Achieving European Union strategic autonomy: circularity in critical raw materials value chains

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The past decade has been increasingly characterized by global rivalry over key technologies for the green and digital transitions, many of which rely upon access to critical raw materials (CRMs). For the European Union, these developments triggered a shift towards an increasingly realist and traditional security-orientated international outlook, which relies on a geopoliticization of the threat stemming from import dependencies.[1] This securitization dynamic has led to the coining of the Open Strategic Autonomy (OSA) concept, which continues the EU's traditional orientation towards free trade while placing emphasis on the necessity to 'act autonomously—that is, without being dependent on other countries—in strategically important policy areas'[2] such as industry, trade, energy or finance.[3] It has also translated into a renewed emphasis on the importance of creating 'secure' and 'resilient' strategic value chains (SVCs), that is, those global value chains (GVCs) which produce critical goods for the EU, especially if they involve imported raw materials.[4] Several of the most recent EU policies frame

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1 Tatiana Romanova, 'A choice between neoliberal engagement and strategic autonomy? The impossibility of EU's green cooperation with Russia between 2019 and 2021', *Energy Policy*, vol. 172, 2023, https://doi.org/10.1016/j.enpol.2022.113329. Geopoliticization is understood here as the framing of an issue or policy as a geopolitical matter: see David Cadier, 'The geopoliticization of the EU's Eastern Partnership', *Geopolitics* 24: 1, 2019, pp. 71–99 at p. 74, https://doi.org/10.1080/14650045.2018.1477754.

2 Mario Damen, *EU strategic autonomy 2013–2023: from concept to capacity* (Brussels: European Parliamentary Research Service, 2022), https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/733589/EPRS_BRI(2022)733589_EN.pdf, p. 1. (Unless otherwise noted at point of citation, all URLs cited in this article were accessible on 3 May 2024.)

3 Joan Miró, 'Responding to the global disorder: the EU's quest for open strategic autonomy', *Global Society* 37: 3, 2023, pp. 315–35, https://doi.org/10.1080/13600826.2022.2110042; Niklas Helwig and Ville Sinkkonen, 'Strategic autonomy and the EU as a global actor: the evolution, debate and theory of the contested term', *European Foreign Affairs Review*, vol. 27, 2022, pp. 1–20, https://doi.org/10.54648/eerr2022009.

4 European Commission, *Europe's moment: repair and prepare for the next generation*, COM/2020/456 final (Brussels: European Commission, 2020), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0456, pp. 12–13.

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threats to the bloc's autonomy as emerging from import dependencies on the so-called 'sensitive ecosystems',[5] or 'highly concentrated' suppliers which are often 'exposed to significant environmental, social and governance risks'.[6] The EU's CRM Act, which entered into force in May 2024, is the key policy document in this context. The Act sets detailed benchmarks to boost the reshoring and diversification of SVCs by 2030. In terms of diversification, it requires that no single third country accounts for more than 65 per cent of EU imports of any strategic raw material. In terms of reshoring, it postulates to increase intra-EU extraction to 10 per cent, processing to 40 per cent and recycling to 25 per cent of the bloc's annual consumption of strategic raw materials.[7] By boosting the recycling targets even higher than the original version of the CRM Act, this piece of legislation aligns the concern for strategic autonomy with the European Green Deal priority of decarbonization,[8] echoing other EU policies of recent years.[9]

In this policy paper, we focus on the titanium metal SVC as a timely case-study which can contribute new insights into the feasibility of such OSA and decarbonization ambitions. We do so by providing first-time analysis of the EU's dependencies in the titanium metal value chain and formulating policy recommendations regarding the potential of circular solutions to mitigate them, including critical reflections on challenges and constraints to our proposed policy options. Titanium metal is important, because it is classed as a CRM and because of its key relevance to the EU's strategic aerospace and defence applications.[10] We focus solely on aerospace applications, firstly because these comprise a vast majority of the titanium metal applications and secondly because this sector is crucial in terms of both economic importance and national security.[11] In addition, the

[5] European Commission, *Updating the 2020 New Industrial Strategy: building a stronger Single Market for Europe's recovery*, COM(2021) 350 final (Brussels: European Commission, 2021), https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52021DC0350.

[6] European Commission, *Commission Staff working document: impact assessment report. Accompanying the document 'Proposal for a regulation of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) 168/2013, (EU) 2018/858, 2018/1724 and (EU) 2019/1020'*, SWD(2023) 161 final (Brussels: European Commission, 2023), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52023SC0161, p. 11.

[7] *Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending regulations (EU) No 168/2013, (EU) 2018/858 and (EU) 2019/1020* (known as the Critical Raw Materials Act or CRM Act) (Brussels: Official Journal of the European Union), 3 May 2024, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1252&qid=1716542362110. It is worth noting that this final version of the law increased the recycling rate from the 15% proposed by the European Commission in the proposal of March 2023.

[8] European Commission, *The European Green Deal*, COM(2019) 640 final (Brussels: European Commission, 2019), https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0002.02/DOC_1&format=PDF.

[9] Apart from the CRM Act, these include European Commission, *A new Circular Economy Action Plan for a cleaner and more competitive Europe*, COM(2020) 98 final (Brussels: European Commission, 2020); and European Commission, *A Green Deal industrial plan for the net-zero age*, COM(2023) 62 final (Brussels: European Commission, 2023), which explicitly links the climate-change mitigation target to the CRM value chains and circularity, among other things.

[10] *Regulation (EU) 2024/1252* (CRM Act), annexes 1 and 2.

