International spillovers embodied in the EU's supply chains

Tracking forced labour, accidents at work and climate impacts in the EU's consumption of fossil and mineral raw materials

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ABSTRACT

Fossil and mineral raw materials enable sustainable development and undermine it, causing unintended and detrimental environmental and social impacts via extraction and production processes. In this study, we analyse how consumer demand in the European Union drives environmental and social impacts in mining sectors worldwide. We employ multi-regional input-output analysis to quantify positive (i.e., income, female and male employment) and negative (greenhouse gas emissions, accidents at work, and modern slavery) impacts of mining in raw material sectors, as indicators of the UN Sustainable Development Goals. We trace these environmental and social impacts across the EU's trading partners to identify sectors and regions as hotspots of international spillovers embodied in the EU's consumer demand and find that these hotspots are wide-ranging in all continents. We estimate that across all sectors, EU's consumption is associated with about 4200 cases of fatal accidents at work and 1.2 million cases of modern slavery annually. Raw material supply chains are respectively responsible for 5% and 3% of these totals, but also 14% of imported GHG emissions. These impacts take place primarily in Central Asia and the Asia Pacific as well as Africa. Our results underline the need for further reforms in mining industries and trade policies to eradicate modern slavery and other adverse social and environmental impacts and to implement safe workplaces for workers.

1. INTRODUCTION

Mining raw materials and Sustainable Development

Sustainable development (SD) requires balancing economic, social, and environmental benefits of use of raw materials against their adverse impacts to meet the needs of the present without compromising the needs of those in the future [1, 2]. Society economically depends on the extraction, processing, and use of fossil fuels, minerals, and metals [3, 4], making them a crucial component in the push for SD [5]. In this study, we use the term *raw materials* and the category *"mining (energy resources, ores and minerals)"* interchangeably in the text and figures to refer to a wide range of fossil and mineral raw materials. Raw materials are embedded in every product we consume and use [5, 6], defining societal and economic progress [4, 6-8]. These are used to develop physical infrastructure, as inputs in instruments of daily use, to produce energy, and to supply agriculture with fertilizers critical for mass food production [9-11]. A defining feature of many raw materials, and especially fossil fuels, is that they are non-renewable on human time scales [7, 12]. As such, SD in the mining sector is exceedingly challenging as the extraction of non-renewable commodities contradicts the notion of long-term sustainability [3]. Therefore, it is imperative to understand how raw material extraction and depletion affect sustainable development [10, 13, 14].

Mining generates significant economic prosperity [15], thus is the economic foundation behind SD. Regions such as the United States (U.S.), Australia, Germany, the United Kingdom (UK), and Canada leveraged their mineral wealth to generate considerable economic wealth [4] to support the development of secondary industries [15]. In recent years, the twin green and digital transformations have fueled increased demand for minerals and mineral products globally. Mineral-related manufacturing, in many less resource rich nations [15], is a significant income earner [16]. The prosperity generated by minerals is sometimes related to improved societal outcomes, often measured by the Human Development Index (HDI). Ericsson and Löf [17] find that the contribution of non-fuel mining to low- and middle-income countries between 1996-2016 is correlated to increases in national HDIs. The contribution of non-fuel mining helped developing nations increase their HDI by 18% between 1996-2015 [17]. Previous reports have also examined the positive correlation between a nation's HDI and its extractive industries [15]. The ripple effects of raw material-related industries extend to many facets of sustainable development [18].

However, despite this sample of positive socio-economic benefits generated by raw materials and the fact that society as we know it cannot function without them, raw material production and consumption adversely impact the planet and also society [9]. The adverse and sometimes lasting environmental impacts of raw material extraction and production are significant, jeopardizing the precarious balance of economic benefits over environmental costs [9]. The extensive impact of raw material production on the planet begins with its extraction [7, 19]. Raw materials must be extracted from on or below the Earth's surface, whether on land or below water. Environmental impacts caused by the extraction process on land include air pollution [19-21], biodiversity and habitat loss [19, 22], soil erosion, decreasing soil quality, water pollution and deterioration of ecosystem [23]. Oceanic or riverbed mining causes environmental impacts, including noise and light pollution, sediment plumes releasing toxic elements, and irreversible changes to the sea floor fauna [24, 25]. Research on the health-related impacts of mining demonstrates the symbiotic nature between environmental impacts and human health [26]. Toxins released into the environment can make their way into the food chain, and pollution can cause deleterious health problems [27]. Many regions have legislation requiring raw material extraction companies to produce Environmental Impact Assessments (EIA) as part of the project approval process [28]. However, the rigour to which these assessments are done can vary significantly based on the company and level of corruption, which hinders their ability to safeguard human and environmental health [29]. Additionally, the socio-environmental impacts of raw materials are multidimensional, often embroidered with systemic issues of justice, equity, and equality [30]. Those in raw material-related sectors in some economies are top wage earners [4]; however, can be subject to harsh and unhealthy working conditions. The likelihood to face such conditions is exacerbated in regions or corporations where labour protections are lacking [31]. Health impacts extend far beyond raw material and mining sectors; for example, metal manufacturing can destabilise the human nervous system and possibly increase the risk of neurodegenerative diseases [32].

Several of the impacts arising from mining are a key priority for sustainable development globally. The internationally accepted blueprint for sustainable development is enshrined in the United Nations (UN) Sustainable Development Goals (SDGs) [33], launched in 2015 as part of the UN 2030 Agenda [2]. The SDGs aim to provide a blueprint for promoting peace and prosperity for people and the planet [33]. Intriguingly, in contrast to other natural resources, raw mineral materials are missing from many SDG goals and targets (See Franks, et al. [34] for a detailed overview). For example, there is no mineral governance SDG, yet minerals underpin many other SDGs [35]. So increasingly, researchers are exploring the synergies and gaps between the SDGs and minerals. Bendixen, et al. [36] identify critical obstacles to a sustainable future for global aggregate resources, focussing on sand and gravel aggregates. Hatayama [37] analysed the reports of 61 metal companies to examine the relationship between the metals industry and the SDGs. Mancini, et al. [35] review the literature on how materials hinder or contribute to the SDGs, with a focus on the EU. However, no quantitative assessment is produced on the impact of the EU's demand for minerals on other countries.

