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ASSESSING THE BUSINESS POTENTIAL, PRICE VOLATILITY AND SUPPLY CHAIN CHALLENGES OF SILICON METAL IN THE EUROPEAN UNION

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ABSTRACT

The European Union (EU) is heavily reliant on raw materials, some of which pose critical supply challenges. The EU's Critical Raw Materials (CRM) policy, initiated in 2011 and recently reinforced by the 2023 Critical Raw Materials Act, seeks to ensure the sustainable supply of crucial raw materials due to scarcity or economic importance. One such sector significantly affected is photovoltaic (PV) energy production, which faces challenges due to the scarcity of materials like silicon metal, crucial for PV cell manufacturing. Despite efforts to mitigate supply risks, challenges persist, including limited recycling and dependency on imports. This study evaluates annual silicon prices and volatility to assess the business potential of silicon metal production in the EU under current import reliance and 2030 targets. Analysing production trends and applications reveals a concentrated supply chain and diverse industrial uses of silicon metal. Price analysis highlights specific events influencing silicon metal prices, emphasizing its criticality to various economic sectors.

1. INTRODUCTION

The sustainability of the European Union (EU) in social, economic and environmental terms depends to a large extent on raw materials. These are necessary for our daily life as well as for modern technologies, but the supply is a matter of concern not only in the EU but globally. Among them, some are particularly important for the EU economy due to the high supply risk. Critical Raw Materials (CRM) are particularly linked to European industry, modern technologies and clean energy production (European Comission, 2023). Since 1977, the EU has been increasingly concerned about the supply of raw materials and the price volatility of some of them (Unión Europea, 1977). 2011 was the start of the EU's CRM policy (Comisión Europea, 2011) which aims to guarantee the sustainable supply of certain raw materials that are particularly important due to their scarcity or economic importance. The Critical Raw Materials Act announced in 2023 is the latest point of this policy (European Commission, 2024).

One of the more affected sectors is photovoltaic (PV) energy, which represents a way of clean energy production (Li et al. 2023), but it requires raw materials, which are in short supply in the EU. The most representative example is silicon metal, which is needed for the manufacture of PV cells and for which up to 60% of the demand is imported in Europe (Grohol & Veeh, 2023; Liu, Phang, & Macdonald, 2022). Although, other CRM such as copper, borates, gallium, germanium and indium are used in this sector.

Despite the dependence of third countries on silicon metal, it was not until the third list in 2017 that it was considered CRM (Comisión Europea, 2017). At that time, the dependence on silicon metal was 64% (imports concerning non-EU countries). In addition, the substitution rate was 0.99 out of 1, indicating that there was no substitute for the technological applications, and the recycling rate was zero (Comisión Europea, 2017). Despite EU efforts to improve this situation in recent years, the current state remains difficult for silicon metal (Table 1). The recycling rate has not improved, dependence has fallen to 60%, and there are no realistic substitutes (0.97 out of 1) (Grohol & Veeh, 2023). It should be highlighted that only the processing stage is assessed for the silicon metal and not the extraction.

To improve this situation, there are three possibilities: improving silicon metal production in Europe, increasing

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TABLE 1: Mains indicator of the silicon metal.

Indicator	2017	2023
Substitution index (SI)	0.99	0.97
Recycling rate	0.00 %	0.00 %
EU import reliance	64.00 %	60.00 %

recycling or finding substitutes for this raw material (Rizzo et al., 2020). These practices could contribute positively to increasing the value of European industry and limiting the effect of silicon price volatility.

The aim of this article is to analyse the situation of Si metal in relation to the CRM policy being developed by the EU and to study the evolution of Si metal supply and recycling in order to understand the effectiveness of this policy. Furthermore, the research focuses on the price volatility of Si metal. CRMs suffer from high price volatility due to various factors. However, this aspect has not been extensively studied and analyses and policies often focus on the economic importance of CRMs or their supply, ignoring the uncertainty due to constantly changing prices. The aim of this article is to study the changes in the price of this metal in order to have more information on this important aspect. This short study assess the business potential of silicon metal production in the EU under the current import reliance and the 2030 targets (European Comission, 2023).

2. SILICON METAL PRODUCTION AND APPLICATIONS IN EUROPE

The silicon metal in the EU comes mainly from third countries, although the dependency has been partially reduced since 2017. At this time, Brazil and China were two of the main suppliers, with 12% each.But, currently, this supply has been reduced to 9% and 2%, respectively (Comisión Europea, 2017; Grohol & Veeh, 2023). The main suppliers to the EU are shown in Table 2.

