Membrane (PEM) for green hydrogen production. Approximately, 33 t (cumulative) of Platinum are demanded by 2050. Europe is a main importer of Platinum. PEM also requires Iridium, one of the most rare and scarce materials. To illustrate, Iridium worldwide annual demand in 2018 was 7.7 t (European Commission B, 2020). CRMs for green hydrogen production can become a bottleneck, especially considering the stability and information provided from supply countries.

CRM in Hydrogen	Cumulative CRM demand for the energy transition by 2050 under the SDS scenario (t)	Supply risk	Main Eu supplier and share (%)	Current annual EU consumption in all applications (t)
Iridium (PMG)	87	3.2	S. Africa (n/a)	n/a
Platinum (PMG)	33	1.8	S. Africa (n/a)	39
Titanium	29319	1,1	China (n/a)	1509000[1]

Note: For information on 2050 CRM cumulative demand and EU suppliers of CRM see Annex 3

DISCUSSION - FOCUS ON EUROPE (5/5)
UNDER SDS SCENARIO

1. In 2019, Niobium consumption in Europe was 12.2 kt (all sectors) (European Commission B, 2020). By 2050, Niobium (cumulative) demand for CSP and Geothermal can increase to 1178 t. Given that Niobium applications are relatively new, the additional demand can bring bottlenecks into the supply. In addition, most of the supply is carried out by Brazil and this CRM is also characterized by a high supply risk.
2. Magnesium is also characterized by a high supply risk. Most if the Magnesium consumed in the EU is supplied by China. Magnesium cumulative demand in 2050 for the energy transition stands at 78.4 Kt, this is 42% of the current EU consumption. The major end-uses of magnesium in the EU are in the transport sector (European Commission B, 2020) and the additional demand can bring challenges related to the energy transition.

CRM	Cumulative CRM demand for the energy transition by 2050 under the SDS scenario (t)	Supply risk	Main Eu supplier and share (%)	Current annual EU consumption in all applications (t)
Niobium[1]	1178	3.9	Brazil (85%)	12200[3]
Magnesium[2]	78401	3.9	China (93%)	184000

Note: For information on 2050 CRM cumulative demand and EU suppliers of CRM see Annex 3

SWOT - FOCUS EUROPEAN CHEMICAL INDUSTRY
STRENGTHS

1. Production of mining chemicals (a.o. flocculants, dispersants, chelating agents, surfactants) and related sustainable business and innovation potential.
2. Technology base (chlorine-alkali), catalysts and electrochemistry expertise that is applicable to scale up sustainable (electrochemical) mining technologies (e.g. Vulcan Energy Resources).
3. Strong innovation (and logistics) system around the industry. Strong collaboration between knowledge institutes, universities and the industry. In addition, there are also governmental incentives to support sustainable innovation related to CRM recycling technologies and substitution of CRMs by non-CRMs.

SWOT - FOCUS EUROPEAN CHEMICAL INDUSTRY
WEAKNESSES

1. Although strong focus on plastics and bulk metal (Al/Fe) recycling, there is a potential lack of critical mass of knowhow, R&D and scale-up capabilities of "old" technologies (electrochemistry, solid state chemistry, metallurgy) that become highly relevant for metal and minerals recycling and purification.

SWOT - FOCUS EUROPEAN CHEMICAL INDUSTRY

OPPORTUNITIES

1. Invest towards research and development:
   - Develop new and update technologies (methods) to reduce material use and therefore, increase the material efficiencies across technologies.
   - Increase the research on CRMs material substitution to diversify material use and reduce dependency on specific CRMs.
   - Introduce (and update) technologies that allow to collect, reuse and recycle CRMs across sectors. Especially to deliver reusable high quality materials that can be used in renewable energy technologies or in different sectors.
   - Elaborate modular designs that allow to recycle materials in the different technologies at a competitive cost
2. Develop long-term investments for new sustainable mining activities in Europe to diversify the supply of CRMs.
3. Promote long-term supply contracts characterized by sustainable development commitments with different countries to diversify supply locations (geopolitics)
4. Assure CRMs traceability from supply location to end use. This will enhance the sustainability along the entire supply chains of renewable energy technologies.
5. Export opportunity from the EU industry to RoW of innovative CRM mitigating technologies and products

SWOT - FOCUS EUROPEAN CHEMICAL INDUSTRY

THREATS

1. Indirect: Due to geopolitics related to CRMs required for clean power generation and transport, the chemical industry can have limited access to low emissions electricity. This access is essential to meet the EU Green Deal emission reduction targets. Geopolitics, access to CRMs, and consequently electrification based on low emissions electricity represents the biggest threat given that electricity is the most important pathway for the EU chemical industry to decarbonize it's energy use and the production of hydrogen.
2. Direct: The increased demand for CRM for the energy transition leads to scarcity which results in price increases of CRMs for a.o. catalysts for the chemical industry and specific process equipment