Global supply chains are complex and connect production and consumption centers across continents, which lead to outsourcing of environmental and social impacts to other countries. The SDG resolution adopted by the European Parliament in June 2022 "*stresses the fact that efforts to mainstream the SDGs across the EU internal and external policies should go beyond a mapping exercise [...] recalls that many EU internal policies not only contribute to the implementation of the SDGs, but also have a very high ecological, social, and economic spillover impacts on developing countries and vulnerable groups and populations*" [38]. Spillovers occur when a country's actions result in benefits or impose costs on another country, and can be grouped into four categories: Spillovers embodied into trade, direct cross-border flows in air and water, economic and financial flow, and peacekeeping and security spillovers. This study aims to quantify spillovers embodied into trade, driven by the European Union (EU) consumption, particularly caused by the EU's demand for fossil and mineral raw materials.

Importance of fossil and mineral raw materials for the EU

The EU and its 27 individual member states [39] produce few primary fossil and mineral products, relying heavily on imports for its secondary and tertiary industries [40]. For example, the **EU consumed approximately 2.7 times more metal ores and 2.9 times more fossil fuel energy than the amount extracted within its borders in 2019** [41]. Further, the EU relies on imports of around 80% of its domestic energy demand, illustrating its energy import dependency [41]. However, the EU is self-sufficient in the production of biomass and non-metallic minerals [41] and the world's largest producer of certain industrial minerals [42], such as magnesite, gypsum, speciality clays or kaolin [14]. The EU also has valuable deposits of copper (in Poland, Iberian Copper Belt, Bulgaria, Sweden), zinc and lead (in Sweden, Ireland, Poland). Recent discoveries of lithium deposits in the Czech Republic, Portugal, and Spain and in neighbouring countries, such as Serbia, indicate potential extraction opportunities [14]. Of the primary mining industries in the EU, 84% of the enterprises were non-metallic and not fossil fuels [40]. The availability of mineral aggregates from regional and local sources is essential for economic development in the EU, especially in secondary industries, such as the logistics and transportation sectors. Secondary industries in the EU are economically important; for example, the manufacturing of basic metals and fabricated metal products witnessed a 28% increase in the value of sold production between 2020-2021 [43].

Although the EU is a major producer of machinery, it can only produce 40% of the raw material inputs it needs [14]. For these products and others, the **EU is highly dependent on imports of "metallic" minerals and "high-tech" metals such as cobalt, platinum, rare earth minerals, and titanium** [44]. Although "high-tech" metals are only needed in small quantities, they are essential to developing technologically sophisticated products. Strategic initiatives have identified ongoing needs for critical minerals, such as the "high tech" minerals needed for the net-zero transition and ongoing technological requirements [45], and how the EU can secure reliable access. The EU also relies on recycled scrap metal imports, representing 40% to 60% of input to the EU metal production. Access to scrap metals, both recycled and ferrous, is becoming more difficult in Europe because end-of-life products are not appropriately recycled and instead illegally shipped outside the EU, resulting in a loss of valuable secondary raw materials and negative environmental impacts [44]. The value of various minerals to the EU economy begs the question of how its raw material consumption, production, and related spillover impacts can foster or hinder national and regional sustainable development and progress towards achieving the SDGs.

Assessing spillover impacts associated with the EU's raw material demand

Beyond the known benefits of raw materials to SD within the EU, it is crucial to examine the effects of the EU's demand on its trading partners and their efforts to advance SD. The 2022 Sustainable Development Report includes an International Spillover Index, which captures how rich countries, many of which are in the EU, generate negative socioeconomic and environmental impacts notably through unsustainable trade and supply chains [46]. This study uses the term spillovers to focus on impacts occurring beyond the EU's borders through trade and consumption. Understanding the drivers of spillovers and taking decisive actions to curb such negative impacts, is important in a context where raw material consumption is rising. Between 2020 and 2021, raw material consumption increased by 4%, with non-metallic minerals accounting for 53% of the increase and metals and fossil fuels accounting for 18% and 6% of the rise in demand, respectively [47].

In this study, we use a comprehensive international trade database to assess spillover impacts associated with the EU's demand for fossil and mineral raw materials. We focus on a range of social indicators (female and male employment, income, accidents at work and modern slavery) and greenhouse gas emissions for quantifying hotspots of impacts embodied in supply chains, and present findings at a detailed regional and sectoral level.

2. METHODOLOGY

Quantifying impacts of mining with links to Sustainable Development Goals

Identifying and monitoring the impacts of mining is paramount to progress sustainable development and mitigate the impacts hindering the SDGs [48]. Although raw materials are, to varying degrees, related to all SDGs [13], we focus on their interrelationships between SDG8 (Decent Work and Economic Growth), SDG7 (Affordable and Clean Energy), SDG12 (Responsible Consumption and Production), and SDG13 (Climate Action) for reasons explained below.

Raw materials and their associated industries provide cascading employment opportunities domestically and internationally, securing decent work opportunities for many people (SDG8). However, employment in raw material-related industries, such as mining and metal refining, can embody adverse social impacts, such as labour abuses and forced labour [26]. Growing evidence of modern slavery (that comprises forced labour and forced marriages [49]) in raw material-related industries hampers progress toward SDG8 targets, primarily target 8.7 and 8.8 [50]. Forced labour includes those engaged involuntarily in work and subject to penalty otherwise [51]. Target 8.7 seeks to eradicate forced labour, end modern slavery and human trafficking, and eliminate child labour by 2025. Target 8.8 concerns itself with protecting workers' rights and safety [50]. Both these targets are jeopardised by how raw materials are currently extracted, produced, and consumed globally [52], triggering potential barriers to progress for SDG12. Many SDG12 targets are tightly related to raw materials because the purpose of SDG12 is to reduce the associated impacts of production and consumption [53]. Target 12.2 concerns itself with the sustainable management and use of natural resources, which is necessary given that several natural resources, like fossil fuels, are finite. Access to and use of several minerals are the backbone of achieving SDG7 targets, like increasing the share of renewables (target 7.2).

Transitioning from fossil fuels to clean energy, which is vital for meaningful progress toward SDG13, however, is mineral intensive [54, 55], raising new issues of how to secure a sustainable clean energy transition [55]. For example, a typical electric car requires six times the mineral inputs of a conventional car, while an onshore wind plant requires nine times more mineral resources than a gas-fired plant [54]. Quantifying the indirect supply chain impacts of raw materials, or footprint indicators, is essential to avoid loopholes in national sustainability assessments [48]. Methods capable of quantifying such impacts underpin ways in which progress can be made to SDG8 (Decent Work and Economic Growth), SDG12 (Responsible Consumption and Production), 13 (Climate

Action), and SDG7 (Affordable and Clean Energy), which we outline below.