It is possible to observe that only the consumption from France and Germany has increased, which indicates a diversification to other countries, such as Bosnia and Herzegovina, Russia, Australia, Iceland, South Africa, Kazakhstan or Malaysia (Grohol & Veeh, 2023). It should be considered as a positive practice that allows to minimize the risk derived from singular factors from specific countries.

The silicon metal production globally is around 3,1 Mt, and just in the EU is around 400 kt (BRGM, 2019; CRM Alliance, 2022). It is concentrated in a few companies: Elkem, Wacker and Finnfjord AS in Norway, Ferroglobe in Spain and France and RW Silicium in Germany (AMG Silicon, 2023; Elkem, 2024; Ferroglobe, 2022; Finnfjord, 2022; Kristiansen & Van der Eijk, 2020; Wacker, 2017). The main applications of the silicon metal are:

- Chemicals production: such as silicone rubber, foam, sealants, adhesives, lubricants, additives, coatings… (Ferroglobe, 2024).
- Aluminium alloys: Silicon is used in aluminium alloys to improve their strength for structural purposes (Belmont, 2022; Ferroglobe, 2024).

TABLE 2: Si metal supply (only countries with a share > 5 % are shown).

Country	2017	2023	Change
Norway	23 %	33 %	+10 %
France	19 %	28 %	+9 %
Brazil	12 %	9 %	-3 %
Germany	5 %	6 %	+1 %
Spain	9 %	4 %	-5 %
China	12 %	2 %	-10 %
Non-EU members	64 %	60 %	-4 %

- Photovoltaics: It is used in PV cell wafer production (Ferroglobe, 2024).
- Electronic components. Mainly in microchips due to their semi-conductivity properties (Belmont, 2022; Ferroglobe, 2024).

Globally and in terms of material consumption, chemical production and aluminium alloys are the most important (25% and 32% respectively). This means that the silicon metal market is related to the aluminium alloy one. Periods with a high urbanistic or mobility development are characterised by an increase in aluminium alloy prices and, therefore, by an increase in silicon metal prices. Energy prices can also deeply affect the silicon metal since aluminium and silicon are electro-intensive industries.

The PV industry accounts for less than 7% of silicon consumption, and electronics for around 1% (BRGM, 2019). However, their impact on the economy is significant. The PV and electronics sectors have a combined value in the EU of €77,000 million similar to the manufacture of basic metals at almost €65,000 million. Chemical production is the most important one with a value of €132,000 million (Grohol & Veeh, 2023). The PV sector could affect the silicon price in the future due to its dependence on energy prices. Vast PV installations in the EU may transform the energy mix, which could change energy prices, affecting the aluminium alloys sector and silicon metal production.

3. SILICON METAL PRICES AND VOLATILITY

In addition to the supply risk of silicon metal, there is also the issue of its price and, in particular, its fluctuation. Although silicon metal is not the most volatile CRM (Rare Earth Elements are likely), its price is deeply affected by specific issues in specific countries and sometimes as a result of national policies of third countries or internal decisions of some companies, which can be not aligned with the EU interests. Figure 1 shows the price evolution in comparison with gold from 1991 to 2022 based on the annual reports of the United States Geological Survey (USGS, 2024) (Metallurgical-grade silicon metal is considered in this study).

The most important conclusion to be drawn from the figure is the variability of the silicon metal price since 2008. If the gold price is taken as the economic benchmark, the greatest stability would be achieved with a symmetric

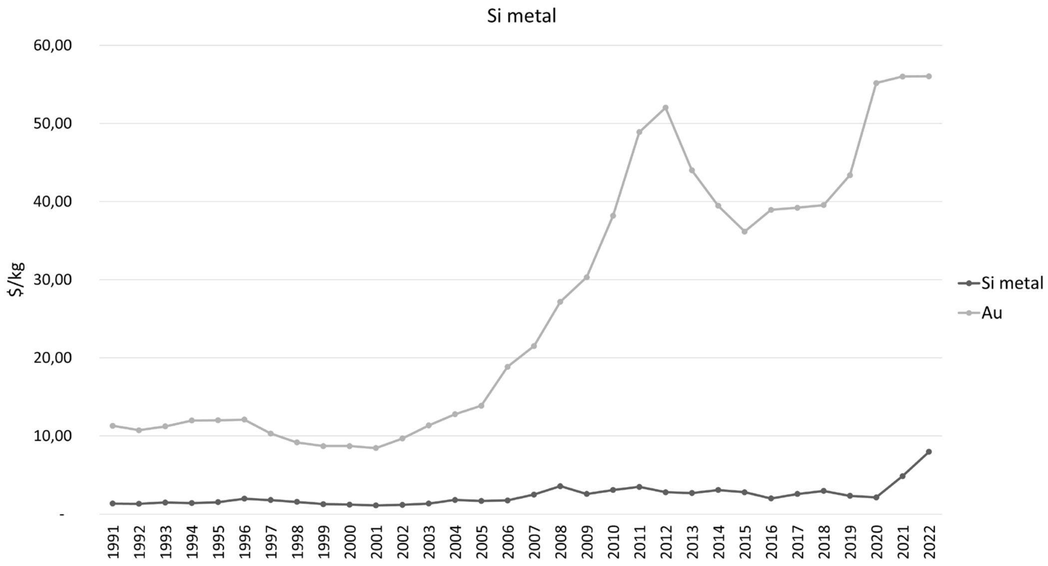

FIGURE 1: Silicon metal prices.