[11] 67% of all titanium metal imported into Europe is used in the aerospace sector, and 2% in defence: Konstantinos Georgitzikis, Eleonora D'Elia and Umberto Eynard, *Titanium metal: impact assessment for supply security* (Luxembourg: European Union Joint Research Centre, 2022), p. 4. The global market value of the aerospace sector is estimated to increase to $3.1 trillion by 2028 (2010 estimates): Stephan Wittig, 'The Airbus–Boeing dispute: implications of the WTO Boeing decision', *Intereconomics* 45: 5, 2010, pp. 262–3, https://doi.

titanium metal GVC is under-researched, especially in terms of its scrap circulation pattern.[12] In comparison, other CRMs—such as cobalt, lithium and graphite (widely used in batteries)—have received more scholarly attention.[13] The sources of aerospace-grade titanium metal imports are scarce[14] in contrast to other raw materials important for aerospace, such as nickel, for which the sources of imports can be more easily diversified.[15] Moreover, the focus on the titanium metal GVC is timely, as it has been particularly affected by the recent COVID–19 pandemic and Russia's invasion of Ukraine.[16] The former caused big losses across the aviation industry,[17] and led to the final dismantling of the ore-to-sponge processing part of the chain in the United States.[18] The latter exposed the strategic dependency on Russian-supplied imports of titanium products, which account for half of European aviation companies' imports of aeronautical-grade titanium.[19]

However, our detailed analysis of the value chain suggests that an even more persistent challenge to the EU's OSA strategy in relation to this particular SVC lies in its dependency on the US part of the value chain. Our findings indicate that the EU aviation industry's vulnerability primarily stems from the virtual lack of midstream industrial capabilities in the EU. Such capabilities are essential to operationalize the recycling of titanium metal, a key instrument postulated by the CRM Act. Instead, the EU relies heavily on the recycling capabilities of the relevant US industry, which goes against both the OSA priorities and the CRM Act's recommended recycling targets. Thus, this policy paper presents important empirical evidence advancing the global decoupling/de-risking debate,[20] by problematizing the tendency towards a 'friendshoring' (moving supply chains to politically aligned states) of SVCs.[21]

This policy paper incorporates new primary data, both qualitative and quantitative, to analyse the current position of the EU in the titanium GVC, and in particular, its dependency on supplies from Russia and the US. In terms of qualita-

org/10.1007/s10272-010-0345-4.

[12] Osamu Takeda and Toru H. Okabe, 'Current status of titanium recycling and related technologies', *Journal of The Minerals, Metals & Materials Society* 71: 6, 2019, pp. 1981–90, https://doi.org/10.1007/s11837-018-3278-1.

[13] Cristina Torres De Matos et al., *Material system analysis of five battery-related raw materials: cobalt, lithium, manganese, natural graphite, nickel* (Luxembourg: Publications Office of the European Union, 2020), https://doi.org/10.2760/519827.

[14] Georgitzikis et al., *Titanium metal*.

[15] European Commission 'Raw material information system (RMIS)—Nickel', https://rmis.jrc.ec.europa.eu/rmp/Nickel.

[16] The slump in the industry is illustrated well in the halved trade in the titanium GVC, as illustrated in figures 2 and 3 in this policy paper.

[17] Pierre-François Louvigné, *Rapport final: étude de veille sur le marché du titane 2018–2020* (Paris: Ministry of Ecological Transition and Solidarity, 2021), https://www.mineralinfo.fr/sites/default/files/documents/2021-10/louvigne_titane_rapport_2018-2020_edition_publique.pdf, p. 24.

[18] Jonathan Ng, 'Henderson TIMET plant workers seeking federal help to prevent closure', *Las Vegas Review-Journal*, 4 Aug. 2020, https://www.reviewjournal.com/local/henderson/henderson-timet-plant-workers-seeking-federal-help-to-prevent-closure-2087819.

[19] Tanmay Kadam, 'Critically dependent on Russia & China, US-led West look to secure "rare" metal in Ukraine vital for fighter jets, airplanes', *EurAsian Times*, 30 Jan. 2023, https://eurasiantimes.com/russia-china-us-led-west-look-to-secure-rare-titanium.

[20] See for instance Tobias Gehrke, 'EU open strategic autonomy and the trappings of geoeconomics', *European Foreign Affairs Review*, vol. 27, 2022, pp. 61–78 at p. 65, https://doi.org/10.54648/eerr2022012.

[21] Günther Maihold, 'A new geopolitics of supply chains: the rise of friend-shoring', *SWP Comment*, no. 45, 2022, https://www.swp-berlin.org/publications/products/comments/2022C45_Geopolitics_Supply_Chains.pdf.

tive data collection, we conducted in-depth analysis of primary materials in several languages (including policies, industrial strategies and relevant companies' portfolios and data), and extensive field research consisting of semi-structured, in-depth interviews with key actors in the titanium industry across several countries. We conducted a total of 25 interviews with stakeholders based in the EU, the US, the United Kingdom, Ukraine, Russia and Kazakhstan, and across the entire value chain. More precisely, we consulted two international industry associations, two titanium research institutes, three independent industry experts, two industry experts advising governments (public servants), two Tier-3 (ore extraction and raw materials trading) companies, three Tier-2 (sponge-to-metal manufacturing) companies, four Tier-1 (product fabrication) and original equipment manufacturers (OEM) (i.e. aviation) companies and four end-of-life and recycling companies. The data retrieved from the interviews allowed us to pinpoint the exact actors and locations of different parts of the value chain in order to understand where the main dependencies lie. We complement these analyses with trade data retrieved from Eurostat, which allowed us to visualize and map the precise quantities of titanium metal at different parts of the value chain for the years 2019, 2021 and 2022 (we omitted the year 2020 due to the effects of the COVID–19 pandemic). This research is innovative both methodologically and empirically, as there are no previous studies on the geopolitics of titanium value chains, nor on the role of circularity in mitigating EU import dependencies for this raw material.