Popular methods for quantifying impacts in supply chains are input-output (IO)-based and process-life-cycle (LC) based approaches. IO-based models rely on economic input-output tables, tracing the monetary flow of goods and services from one entity or region to and between each other [56]. They can also assess various impacts and scenarios related to supply chains and be used at multi-regional resolutions. Multi-regional IO (MRIO) models are particularly valuable as they provide the resolution needed to capture interregional international trade. Applications of MRIO include the quantification of social and environmental footprints [48], natural and climate-related hazards [57-60], and consumption, production, and trade [61].

These applications can provide the means to understand where supply chain resilience towards hazards is needed (SDG target 13.1), support policies aimed at tackling emissions (SDG target 13.2) and promote ways of understanding transboundary impacts associated with production and consumption (SDG target 12.2-12.3). An important feature of IO-based methods is that they are upstream methods, as they can quantify impacts at various links in supply chains for satisfying final consumption [56]. Another popular method to examine impacts is a lifecycle assessment or LCA [62]. LCAs "*analyse and calculate the environmental effects and impacts caused by the manufacturing of a product, process or activity throughout its entire lifecycle*" [21]. Studies that use LCA are primarily product focused, offering specificity that is sometimes lacking in an IO-based assessment, however LCA approaches lack the complete supply chain coverage that is offered by IO assessments. In the context of raw materials, LCAs are employed by researchers [63], underlying the means by which impacts and inefficiencies can be identified to progress SDG12 targets 12.4 and 12.5 [53]. LCAs have been conducted for mineral-intensive products [64, 65], coal-fired electricity generation [66], and mining and mineral recycling processes [21, 67, 68]. LCAs result in truncation errors [69] and virtual laboratories based on IO analysis can offer a more complete assessment [70] for addressing the boundary issue [71]. Given the capabilities of these models, they are applied in the context of raw materials and their supply chains.

We observe that the literature on the indirect impacts of raw materials using IO-based techniques can be grouped into two broad categories. The first and larger tranche of research examines impacts arising from trade flows, providing some insight into raw material supply chains [72-76], though they are not the sole focus of the study. Qi, et al. [74] quantified the sulphur emissions in Chinese supply chains, finding that the manufacture of non-metallic products to the construction supply pathway contributed the most to emissions. Jiang, et al. [75] used an environmentally extended MRIO (EEMRIO) model to examine the particulate matter (PM2.5) emissions in China-US trade, finding that the PM2.5 embodied in machinery and equipment exports from China to the U.S. increased substantially over 2000-2015 and Wang, et al. [72] calculated the carbon emissions in China–Australia trade during 2000–2014. Acquaye, et al. [73] used MRIO analysis to quantify carbon, sulfur oxide and water impacts associated with global supply chains, only briefly mentioning the contribution of minerals and their by-products. The second and smaller tranche of research focuses on specific minerals, groups of minerals, or mineral products and their supply chains [77-85] (some examples captured in Table 1).

Like the literature on the direct impacts from raw material extraction (i.e., mining) and production (i.e., manufacturing), research using the various methods is skewed towards quantifying environmental impacts, particularly emissions, such as carbon dioxide (CO_2) emissions [81, 82] and sulphur, nitrogen, mercury, or particulate matter (PM) emissions [76, 86-88], and impacts such as land-use change, climate change, and water quality [78, 83]. The quantification of social impacts in the supply chain has emerged recently. Moran, et al. [80] used a high-resolution multi-region input-output (MRIO) table and a hybrid LCA model to examine supply paths of potentially conflict-sourced Coltan from the Democratic Republic of Congo (DRC). Gómez-Paredes, et al. [89] conducted a systematic assessment of Indian child labour involved in the production of commodities consumed worldwide, including raw materials. Cabernard, et al. [78] evaluated various impacts including a social indicator, represented as a health impact, to examine the impact embodied in several raw materials. As for economic impacts, Xing, et al. [84] measured the value-added, employment gains, tax revenue, and labour income of stone mining and quarrying, and Motoori, et al. [81] ranked the contribution to labour arising from copper production and recycling in Japan. We also observe that the geographical concentration of IO/LCA studies are conducted for Asian regions, particularly for Japan [77, 81, 86, 87] and China [74, 76, 82, 85, 88, 90], or at a global level. Motoori, et al. [81] and Aoki-Suzuki, et al. [77] quantified the environmental and economic impacts of Japan's domestic mineral production from the recycling of end-of-life products and deep ocean mining and urban air pollution, waste, eco-toxicity, and land use, of various raw materials, such as petroleum, coal, copper, and steel in Japan's supply chains, respectively. Zhang, et al. [76] and Meng, et al. [91] examined virtual flows of aquatic heavy metal emissions (i.e., mercury) and PM emissions in domestic supply chains in China, respectively.

TABLE 1. Examples of studies focused on the indirect impacts of raw materials and mineral-related products.

Case study examples	Case study coverage	Sustainability dimension (Impact/s quantified)	Method/s; SDGs mentioned (denoted by #)*	Source
Stone mining and quarrying	United States (Missouri)	Economic (various)	IO	Xing, et al. [84]
Aluminum	United States	Economic (use)	IO and network analysis	Nuss, et al. [92]
Neodymium, Cobalt, and Platinum	Asia (Japan)	Multi (material footprint)	MRIO	Nansai, et al. [93]
Copper production and recycling	Asia (Japan)	Environmental (CO_2 emissions) and economic (labour impacts)	EEIO and LCA	Motoori, et al. [81]
Coltan	Global (DRCongo)	Social (illegal mining)	MRIO-LCA	Moran, et al. [80]
Rare earth elements	Africa (Malawi)	Environmental (CO_2 emissions)	LCA	Pell, et al. [82]
Various	Asia (Japan)	Environmental (various)	EEMRIO, *not specific*	Aoki-Suzuki, et al. [77]
Manganese	Non-defined	Environmental (particulate matter)	LCA	Davourie, et al. [79]
Materials (biomass, metals, non-metal minerals and fossils)	Asia (Japan)	Environmental (GHG emissions)	Hybrid MRIO	Dente, et al. [87]
Materials (biomass, metals, non-metal minerals and fossils)	Asia (Japan)	Environmental (GHG emissions)	Hybrid MRIO	Dente, et al. [86]
Materials (biomass, metals, non-metal minerals and fossils)	Global	Environmental (various), socio-economic (health)	Hybrid MRIO, #SDG12 *(Responsible Consumption and Production)*	Cabernard, et al. [78]
Copper	Europe (France)	Economic (value)	IO	Beylot and Villeneuve [94]
Metals	Oceania (Australia)	Environmental (emissions)	LCA	Strezov, et al. [95]