KEY TAKEAWAYS FROM THIS STUDY AND WAY FORWARD

1. Based on this analysis a supply-demand gap is expected for Critical Raw Materials that are required for the energy transition and achieving our climate targets (i.e. Net zero emission by 2050)
2. Prioritization based on the EU supply risk indicator show that specifically for Wind energy the REE are most critical to achieve a net zero energy system in the EU by 2050.
3. For the production of green hydrogen the reduction or substitution of Iridium is critical for scaling up PEM electrolyzers to multi GW scale.
4. Although batteries CRMs have not been analyzed in detail, a supply demand gap for Lithium, Cobalt, Nickel and Graphite (in the coming decade) is expected, driven by a steep increase of Electric Vehicles (EV) and batteries for (renewable) energy storage.
5. For the chemical industry the above-mentioned results offer both risks and a huge opportunities for providing sustainable solutions to mine, reduce the use of and substitute CRMs for power generation and storage.

EXAMPLES OF INNOVATION OPPORTUNITIES
THE CHEMICAL INDUSTRY SUPPORTING CRM SECURITY

- Perovskite can reduce dependance on silicon for solar PV.
- Magnesium (as well as many other elements) can be extracted from seawater and brines by means of electrolysis, a process that requires the passing of a current through a molten salt. Extracting high-quality magnesium sulphate from seawater desalination brine (phys.org)
- Mining lithium from geothermal brine in the Rhine valley: Zero Carbon Lithium™ - Vulcan Energy Resources (v-er.eu) in collaboration with Nobian: Nobian and Vulcan sign agreement for unique lithium project to supply European EV-battery production
- Canadian based company Solumet (founded by a Dutchman) is looking for opportunities to expand their steel waste recycling business in the EU with battery recycling: Solumet – Material recycling innovation

EU Green Deal: rapidly increasing awareness of the vulnerable position wrt CRM resulting in increased budgets for innovation that improves resilience.

ANNEX 1
SILICON

1. Despite the considerably high demand of silicon for PV, the role of silicon is less critical in terms of supply and demand than other CRMs.
2. Reserves of high purity quartz (used to produce silicon) are not known but they are acknowledged to be large enough to meet the worldwide consumption needs for the next decades.
3. In 2019, China's capacity to produce silicon was 6.5 Mt/year. This is already 3 times more than the amount of cumulative silicon required by 2050 for the energy transition in Europe under the SDS scenario. Currently China provides 66% of the total silicon demand for all sectors and will continue to dominate the market. However, note that global silicon production is less than production capacity. In the last years Europe produced 158 kt(Silicon)/year (European Commission B, 2020).
4. Europe is and will be completely reliable on China for Silicon imports. Therefore, new designs for PV and an increase of recycling capacity is required to reduce such dependency.

ANNEX 2

ANNEX 2.1. CRITICAL RAW MATERIAL INTENSITY PV

Material	PV			
	Technology type			
	c-SI *(t/GW)*	CdTe *(t/GW)*	CIGS *(t/GW)*	a-SI *(t/GW)*
Gallium	-	-	4	-
Germanium	-	-	-	48
Indium	-	-	15	-
Silicon Metal	4000	-	-	150

c-SI = Wafer-based crystalline silicon, either single-crystalline or multi-crystalline silicon; CdTE = Cadmium telluride; CIGS = Copper indium gallium diselenide; a-SI = Amorphous silicon

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

Reference: Materials reference: Carrara, S., Alves Dias, P., Plazzotta, B., & Pavel, C. (2020). Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system. doi, 10, 160859.

ANNEX 2

ANNEX 2.2. CRITICAL RAW MATERIAL INTENSITY CSP

Material	CSP	
	Technology type	
	Trough *(t/GW)*	Tower *(t/GW)*
Magnesium	3000	2600
Niobium	-	140
Titanium	25	-
Vanadium	1.9	1.7

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

Reference: Materials reference: Pihl, E., Kushnir, D., Sandén, B., & Johnsson, F. (2012). Material constraints for concentrating solar thermal power. Energy, 44(1), 944-954.