Between Russia and the US: the EU's position in the titanium value chain

Although titanium ore is abundant globally, aeronautical-grade titanium metal requires the best quality ilmenite and rutile deposits for its production. These are relatively sparse.[22] Moreover, in order to process titanium ore into titanium metal, the ore needs to undergo costly and energy-heavy chemical processing, known as the Kroll process, which requires a complex industrial base that few countries possess.[23] These are the main reasons why less than 10 per cent of titanium ore ends up as titanium metal, and also why titanium metal is considered a CRM while titanium ore is not.[24] As of 2022, titanium deposits were mainly being exploited in China (with an estimated 36% of total mine production of ilmenite and rutile), Mozambique (13%), South Africa (10.5%) and Australia (9%).[25] However, not all of these countries possess good quality ore, nor do they have the necessary industrial base to process titanium ore into sponge, the primary material from which titanium ingots are then produced (see figure 1). As of 2022 only China (with 58% of global sponge

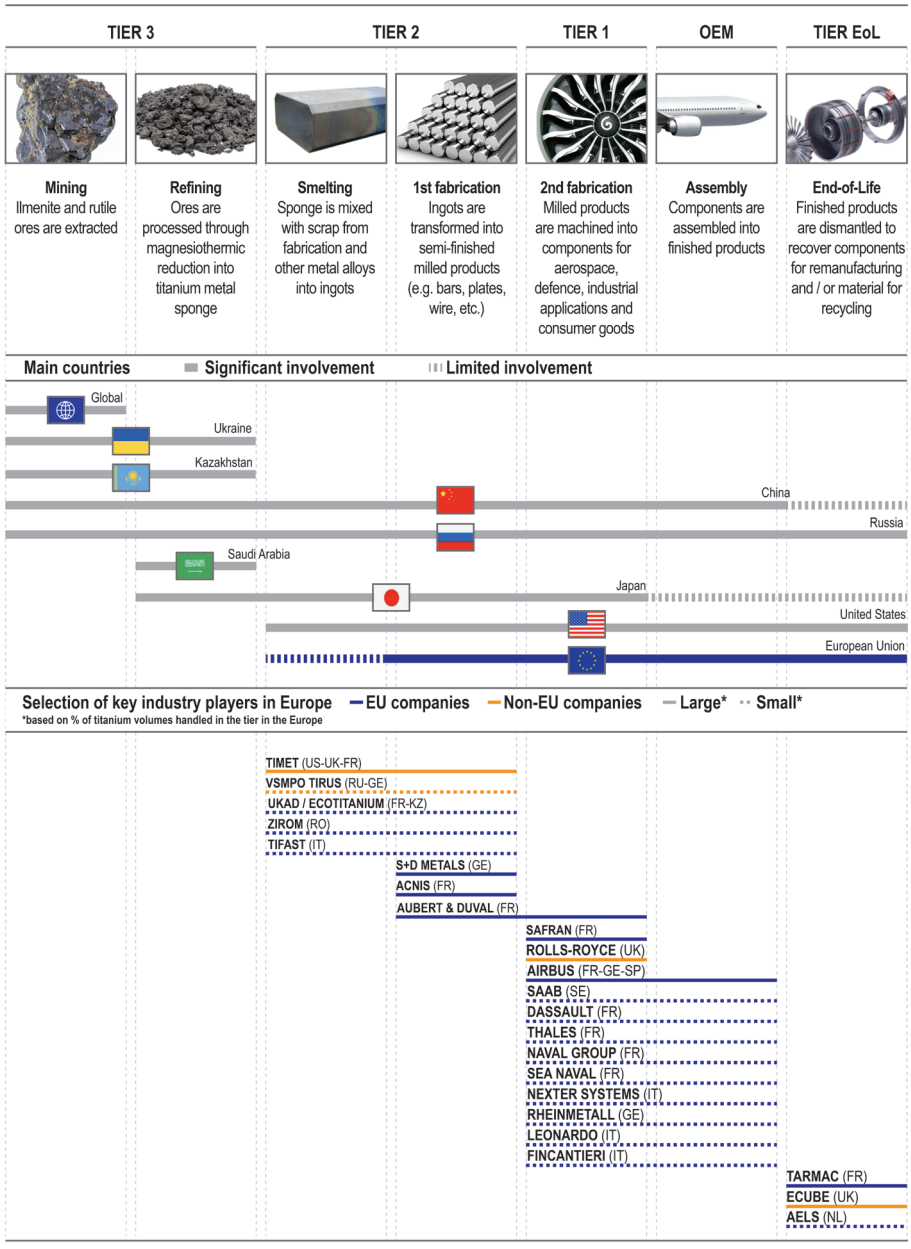
[22] The aeronautical-grade titanium alloys are classed as grade 5, or 90% titanium content.

[23] In the Kroll process, titanium ore is transformed into sponge via chlorination and then reduction with magnesium. This process requires special vacuum furnaces and adjacent electrolyser and magnesium chloride recovery plants. It also creates a large amount of toxicity, requiring appropriate wastewater treatment: Interview no. 19, 12 Jan. 2023, R&D management, Tier-2 (sponge/scrap-to-ingot) company 3, US.

[24] Louvigné, *Rapport final*, p. 97; Cynthia E. L. Latunussa et al., *Study on the EU's list of critical raw materials* (Luxembourg: Publications Office of the European Union, 2020), https://doi.org/10.2873/92480.

[25] United States Geological Survey, 'Titanium mineral concentrates' in *Mineral commodity summaries 2023* (St Louis, MO: US Government Publishing Office, 2023), https://pubs.usgs.gov/periodicals/mcs2023/mcs2023.pdf, p. 187.

Figure 1: The supply chain for titanium metal used in commercial aviation and defence by country (global value chain) and industry players (the EU part of the value chain).