In this table, we exclude literature where the impacts of raw material supply chains are discussed in a larger context of national supply chains, i.e., we solely isolate studies that examine raw material supply chains. **Here, we denote if the research included references to the SDGs and specify the SDG goal number (#) if relevant.*

Mathematical formulation – measuring international spillover impacts

MRIO analysis is a robust methodology for quantifying upstream impacts and undertaking footprint assessments [96]. It is a key methodology that enables the assessment of impacts embodied in supply chains, which is limited in conventional life cycle assessments [69]. For example, MRIO analysis is used in emissions accounting to calculate the direct (Scope 1 and 2) and indirect (Scope 3) emissions arising from production and consumption activities, with the results of such assessments referred to as a carbon footprint [97, 98]. The same concept applies to studies examining social footprints, whereby MRIO analysis is used to capture social effects in supply chains. The starting point for footprint calculations is constructing custom multi-regional input-output tables. MRIO analysis capture the transactions between industry sectors and regions [99, 100]. The input-output economic accounting system consists of three primary matrices: Intermediate demand **T** that captures interdependencies between the EU's demand for raw materials and trading partners, Final demand **y**, which links final consumption in the EU with the rest of the world and Primary inputs **v**. For a detailed review on the construction and set up of MRIO tables, please see Lenzen, et al. [99]. We use the GLORIA MRIO tables for this study, featuring 160 countries and 4 aggregated regions, with 97 sectors in each region/country [101].

The second part involves collection of data for the indicator/s being studied, which informs the construction of a so-called satellite account (**Q** matrix). The **Q** matrix holds information on physical indicators, such as environmental and social indicators, and enables the examination of various environmental and social footprints [100]. Here, we outline MRIO analysis algebraically. First, we calculate the total output **x** by summing a *N* x *N* intermediate demand matrix (**T**) and a *N* x *K* final demand matrix (**y**) to get $\mathbf{x} = \mathbf{T1^T} + \mathbf{y1^y}$, where *N* is the number of sectors in the intermediate demand matrix, *K* are the number of final demand categories, the vector $\mathbf{1} = [1,1,...,1]$ is a summation operator. Next, we calculate the direct coefficients matrix $\mathbf{A} = \mathbf{T\hat{x}^{-1}}$., which represents the inputs needed to produce 1$ of output of a sector and $\mathbf{\hat{x}^{-1}}$ denotes the inverse of a diagonal matrix for total output. The fundamental Leontief input-output equation can be calculated as: $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y}$, where **I** is the identity matrix and $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse **L**. The matrix **L** holds information on all upstream supply chains, enabling the quantification of international spillover impacts, such as mining in China and final consumption in the EU.

The monetary MRIO database is environmentally- and socially-extended by integrating data on greenhouse gas emissions, modern slavery, accidents at work, female and male employment and income in the form of a satellite account matrix **Q**. The coefficients of the matrix **Q** – e.g., carbon dioxide (equivalent) emissions produced for every dollar of output of an industry sector – can be derived as $\mathbf{q} = \mathbf{Q\hat{x}^{-1}}$ that represent direct impacts, multipliers $\mathbf{m} = \mathbf{qL}$ capture impacts across the entire supply chain. Quantification of spillover impacts across multiple upstream supply chain networks – production layer decomposition – can shed light on the regional and sector hotspots of raw material-related impacts: $\mathbf{qL\tilde{y}} = \mathbf{q}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{\tilde{y}} = \mathbf{q}(\mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \mathbf{A}^4 + \cdots)\mathbf{\tilde{y}}$. Here, the first layer is $\mathbf{qI\tilde{y}}$, the second layer ($\mathbf{qA\tilde{y}}$), the third layer ($\mathbf{qA^2\tilde{y}}$), and so on. $\mathbf{\tilde{y}}$ captures final demand of each of the 27 EU nations for all economic sectors (primary, secondary, and tertiary). Raw material impacts embodied in supply chains are calculated by slicing the matrix **Q** to only capture direct impacts of primary fossil fuel and mineral sectors ($\mathbf{Q}_{min}$); these direct impacts are then modelled via international supply chain networks, using the equations provided above to quantify supply chain impacts embodied in the EU's final consumption $\mathbf{\tilde{y}}$, and associated demand for raw materials to satisfy this consumption. Data on matrix **Q** for greenhouse gas emissions (units: tonnes), female employment and male employment (units: number of people) are obtained from the Responsible Consumption and Production Hotspots Database [102, 103], which relies on the Emissions Database for Global Atmospheric Research (EDGAR) for emissions data [104] and the International Labour Organization for employment statistics [103]. Data on accidents at work (units: number of cases) are taken from the International Labour Organization [105] (note: this is a varied data source from [106] that uses a range of data-sets for developing the fatal occupational hazards dataset). Modern slavery (expressed as cases of forced labour victims) data are obtained from a global study of modern slavery impacts in supply chains [107]. Our study focusses on forced labour that covers exploitation (including debt bondage and human trafficking) as found in industry sectors. Child labour and forced marriage are excluded from the calculations, so are victims that are found within households [107]. Concordance matrices were used to bridge across sectoral and regional resolution between physical datasets and MRIO data. As described by Shilling, et al. [107], national estimates of modern slavery are limited, which is not surprising as incidents of human exploitation are under reported. Thus, assumptions need to be made in linking raw data with MRIO tables, as done in Shilling, et al. [107], and we further link the estimates on forced labour victims to the GLORIA MRIO database used in this study via concordance matrices.

3. RESULTS

We estimate that in 2018, across all sectors, the EU's consumption of goods and services was associated with the following impacts:

- US$ 7.3 trillion (t) in income,
- 112 million jobs for women,
- 143 million jobs for men,
- 4.7 Gigatonnes (Gt) of greenhouse gas emissions,
- 4217 cases of fatal accidents at work,
- 1.2 million cases of modern slavery.