graph. It can be seen that around 2005, the gold price started a steady rise until 2012 and then another stage of price increase in 2020. There are two main reasons for the increase in the gold price:

- Economic recessions: When the global economy is in recession, investors prefer safe options like gold to financial markets. This was the situation in 2007-2008 with the global economic crisis and in 2019-2020 with the COVID-19 crisis.
- Devaluation of the US dollar and high oil prices: The devaluation of the US dollar and the high price of oil also contribute to the rise in the price of gold, as large companies use gold to offset the fluctuations in the US dollar. Additionally, since 2001, gold mine production was decreasing until 2007, which increased the gold price.

In the 1990s, prices for silicon metal were considered to be heavily dependent on energy costs, accounting for up to 20% of the final price in addition to the ore. In 1996, the peak coincided with the maximum of steel production, which indicates a period of strong demand related to the industrialisation of China, Brazil and India (Comisión Europea, 2011; USGS, 2013).

The silicon metal prices were stable until 2004, when PV energy started its development. The trend seemed to be upwards, but in 2005 and 2006, the price declined. This is because the demand forecasts of the PV sector were met by the processing of the domestic reserves of the wafer producers and the Chinese government's permissiveness for the export of silicon metal in order to promote PV energy (PHOTON International, 2004). However, in 2007, China increased tariffs on silicon metal exports, which affected global prices until 2009, when the global economic crisis deeply reduced the consumption of aluminium (USGS, 2013). However the aluminium marketrebounded since 2010, when the economy started to recover. This recovery was supported by the integration of silicon producers by primary consumers (USGS, 2013).

In 2011, there was a change in EU policy that stopped supporting the development of PV, which led to a decrease in polysilicon supply in 2012 (Wang, Z. & Wei, 2017). This was countered by an increase in exports from China, which allowed for an increase in production in countries such as China, Russia, Malaysia, Sweden and Uzbekistan, which led to a slight decrease in the price until 2013 (USGS, 2012; USGS, 2013). The situation remained stable until a decrease in 2016 related to a weak global aluminium alloy demand coupled with an oversupply of silicon metal (USGS, 2017).

In 2018, there was a small spike that could be due to market dominance by Ferroglobe, which would have acted as a virtual monopoly by positioning the price of silicon metal as a way to put up trade barriers to certain countries (US International Trade Commission, 2020).

The huge price increase since 2021 has been driven by two determining factors. Firstly, due to the Chinese government's carbon reduction policy. Many coal-fired silicon metal plants were forced to stop production. This was compounded by rising energy prices in Europe, particularly affecting production in Norway (Sadhna Gupta, 2023).

In addition to annual price variability, silicon price volatility within the same year must be considered. The reports of the German Geological Survey (BGR, 2023) show how in the last 10 years it has been relatively stable with variations of 10% except for the last three years: 17.9% in 2020, 107% in 2021 and 24.5% in 2022. These are the years when the price rises sharply, so it is possible to correlate volatility with rising silicon metal prices.

4. BUSINESS POTENTIAL

The EU's 2030 targets for CRM imply the processing of at least 40% of CRM in Europe and a recycling rate of 15%. With regard to silicon, processing in Europe is currently already at 40%, with a 4% increase in the period 2017-2023 (Grohol & Veeh, 2023; Comisión Europea, 2017), so it is not ambitious to think that it is possible to improve by another 4% by 2030. Although, these goals are for all CRM as a whole, considering a current demand of 6 million tonnes (Mt) and a projected demand of 10.7 Mt in 2030 (European Commission, 2023), silicon processing and recycling in Europe both current and desirable in 2030 are illustrated in Figure 2.

With these targets, in terms of production, the EU would produce more than twice as much as it is currently producing. However, the recycling rate is optimistic as there are currently no industrial processes and only research (Moen, et. al., 2017).