Source: Interviews. Elaboration on a similar figure from EFESO consulting, *Aerospace and defence: industry outlook*, 2022, https://www.efeso.com/files/63/Point-of-view/55/, p. 3.

output in 2021), Japan (19%), Russia (10%), Kazakhstan (6%), Ukraine, Saudi Arabia and India process ore to sponge.[26] As of 2023, out of all sponge producers, only Japan, Russia and Kazakhstan were producingaeronautical-grade titanium sponge for export.[27] Despite being the largest global producer of titanium sponge, China produces lower-grade titanium metal, which it largely keeps within its domestic market, and it remains a net importer, particularly of high-quality sponge.[28]

Due to the 85 per cent concentration of the global aviation market in the hands of Airbus (EU) and Boeing (US),[29] US- and EU-based companies constitute the two largest consumer groups for aeronautical-grade titanium metal.[30] Neither the EU nor the US has Tier-3 facilities to process ore into sponge, so they are both entirely dependent on imports of titanium sponge. The US, however, has a complete industrial base for the rest of the production cycle, and currently uses almost exclusively Japan-imported sponge.[31] Japanese companies have managed to maintain the sponge-production industry, as they are able to leverage nuclear energy to operate at large scale, multiplying the tight profit margins per tonne.[32] US companies assumed a dominant position in the mid-value part of the value chain (Tier 2), that is, the sponge-to-ingot and ingot-to-wrought-titanium (milled products and parts) manufacturing processes. They have achieved this position by mixing roughly 50 per cent imported sponge with 50 per cent scrap into new ingots, making the production of ingots much less energy-heavy than if relying only on sponge as an input material and giving rise to industrial practices which are both substantially cheaper and less polluting.[33] Due to a smaller and less technically advanced industrial base for ingot manufacturing, the EU is dependent on imports of both ingots and wrought titanium from other countries.

In terms of imports of aeronautical-grade titanium metal ingots and fabricated parts, the EU relies mostly on two sources: the US and Russia (see figure 2). Data for 2019 show that the EU imported nearly 55,000 tonnes of all-grades titanium metal (34% of global production in that year), at a total value of more than €1.7 billion, the majority of which comprised wrought titanium products. The main sources of imports in 2019 (in terms of volume) were the US (25%), Russia (18%), UK (16%),[34] China (11%), Japan (11%) and Kazakhstan (7%). In value

[26] US Geological Survey, *Titanium and titanium dioxide*, 2023, https://pubs.usgs.gov/periodicals/mcs2023/mcs2023-titanium.pdf, p. 2.

[27] Since 2022, Ukraine has been producing only small amounts of sponge: US Geological Survey, *Titanium and titanium dioxide*, p. 2. As of 2023, Saudi Arabia was still developing its capacities to produce high-quality sponge: Bandar al-Mosalam, 'Saudi Arabia signs agreement to develop aviation-grade titanium alloy value chains', *Asharq Al-Awsat*, 28 Feb. 2023, https://english.aawsat.com/home/article/4184351/saudi-arabia-signs-agreement-develop-aviation-grade-titanium-alloy-value-chains.

[28] Georgitzikis et al., *Titanium metal*, p. 7.

[29] Louvigné, *Rapport final*, pp. 47–50.

[30] 70–80% of titanium metal is used in civil aeronautics and defence sectors in the US: Louvigné, *Rapport final,* p. 25. For the EU numbers, see footnote 11.

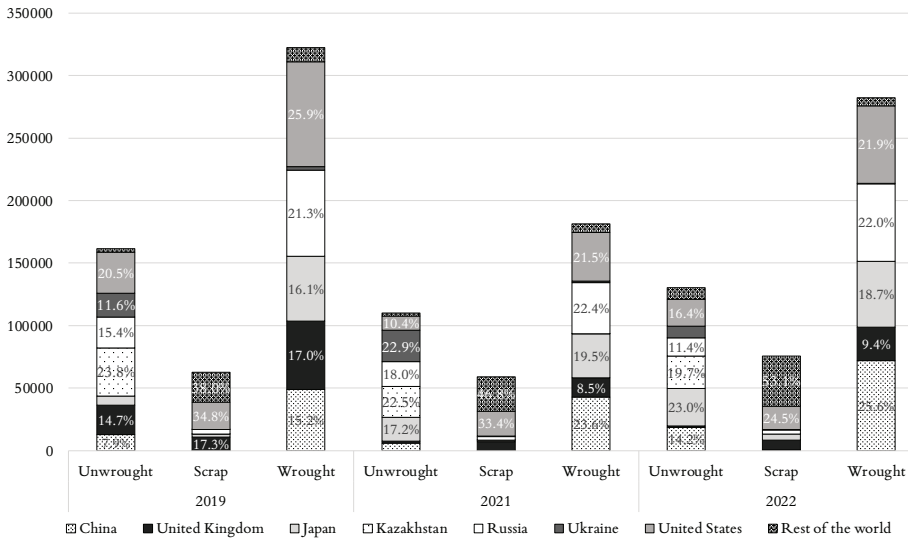
[31] In the years 2018–21, the US imported titanium sponge from: Japan (89%), Kazakhstan (9%) and Ukraine (1%): US Geological Survey, *Titanium and titanium dioxide*, p. 1.

[32] Interview no. 3, 27 Oct. 2022, industrial expert advising French government, EU.

[33] Interview no. 6, 10 Nov. 2022, CEO, Tier-2 (scrap-processing) company 1 and EU and sales representative, Tier-2 (sponge-to-ingot) company 2, EU; and interview no. 11, 9 Dec. 2022, independent expert 1, EU.

[34] It is important to point out that imports from the UK are carried out via a subsidiary of the US company TIMET, so they are indirect imports from the US. Interview no. 19.

Figure 2: Imports of titanium metal to the EU in 2019, 2021 and 2022 by country of imports, distinguishing the amounts of unwrought (sponge, powder and ingots), wrought (semi-finished products and components) and titanium scrap; volumes are in 100kg.