These impacts are broken down in Fig. 1 into contribution from domestic production and imports, for all supply chains. Specifically for imports, the EU's demand for goods and services results in the following international spillovers, across all sectors: US$ 0.9t in income, 33 million jobs for women, 53 million jobs for men, 1.9 Gt of greenhouse gas emissions, 1174 cases of fatal accidents at work and 0.5 million cases of modern slavery. Out of the total impacts, those resulting from raw material supply chains for satisfying the EU's consumption contribute to 0.9% (US$ 0.07t) of income, 0.3% (0.3 billion jobs) for women, 1.2% (1.8 billion jobs) for men, **14% (0.67Gt) of total greenhouse gas emissions, 5.8% (243 cases) of accidents at work and 3% (36 thousand cases) of modern slavery impacts** (Fig. 1). These impacts from raw material supply chains are further broken down into contribution from domestic production and imports (Fig. 2). Our results suggest that about 40% of the total GHG and modern slavery footprint of the EU is embodied in imports, which underlines the need to clean up international supply chains but also echoes the findings of other organizations which highlight that modern slavery cases are found in both developed and developing countries [49].

The categories presented in Fig. 1 are broad categorisations to present aggregations of the individual 97 sectors of the MRIO database for ease of representation in a diagram. For example, the category mining (energy resources, ores and minerals) includes energy resources (coal, lignite, peat, petroleum, natural gas), ores (ores of uranium, aluminum, copper, gold, lead, zinc, silver, nickel, tin and other ferrous and non-ferrous ores) and minerals (stone, sand, clay, chemical and fertilizer minerals, salt). The category agriculture, fishing and forestry includes growing of crops, raising of animals, wood production and aquaculture. The category names are indicative of the sectors included in the category.

A comparison of the EU's absolute impacts with the U.S. and Canada for fossil and mineral raw materials reveals that the EU's supply chains are more unsustainable compared to the two countries. The EU's imports embody about 34 thousand cases of modern slavery: whilst for the U.S. about 6600 and 1900 for Canada. For accidents at work, there are 197 cases for the EU, 100 for the U.S. and 12 for Canada. The EU's per capita impacts embodied in imports for accidents at work are 0.00000044 cases per person[1].

The EU's total impacts across all sectors

The EU's final demand comprises of a range of primary and secondary commodities and tertiary services. This demand is met by domestic production (within the EU, including trade between the EU nations) and imports. To meet this demand, production takes place in primary, secondary and tertiary sectors – connecting this production with final consumption enables answering the following question: *What are the environmental and social impacts taking place in different economic sectors during production of goods and services that are eventually required for satisfying the EU's final demand?* This production takes place within the EU (domestic; Fig. 1) and abroad (imports; Fig. 1). We calculate the EU's total footprint across each of the six indicators considered in this study (see Section 2); and disaggregate the total footprint across 13 broad sectors (Fig. 1). Taking the example of modern slavery as an indicator, most impacts considering both domestic and imports take place in the construction sector for satisfying the EU's final demand (modern slavery; top row; Fig. 1); when considering imports-only most of the impacts take place in the agriculture sector (bottom row).

As can be seen in Fig. 1; the impacts across sectors vary depending on the indicator considered. For indicators linked with socio-economic development, income, and jobs, most of the descriptive positive spillovers occur in tertiary sectors (such as services) that employ people in relatively high-paying salaries in comparison to primary sectors such as agriculture, fisheries, and forestry. In this study, we unravel the impacts

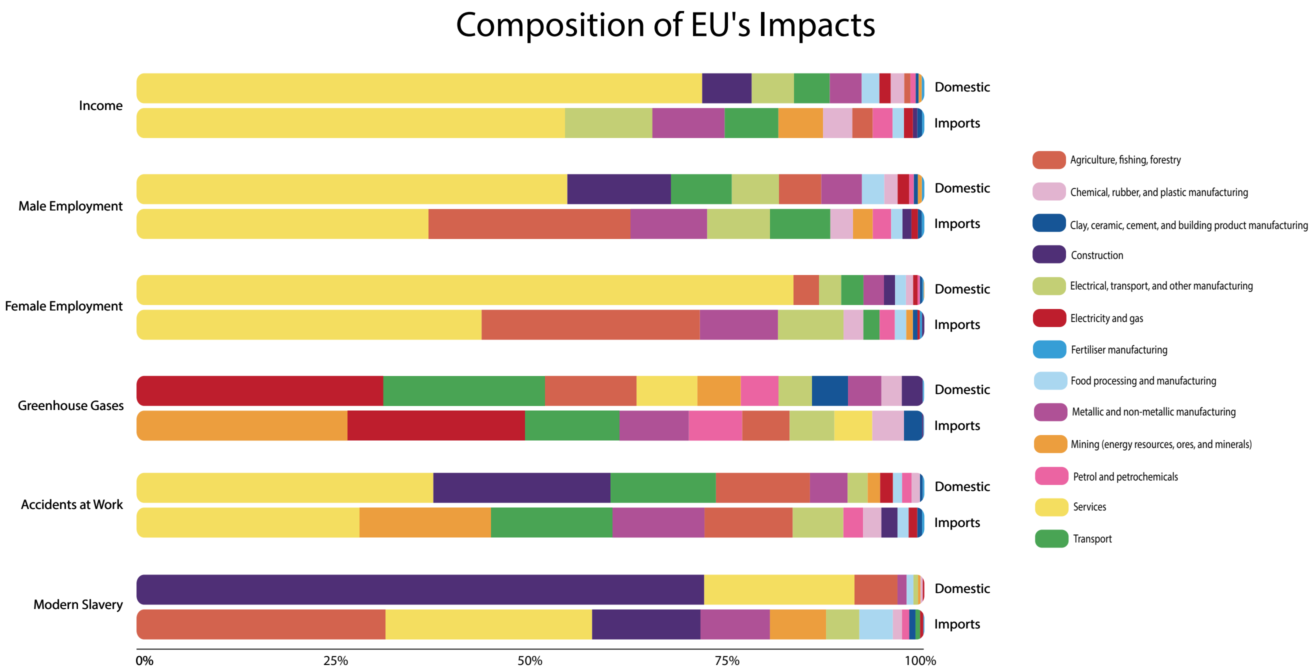
[1] This equates to 0.00000031 cases per person for the U.S. and 0.00000033 cases per person for Canada and 0.000008 forced labour victims per person for modern slavery (0.00002 victims per person for the U.S. and 0.00005 victims per person for Canada).