ANNEX 2

ANNEX 2.3. CRITICAL RAW MATERIAL INTENSITY WIND

Material	Wind			
	Technology type			
	DD-EESG *(t/GW)*	DD-PMSG *(t/GW)*	GB-PMSG *(t/GW)*	GB-DFIG*(t/GW)*
Borate	-	6	1	-
Dysprosium (HREE)	6	17	6	2
Neodymium (LREE)	28	180	51	12
Praseodymium (LREE)	9	35	4	-
Terbium (HREE)	1	7	1	-

DD-EESG = Direct Drive-Electrically Excited Synchronous Generator; DD-PMSG =Direct Drive-Permanent Magnet Synchronous Generator; GB-PMSG = GearBox-Permanent Magnet Synchronous Generator; GB-DFIG = GearBox-Double-Fed Induction Generator

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

Reference: Materials reference: Carrara, S., Alves Dias, P., Plazzotta, B., & Pavel, C. (2020). Raw materials demand for wind and solar PV technologies in the transition towards a decarbonised energy system. doi, 10, 160859.

ANNEX 2

ANNEX 2.4. CRITICAL RAW MATERIAL INTENSITY HYDROPOWER

Material	Hydropower
	Technology type
	Hydro *(t/GW)*
Magnesium	1.92
Titanium	0.24

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

Reference: Materials references: Moss, R. L., Tzimas, E., Willis, P., Arendorf, J., Thompson, P., Chapman, A., ... & Ostertag, K. (2013). Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector. Assessing rare metals as supply-chain bottlenecks in low-carbon energy technologies.

ANNEX 2

ANNEX 2.5. CRITICAL RAW MATERIAL INTENSITY GEOTHERMAL

Material	Geothermal
	Technology type
	Geo *(t/GW)*
Niobium	128
Tantalum	64
Titanium	1.6

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

Reference: Materials references: Moss, R. L., Tzimas, E., Willis, P., Arendorf, J., Thompson, P., Chapman, A., … & Ostertag, K. (2013). Critical Metals in the Path towards the Decarbonisation of the EU Energy Sector. Assessing rare metals as supply-chain bottlenecks in low-carbon energy technologies.

ANNEX 2

ANNEX 2.6. CRITICAL RAW MATERIAL INTENSITY NUCLEAR

Material	Nuclear
	Technology type
	AP1000 – only nuclear reactor *(t/GW)*
Hafnium	0.48
Indium	1.6
Tungsten	5
Vanadium	0.6
Yttrium (HREE)	0.5

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

Reference: Joint Research Centre, Institute for Energy and Transport, Willis, P., Kooroshy, J., Tzimas, E., et al., Critical metals in strategic energy technologies : assessing rare metals as supply-chain bottlenecks in low-carbon energy technologies, Publications Office, 2014, https://data.europa.eu/doi/10.2790/35716

ANNEX 2

ANNEX 2.7. CRITICAL RAW MATERIAL INTENSITY HYDROGEN

Material	Hydrogen	
	Technology type	
	PEM-cells only *(t/GW)*	AE-cells only *(t/GW)*
Iridium (PMG)	0.45	-
Platinum (PMG)	0.17	-
Titanium	151.3	-

HREEs = Heavy Rare Earth Elements; LREEs = Light Rare Earth Elements; PGMs = Platinum Group Metals (e.g., Palladium, Iridium, etc.)

Reference: https://www.nrel.gov/docs/fy19osti/72740.pdf, A One-GigaWatt Green-Hydrogen Plant Advanced Design and Total Installed-Capital Costs, TNO

ANNEX 3

CRM DEMAND FOR EUROPE TECHNOLOGIES MIX (2050 COMPARE TO 2020 SDS SCENARIO)

CRM	Demand increase	Main global supplier	Share	Main EU supplier	Share
Borate	413%	Turkey	42%	Turkey	98%
Cobalt	n/a	DR Congo	59%	DR Congo	68%
Dysprosium	413%	China	86%	China	98%
Gallium	305%	China	80%	Germany	35%
Germanium	305%	China	80%	Finland	51%
Hafnium	-9%	France	49%	France	84%
Indium	47%	China	48%	France	28%
Iridium	765%	S. Africa	92%	S. Africa	n/a
Lithium	n/a	Chile	44%	Chile	78%
Magnesium	868%	China	89%	China	93%
Natural graphite	n/a	China	69%	China	47%
Neodymium	413%	China	86%	China	99%
Niobium	98%	Brazil	92%	Brazil	85%
Platinum	765%	S. Africa	71%	S. Africa	n/a
Praseodymium	413%	China	86%	China	99%
Silicon metal	305%	China	66%	Norway	30%
Tantalum	83%	DR Congo	33%	DR Congo	36%
Terbium	413%	China	86%	China	98%
Titanium	9304%	China	45%	China	n/a
Tungsten	-9%	China	69%	China	26%
Vanadium	46%	China	39%	China	n/a
Yttrium	-9%	China	86%	China	98%

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SIGNATURES

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