Source: Eurostat data, https://ec.europa.eu/eurostat.

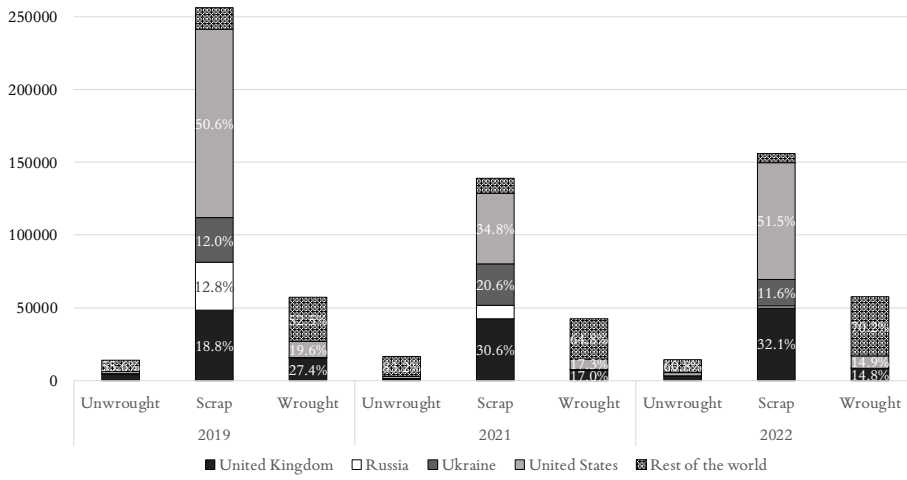
terms, the EU's dependency on imports from the US is much starker: US-supplied imports constitute 39 per cent of all titanium metal imports to the EU.[35] Just one Tier-2 American company, TIMET, supplies 50 per cent of EU imports of semi-finished wrought titanium (in the form of plates, sheets or bars), from which European companies then fabricate parts (see figure 1).[36] Russia also figures highly in EU import statistics; the Russian state-controlled titanium conglomerate, VSMPO-AVISMA, which encompasses the entire titanium value chain, is a major source of EU import dependency, being claimed to supply at least 50 per cent of Airbus's titanium requirements.[37] Due to the splitting of parts of the value chain between Ukraine, Kazakhstan and Russia in the post-Soviet period, AVISMA has relied heavily on imports of Ukrainian high-quality ore, which helped to maintain Ukraine's locked position in the upstream part of the value chain. Since Russia's full-scale invasion of Ukraine in February 2022, US companies (including Boeing and ATI) curtailed their imports of Russian titanium products entirely.[38] EU companies such as Airbus, which had maintained lower titanium stock levels

[35] Eurostat data, https://ec.europa.eu/eurostat.
[36] Interview no. 19.
[37] Kadam, 'Critically dependent on Russia & China'.
[38] Gaurav Joshi, 'Boeing isn't worried about a lack of Russian titanium', *Simple Flying*, 8 March 2022, https://simpleflying.com/boeing-isnt-worried-about-a-lack-of-russian-titanium; ATI, 'ATI announces termination of joint venture with Russian-based VSMPO', 9 March 2022, https://ir.atimaterials.com/news-events/news-details/2022/ATI-Announces-Termination-of-Joint-Venture-with-Russian-Based-VSMPO/default.aspx.

than American companies, were not able to instantly wean themselves away from Russian titanium supplies.[39] As a consequence, titanium was exempted from otherwise sweeping EU sanctions against Russia in 2022, which further demonstrates the strategic importance of titanium metal for European industrial security.

However, the main long-term challenge for the EU, in terms of its ability to achieve OSA and decarbonization by meeting the circularity targets laid down in the CRM Act, stems from its dependency on the US part of the value chain. The reason for this becomes clear when exports of titanium are disaggregated between wrought titanium and scrap (see figure 3 below). According to Eurostat data and information provided by interviewees, over half of the EU's titanium scrap is exported directly to the US, in addition to the scrap exported to the UK and then re-exported to the US through a subsidiary of TIMET.[40] This means that nearly 70 per cent of EU titanium scrap ends up in the US.

Figure 3: Exports of titanium metal (all) from the EU in 2019, 2021 and 2022 by country of imports, distinguishing the amounts of unwrought (sponge, powder and ingots), wrought (semi-finished products and components) and titanium scrap; volumes are in 100kg.



Source: Eurostat data, https://ec.europa.eu/eurostat.

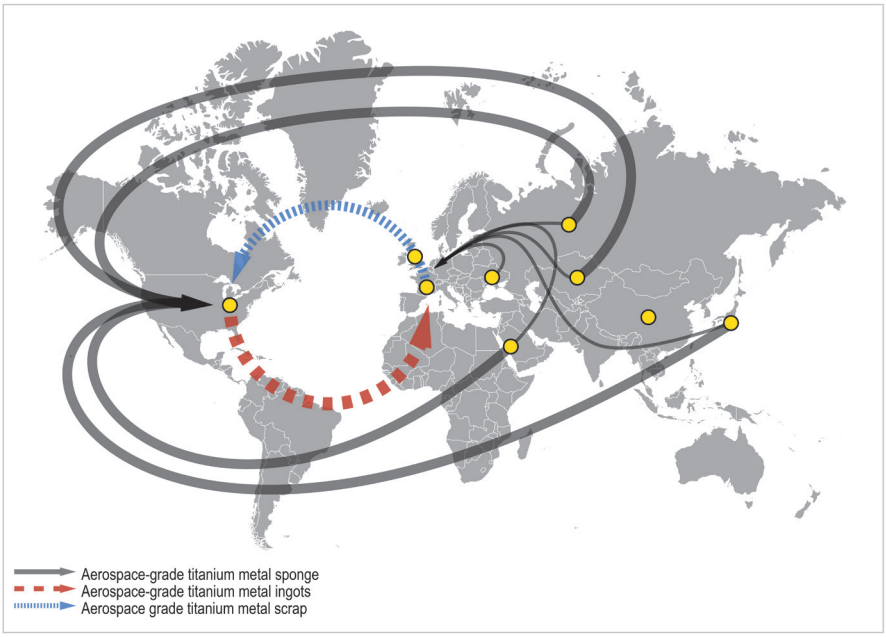
In a way, then, circularity has already been achieved on a large scale, but the loop is transatlantic rather than domestic (see figure 4 below). There are two mutually reinforcing reasons for this. First is the existence of buy-back agreements that oblige UK- and EU-based Tier-1 companies (machining parts) and OEMs (designing and assembling aircraft) to send titanium scrap left over from the fabrication