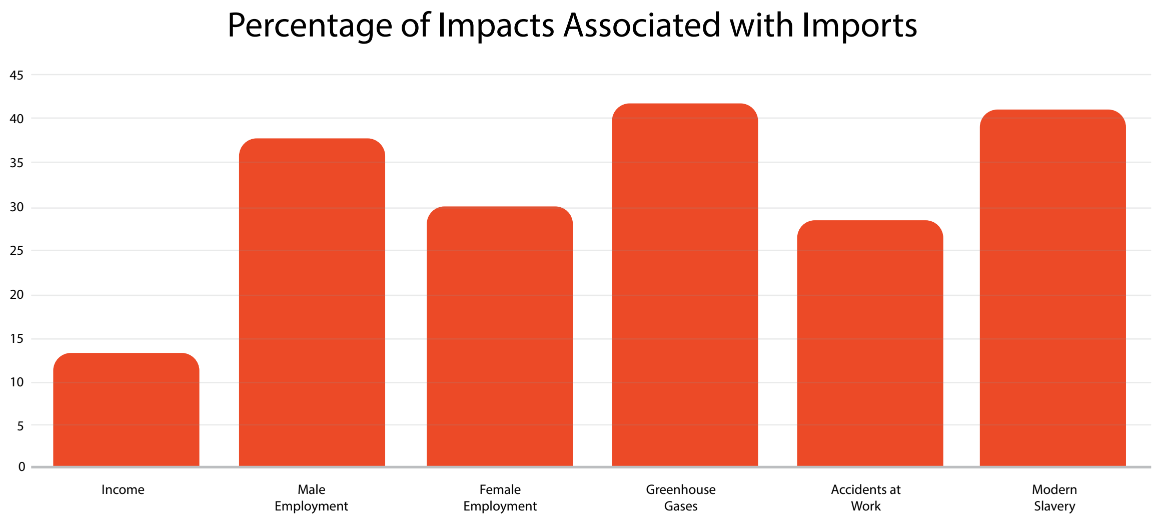
associated with fossil and mineral raw materials – in other words – the mining (energy resources, ores, and minerals) category in Fig. 1; in terms of impacts embodied within the EU (domestic) and imports (next section). In the subsequent sections, we study supply chain linkages to capture hotspots of raw material-related impacts in the EU's final demand.

The EU's impacts embodied in raw material supply chains

Raw material supply chains that connect producers with final consumers in the EU originate both domestically (within the EU) and internationally. Across all indicators,

FIGURE 1. The composition of EU's total impacts (domestic + imports) across all indicators and sectors (top) and the contribution of imports to total impacts (bottom).





EU's total impacts can be broken down into impacts resulting from domestic production and imports. Collectively, the term total impacts refers to domestic impacts plus impacts resulting from imports. The top panel categorises EU's total consumption-based impacts according to 13 broad production sectors to showcase the hotspots of impacts taking place in primary, secondary and tertiary sectors of the EU economy (Domestic; top-row; top-panel) and impacts taking place outside of the EU border (Imports; bottom-row; top-panel) for satisfying the EU's final demand. The impacts associated with domestic production and imports are shown as stacked bar charts. The bottom panel shows the percentage of impacts associated with imports, for example 41% of impacts related to greenhouse gas emissions take place outside of the EU and the rest domestically for meeting the EU's final demand. The contribution of various sectors to these 41% of the greenhouse gas impacts associated with imports is shown in the top-panel, bottom-row. *Note: The category mining (energy resources, ores and minerals) includes energy resources (coal, lignite, peat, petroleum, natural gas), ores (ores of uranium, aluminum, copper, gold, lead, zinc, silver, nickel, tin and other ferrous and non-ferrous ores) and minerals (stone, sand, clay, chemical and fertilizer minerals, salt).*

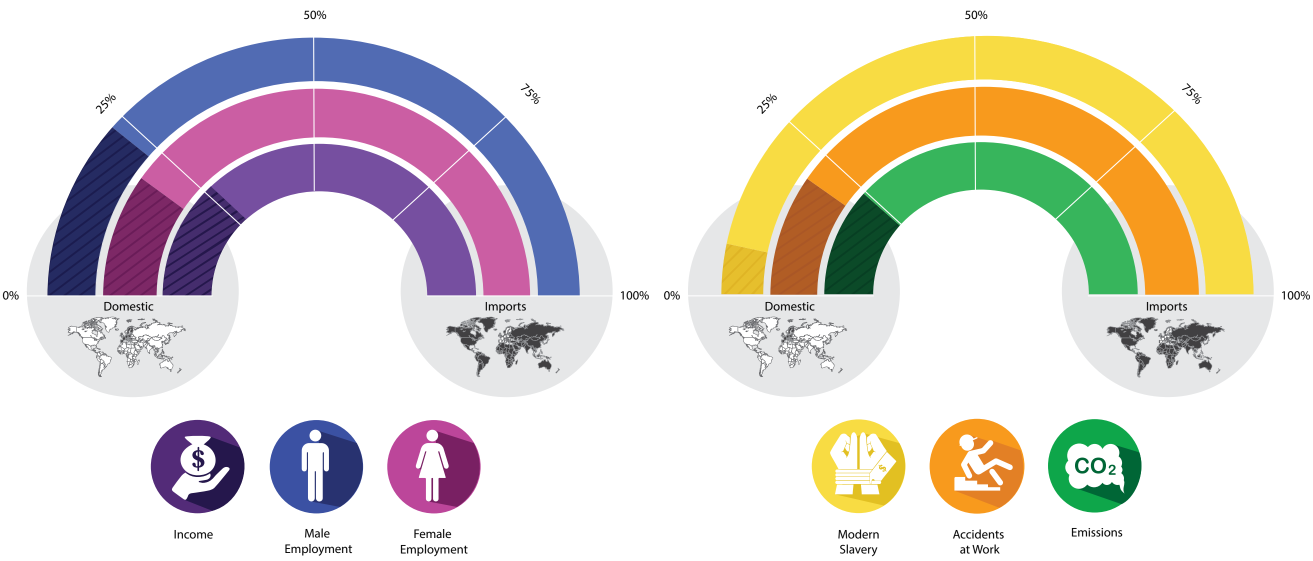
production-based impacts embodied in imports into the EU are higher than domestic production-based impacts (Fig. 2), highlighting that substantial spillover impacts of environmental and social indicators take place in international supply chains to satisfy the EU's consumption (Fig 2) that relies on raw material. Particularly for the social indicator: modern slavery, about **95% of impacts take place outside of the EU borders, underscoring risks present in raw material supply chains that originate in the EU's trading partners.** Just 5% of the modern slavery impacts take place in raw material supply chains that originate within the EU.