Based on the price analysis carried out, a realistic price for silicon metal can be set as an average of the values between 2007 and 2020, which remained between 9000 and 14000 $/kg. This is 12500 $/kg (11576 €/kg) with a positive variability of 30% and a negative fluctuation of 27%. In addition to the 2022 value of 36186 $/kg (33506 €/kg). The business potential of silicon processing and recycling is shown in Table 3.

However, it is necessary to consider that these are gross amounts without considering production costs and therefore these values are not profit. It has already been seen that the energy cost alone account forat least 20% and is probably higher today. The other costs would also be relevant (but they have not been assessed by the Commission).

Another important issue is the recycling rate. Today, there are several recycling processes under research (Deng, et. al., 2022; Moen et al., 2017; Riech et al., 2021; Wang, et.al., 2022). However, it does not seem realistic to think that by 2030 the processes under research will have reached industrial scale and will be able to achieve the 15% recycling rate.

In any case, an increase of 19 billion euros (minimum realistic scenario) or even 26 billion euros (AVG realistic scenario) is an important economic volume to be considered. Even if it is not the final profit, this economic volume opens up a business opportunity that would remain in the EU instead of in other third countries where the industry may not be environmentally or socially sustainable.

TABLE 3: Business potential of silicon metal processing and recycling in 2030.

Stage	Realistic scenario in 2030 (M€)			2022 value
	AVG	MAX	MIN	
Processing	54,501	70,620	39,669	157,744
Recycling	18,580	24,075	13,524	53,776
Processing (increase)	26,292	34,068	19,137	76,098
Recycling (increase)	18,580	24,075	13,523	53,776

5. CONCLUSIONS

Several interesting conclusions at different levels can be drawn from this research.

The EU relies heavily on CRM to sustain its economy and technology. The EU's CRM policy, launched in 2011 and updated in 2023, aims to ensure the sustainable supply of essential raw materials. In the case of silicon metal, dependency has been improved, but recycling is an ongoing challenge that needs to be addressed. Diversification has been observed in the countries supplying silicon metal to the EU, suggesting a risk mitigation strategy. Silicon metal is essential for PV energy production, but is in short supply in the EU, posing a risk to energy and economic security.

One of the issues with silicon metal is its price volatility, which is not as high as other CRM (REE). Despite this, some important price changes are observed occasionally motivated by specific factors such as Chinese domestic policies, business decisions or energy crises.

The improvement of the silicon metal processing situation in the EU under the targets set for 2030 could bring an enormous business potential with an estimated increase of 19 billion euros (B€) in the most favorable scenario for transformation and 13.5 B€ in the case of recycling.

However, further analysis of silicon metal prices and volatility is needed to try to anticipate price behaviour and minimise investment risks in order to develop a stronger EU industry to reduce imports, and mitigate price fluctuations.

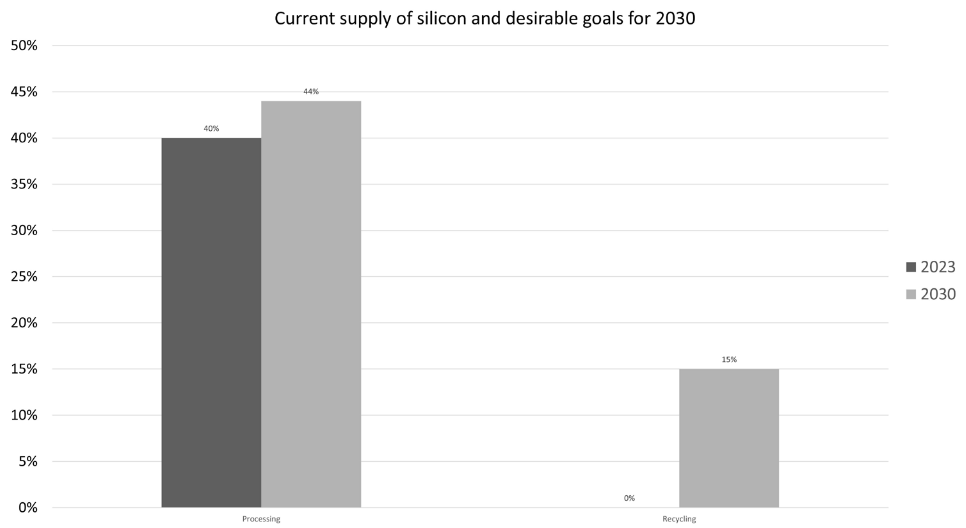

FIGURE 2: Current supply of silicon and desirable goals for 2030.

It is necessary to study the different silicon metal products and to understand their intra-year volatility (rather than considering solely annual average values). Furthermore, this price analysis has been carried out on the American price basis, so there is a need to analyse the differences with the European market. Finally, a study of silicon metal processing costs is required to understand the potential direct economic benefits of increasing silicon metal production in the EU.

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