[39] However, diversification of the source of ingot imports has been taking place ever since: interview no. 22, 17 Jan. 2023, top management, Tier-2/end-of-life company 4, US; interview no. 24, 10 Feb. 2023, four respondents (circularity, commercial executive, defence and space, and critical raw material divisions), Tier-1/OEM company 1, EU.

[40] Interview no. 19.

process (which can constitute up to 90 per cent of the original ingot volume) back to the US.[41] These agreements are attractive, since UK and EU companies are reimbursed for the scrap they send back, which keeps the price of titanium low enough for them to benefit.[42] Second, the structural barrier of the lack of a domestic titanium remelting industry makes such agreements a necessity. Were the buy-back agreements to be removed abruptly in order to keep scrap in Europe, prices would rise unchecked and a major crisis would result in an already shaken industry.[43] This situation locks European companies into an asymmetric relationship with their US counterparts, disincentivizing investments in the establishment of a European titanium recycling industry and, in effect, deepening the problem of European strategic dependency on both Russia and the US. However, it is the dependency on the latter that prevents the EU from pursuing a titanium circularity strategy which would be best aligned with both the European Green Deal's priorities of decarbonization, and with the OSA objectives presented in the CRM Act.

Figure 4: Simplified representation of titanium metal trade patterns, focusing on key material flows of aerospace-grade sponge, ingots and fabrication scrap.



Source: Eurostat data and interviews.

[41] Interview no. 21, 16 Jan. 2023, commercial division, sustainability research project leader, Tier-1/OEM 1, EU; interview no. 19.
[42] Interview no. 23, 20 Jan. 2023, two representatives from engineering and sustainability parts of the Tier-1/OEM company 3, UK.
[43] Interview no. 24.

Policy options for increasing titanium circularity in Europe

There are several possible policy options for addressing the EU's dependent position in the mid-value and upstream parts of the value chain. In terms of the mid-value part of the chain, the establishment of a titanium recycling industry in the EU would be a priority. However, since the recycling would use the same industrial facilities as those converting sponge into ingots, this would mean the reshoring of the Tier-2 part of the supply chain with the technologically advanced titanium-remelting facilities. However, this is a slow-paced and costly option, beset by uncertain prospects in a highly competitive industry. Moreover, the former and current attempts at establishing such facilities in Europe suggest that it would be necessary for the EU to coordinate both policy and the provision of public funding. For instance, a scrap-recycling plant was set up in Germany in 2009, but it closed due to being financially unsustainable. Currently, the only European industrial plant recycling high-grade titanium scrap is the EcoTitanium facility in central France.[44] EcoTitanium was set up by a French ingot-producing company, UKAD, itself a joint venture established in 2011 between Aubert & Duval, a major Tier-1 supplier to Airbus, and UKTMP, a Kazakh supplier of sponge and ingots. UKAD was funded largely by Airbus, with the aim of creating a more stable titanium supply to Europe. UKAD owns a Tier-2 plant which produces ingots (from sponge) and semi-finished products. It expanded into recycling in 2015 by setting up the EcoTitanium plant with financial support from the European Investment Bank.[45] The plant uses advanced plasma arc melting (PAM) and electron beam melting (EBM) technologies, which are energy-efficient and ensure a reduced carbon footprint.[46] However, due to the idling of both plants for more than a year during the COVID–19 pandemic, both UKAD and EcoTitanium were struggling.[47]

Moreover, European companies have been challenged by competition with their US counterparts, due to a lack of economies of scale, limited access to scrap and comparatively high energy costs. All this indicates that even a large investment on the part of the companies alone is insufficient to reshore a competitive Tier-2 industry to Europe, and that there is a need for industry-specific and energy cost-related policies paired with financial incentives.[48] Indeed, the major aviation OEMs are interested in the reshoring of titanium scrap-melting facilities into the EU; they prioritize in-house circularity[49] and see EU institutions as important

[44] Interview no. 19.

[45] Chris Knight, 'Titanium recycling gives Europe a valuable new metal supply', European Investment Bank, 24 Jan. 2018, https://www.eib.org/en/stories/titanium-recycling.

[46] In the advanced PAM and EBM technologies, the percentage of scrap vs sponge can be much higher—with a scrap-to-sponge ratio of up to 80:20—than in the more traditional vacuum-arc remelting (VAR) process or skull furnaces (used in the post-Soviet countries), which can only produce ingots using 20–30% titanium scrap. Interview no. 6; interview no. 19.

[47] Interview no. 6.

[48] Interview no. 6; interview no. 9, 25 Nov. 2022, head of safety and environment division, end-of-life company 3, EU.

[49] Interview no. 3; interview no. 9; interview no. 19; interview no. 20, 12 Jan. 2022, two respondents, defence wing, Tier-1/OEM company 2, EU; interview no. 24.

actors aiding this shift.[50] The policy context is already conducive to this transition, as recent EU-level legislation, in particular 2020's European Green Deal Industrial Plan, allows the repurposing of existing EU funds towards supporting domestic businesses in transitioning to green technologies, as well as faster processes for permits and simpler rules for allowing cleantech firms to build production facilities in Europe.[51] This creates a momentum for change in the industry.