We present information on negative environmental spillovers including greenhouse gas emissions, and negative social impacts such as accidents at work and modern slavery (Fig. 2; panel A) as well as descriptive statistics on male and female employment and income generation (Fig. 2; panel B).

Insights on links between international trade and poverty have long been documented – international trade as a vehicle for alleviating poverty in the developing world by generating jobs and income, and there being a complex relationship with trade negatively impacting some communities [108-110]. International trade can advance or hinder a country's progress towards the UN SDGs. On positive spillovers (Fig. 2, Panel B), international trade facilitates meeting of Target 8.3 *(Promote...[...]...decent job creation); Target 8.5 (...[...]...achieve full and productive employment and decent work for all women and men...)* under Goal SDG 8. Current international trade practices do not distinguish between decent work and forced labour, and this is where social indicators such as accidents at work and modern slavery can highlight the nature of employment and negative spillover impacts (Fig. 2; Panel A; Fig. 3) that can hinder the EU's trade partners in making progress on Target 8.7 *(...[...]...immediate and effective measures to eradicate forced labour...)* and Target 8.8 *(Protecting labour rights...)*[2, 111].

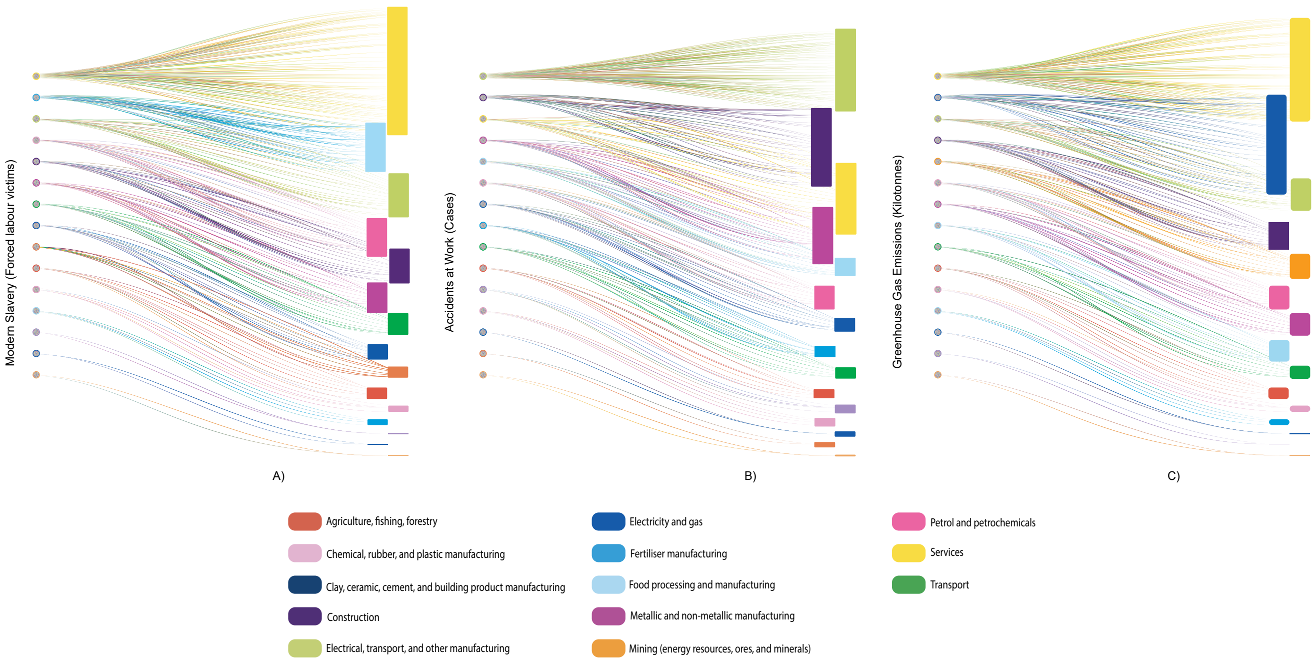
International trade is depicted by supply chains that connect producers and consumers (Fig. 3, panels A-C). From a consumption-based perspective, the **EU's secondary and tertiary sectors are key drivers of raw material-related impacts in supply chains, particularly electricity, manufacturing, construction, and service industries**; across all three negative spillovers. Mining industries provide materials that are the building block of all things around us: instruments, infrastructure and energy, to name a few [9]. Imagine a service sector - a bank – with vast offices that need lighting, technical and electrical equipment, buildings, and infrastructure and much more. Buildings are composed of construction minerals, such as sand, gravel, stone [112], and mining industries dealing with these minerals and others are prone to human right violations [113].

FIGURE 2. Impacts of raw material supply chains (mining of energy resources, ores, and minerals) for supporting EU consumption, broken into impacts taking place within the EU (domestic) and impacts embodied in EU's imports.



The graph shows the total environmental and social impacts of fossil fuel and mineral mining for satisfying the EU's consumption. Negative spillovers are modern slavery, accidents at work and greenhouse gas emissions that hinder a country's progress toward the UN SDGs; and (descriptive) positive spillovers could include income; male and female employment; although caution must be taken in addressing these as positive as these could embody unfair work and income. For this purpose, we call these descriptive indicators in the study.

FIGURE 3. Negative spillovers embodied in consumption-based impacts of EU's final demand sectors.



The figure highlights the contribution of the EU's primary, secondary and tertiary sectors (as final consumers) in contributing to environmental and social impacts in fossil and mineral raw material supply chains across the world. For example, raw materials are required in electronic and technical equipment that is used in Services sectors, which emphasises the complexity of global supply chains, with EU's Service sectors being the key contributor (Panel A) of cases of forced labour victims in supply chains. Panels: A) Modern Slavery; B) Accidents at work; C) Greenhouse gas emissions. The dots on the left of the figures depict production taking place around the world.