However, any EU policy in this space would need to be carefully balanced between the interests of EU-based aerospace companies, the leverage of American suppliers and the long-term goal of developing the EU industrial base. A policy aiming at prohibiting sales of titanium scrap to the US without first ensuring the presence of a viable industrial base in the EU would be unsustainable and could lead to an EU–US trade dispute. The latter is possible, considering the historical emergence of similar disputes (such as the 2004–2021 Boeing–Airbus trade dispute), and the US government's critical response in 2022 to the EU-proposed regulations on both hazardous and non-hazardous waste, aimed at keeping metal scrap (including titanium) in the EU, now adopted as law.[52] In the light of the US' critical stance and the limited Tier-2 industrial base in the EU, the initial push should come from direct negotiation (at EU level) of the buy-back agreements with the US government, as well as a joint US–EU stakeholder consultation.[53] The 2021 *Understanding on a cooperative framework for large civil aircraft*, which ended the Boeing–Airbus trade dispute, created a bilateral Working Group on large civil aircraft which could be a viable channel for the negotiations on buy-back agreements.[54] In addition, the potential involvement of US companies in the construction of the European titanium recycling base could allow European access to mature US recycling technologies while avoiding a possible trade dispute.[55]

As for the upstream part of the value chain, if the industry were to follow the CRM Act's recommendation to extract at least 10 per cent and process 40 per cent of the annual consumption of the strategic raw materials in the EU, it would require the creation of a titanium metal Tier-3 industrial base. This would indeed be conducive to achieving greater strategic autonomy, as even the most advanced

[50] Interview no. 24.

[51] European Commission, *A Green Deal Industrial Plan*. Innovation Fund and InvestEU are two examples of relevant financial instruments linked to the plan.

[52] European Commission, *Proposal for a regulation of the European Parliament and of the Council on shipments of waste and amending Regulations (EU) No 1257/2013 and (EU) No 2020/1056*, 2021/0367 (COD) (Brussels: European Commission, 2021), https://eur-lex.europa.eu/resource.html?uri=cellar:6c0588b1-4878-11ec-91ac-01aa75ed71a1.0001.02/DOC_1&format=PDF; United States Government, 'Comments regarding a proposal for a Regulation of the European Parliament and of the Council on shipments of waste and amending Regulations (EU) No 1257/2013 and (EU) No 2020/1056', 23 Aug. 2022, G/TBT/N/EU/893. Version adopted into the law following amendments by the European Parliament and the European Council calling for improvement of the recycling and waste management capacity and increased financial and other support for the companies involved: *Regulation (EU) 2024/1157 of the European Parliament and of the Council of 11 April 2024 on shipment of waste, amending Regulations (EU) No 1257/2013 and (EU) 2020/1056 and repealing Regulation (EC) No 1013/2006* (Brussels: Official Journal of the European Union), https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1157&qid=1715943208022.

[53] Suggestion provided in interview no. 21.

[54] Executive Office of the President of the United States, Office of the United States Trade Representative, *Understanding on a cooperative framework for large civil aircraft*, 2021, https://ustr.gov/sites/default/files/files/FINAL%20Understanding%20on%20Principles%20relating%20to%20Large%20Civil%20Aircraft.pdf.

[55] Interview no. 21.

plasma-melt technology cannot solely recycle scrap.[56] However, it would be a costly endeavour with significant risk to profitability. Moreover, as the only exploitable titanium deposits in Europe are located in Ukraine,[57] the creation of such an industry would only be possible once the Russian invasion were over—and if Ukraine were to join the EU.

Some efforts to enmesh the EU and Ukrainian elements of the CRM value chains had already taken place before 2022, and they laid the foundations for nearshoring of the Tier-3 portion of the EU titanium value chain to Ukraine. In 2020/21 Volodymyr Zelensky's administration regained control over several major titanium facilities and established a ministry of strategic industries in the country, tasked with promoting the development of CRM production, mapping deposits and ensuring sustainable financing for their exploration.[58] This change coincided with the EU's own attempts at diversifying its SVCs to include Ukraine, marked by the signing of the 2021 EU–Ukraine Strategic Partnership on raw materials and batteries, through which the EU invested €750,000 in technical support programmes;[59] and by the 2022 memorandum of understanding aimed at modernizing geodata management in Ukraine, explicitly targeting Ukraine's potential for building resilient value chains for Europe's green and digital transition.[60]

However, even if Ukraine continues its pro-EU stance once the war is over, and provided that it retains the titanium ore deposits and industry within its territory, there would remain sizeable challenges to successful integration of the Ukrainian industrial base into the EU titanium value chain. First, although Ukraine already owns ore-to-sponge processing plants, these are outdated and polluting.[61] In addition, while extracting companies in central Ukraine can continue their activities, the situation of the eastern Ukraine-based sponge maker ZTMK (Zaporizhzhia Titanium–Magnesium Plant) is more dramatic. Due to Russian bombings and the pro-Russia management's sabotage, ZTMK has suffered losses in terms of human resources and slower production.[62] In addition, even the EU–Ukraine Deep and Comprehensive Free Trade Area, in force since 2016, was insufficient to put an end to oligarchic control and corruption in this industry or to its close links to Russia.[63] As result, some amounts of Ukrainian ore were still being shipped to

[56] See footnote 46.

[57] Incidentally, these are also some of the world's purest deposits, with 93–96% titanium content: Louvigné, *Rapport final*, p. 97.

[58] See Volodymyr Zelensky, 'Ukaz prezydenta Ukrainy No. 306/2021' [Decree of the President of Ukraine no. 306/2021], 23 July 2021, https://www.president.gov.ua/documents/3062021-39457.

[59] EU NeighboursEast, 'EU and Ukraine kick-start strategic partnership on raw materials', 14 July 2021, https://euneighbourseast.eu/news/latest-news/eu-and-ukraine-kick-start-strategic-partnership-on-raw-materials.

[60] European Neighbourhood Policy and Enlargement Negotiations, 'EU–Ukraine strategic partnership on raw materials: the European Bank of Reconstruction and Development will support digitalisation of geological data in Ukraine', 17 Nov. 2022, https://neighbourhood-enlargement.ec.europa.eu/news/eu-ukraine-strategic-partnership-raw-materials-european-bank-reconstruction-and-development-will-2022-11-17_en.

[61] Interview no. 12, 10 Dec. 2022, senior researcher, research institute 2, Ukraine.

[62] Interview no. 12.

[63] Thorvaldur Gylfason, Inmaculada Martínez-Zarzoso and Per Magnus Wijkman, 'Free trade agreements, institutions and the exports of Eastern Partnership countries', *Journal of Common Market Studies* 53: 6, 2015, pp. 1214–29, https://doi.org/10.1111/jcms.12275; Svitlana Albinovska, 'Zavdav zbytkiv ta vtik: u mizhnarodnyy rozshuk oholosyly kolyshn' oho dyrektora Zaporiz' koho tytano-mahniyevoho kombinatu?' '[He caused damage and escaped: the former director of the Zaporizhzhia titanium–magnesium plant was declared an

Russia in 2022.[64] In early 2023, due to financial insolvency, the Ukrainian government—which holds a 51 per cent stake in ZTMK—decided to privatize the enterprise, opening the industry to further possible infiltration through Russian shell companies, which could complicate the EU companies' involvement in the postwar reconstruction.

Conclusion

Three principal dynamics underpin the current position of the EU in the titanium value chain; they need to be taken into consideration if an effective policy is to be produced in this space. The first, short-term dynamic is the COVID–19-inflicted shock across the aviation industry, which led to a halving in the EU's external trade in titanium products in 2021–22 (see figures 2 and 3), and which had a severe impact on emerging industrial circularity initiatives. The second dynamic is of a longer-term, structural nature. While a post-COVID bounce-back in the industry is expected to be under way by 2025,[65] this alone will not resolve the long-term dependency concern. Despite titanium's importance, decades of trade liberalization policies, the assumptions of relative geopolitical stability and the lack of titanium ore deposits have made the EU particularly dependent on imports of titanium sponge and ingots. While US companies have been investing for some decades in mid-value chain processing facilities, including recycling facilities which drive down the financial and environmental costs of production, the EU industry has been progressively offshored or bought up by the US industry, with its highly dependent position being solidified by the buy-back agreements. The EU companies operating within the titanium value chain, such as Airbus and its suppliers, continue to be the key global players in the downstream part of the value chain, but are unable to reshore either the upstream or the mid-value parts of the industry alone. The third dynamic takes the form of widespread concern over long-term strategic autonomy. The EU has recognized titanium metal as a CRM, and has formulated policy objectives around making SVCs more resilient and sustainable, seeking to reshore the raw material's extraction and processing to the EU. Yet, these new objectives are emerging at a time when the demand for titanium metal is growing exponentially; this is due to the increasing amount of titanium used in newer plane models; a growing militarization internationally; and similar policies prioritizing domestic elements of the US and Chinese value chains.

The case of the titanium metal global value chain highlights some of the difficulties that the EU has encountered in achieving its combined ambitions of decarbonization and reindustrialization, at a time of increased global competition for strategic raw materials. So far, the EU's New Industrial Strategy and the CRM

international wanted man]' [in Ukrainian], *zprz city,* 11 Sept. 2023, https://zprz.city/news/view/sprichinivzbitkiv-ta-vtik-u-mizhnarodnij-rozshuk-ogolosili-kolishnogo-direktora-zaporizkogo-titanominusmagnievogo-kombinatu.

[64] This took place mainly through requests from shell companies: interview no. 14, 14 Dec. 2022, senior management, Tier-3 (extraction) company 2, Ukraine.

[65] Airbus data shared in interview no. 16, 21 Dec. 2022, two respondents, top management, industry association 2, non-EU.

Act have sought to achieve this by increasing processing (as compared to extraction and recycling pillars) and making it a central element of the OSA strategy. However, the case of titanium illustrates that doing so in a way that is economically competitive and at the same time socially and environmentally sustainable might be challenging. The process of turning ores into titanium sponge is energy-intensive and polluting. Performing it in the EU using only renewable energy sources is hardly feasible, as the EU will have to compete with countries that leverage fossil fuels or nuclear energy sources, cheap labour and lower waste-water treatment standards.[66]

In this policy paper we argue that the reshoring of the mid-value chain industry to the EU in a globally competitive way would be best achieved by boosting a circular economy strategy similar to that pursued in the US. This demonstrates the key relevance of the recycling pillar of the CRM Act (as compared to its other pillars) for the reshoring of the titanium value chain, considering both the post-fabrication virgin scrap and the thus far untapped potential of recycling materials embedded in end-of-life aircraft. As to the upstream part of the value chain, the EU's OSA priorities imply that it should adopt a more active approach to securing its access to the extraction and processing facilities. One of the most obvious solutions would be to turn the challenge of Ukraine into an opportunity for the creation of intra-EU extraction and processing facilities. In the long term, it is important to diversify the sources of imports of both sponge and ingots, rather than solely relying on 'friendshoring' of the dependencies. This would mean sourcing supplies from states with different political systems to the EU's (in particular, from Kazakhstan), as long as these states adjust their value chains to meet the EU's environmental, governance and social standards.

[66] Interview no. 3; interview no. 19.