Social and environmental impacts are intrinsically interlinked [114], and recognising the complex relationships between these impacts is crucial for meeting the SDGs [114]; and the goals of the Paris Agreement [115]. Mining supply chains embody environmental and social impacts; and a key environmental impact is greenhouse gas emissions. The global mining sector is responsible for about 4-7% of greenhouse gas emissions [116] with worldwide damages from the sector range between €0.4 to €5 trillion [117]. Given the diversity of mining operations (that are specific to the raw material being mined), greenhouse gas impacts vary according to mining and mineral processing industries, for example, loading and hauling operations are primary contributors of emissions during the mining and processing of iron ore and bauxite; whilst crushing and grinding operations result in emissions during the production of copper concentrate from copper ore [118]. Low emission technologies are being developed to transform the mining sectors [119], but there is a "decarbonisation divide" between Global North and Global South – with the Global North transitioning to cleaner production with environmental and social harm being displaced to the Global South [120]. There is a conundrum at play here – raw material extraction results in global environmental and social impacts; whilst at the same time, these industries are at the heart of the global drive for decarbonisation with metals and minerals serving as raw materials for low-emission technologies [121].

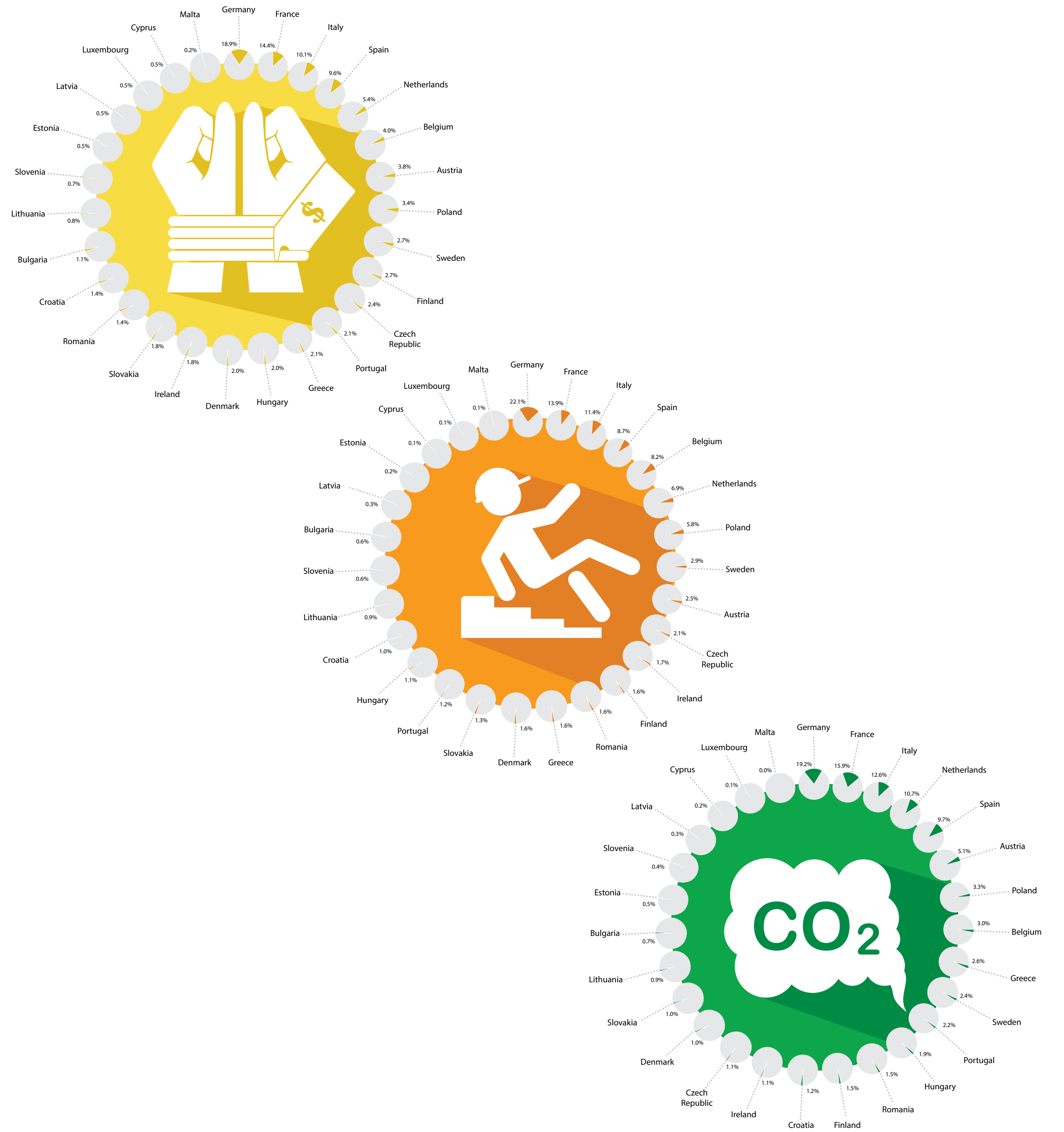
Contribution of the EU countries to negative spillovers

Across all indicators, Germany, France, and Italy are responsible for about half of social and greenhouse gas impacts embodied in the EU's raw material supply chains (Fig. 4). In 2020, Germany imported US$ 40.8billion (b) of stone, US$ 75.5b of raw materials, US$ 80.3b of metals, US$ 139b of vehicles, US$ 187b of machinery and US$ 131b of electronics. In the same year, France's imports of these commodities included US$ 15.3b of stone, US$ 36.9b of raw materials, US$ 37.0b of metals, US$ 79.8b of vehicles, US$ 96.7 b of machinery and US$ 50.8 b of electronics; and Italy's US$ 20.2b, US$ 37.7b, US$ 34.5b, US$ 38.7b, US$ 57.6b, US$ 33.8b [122], respectively. These import amounts include intra-EU trade (raw materials embodied in supply chains that originate and end in the EU in terms of producers and consumers); and inter-EU trade (the EU's trade with countries that are outside of the EU).

Germany is a key player in technological innovation and development. A steady supply of raw materials is vital for

Germany to sustain its energy, manufacturing, and service industries. Germany's demand for metals is primarily met via imports or recovery technologies (scrap to useful products: metals) as the country closed its last metal ore mine in 1992 [123]. Germany's demand for raw materials has risen as the country progresses toward low-emission technologies in car manufacturing, renewable power, aerospace, automotive, mechanical engineering and construction industries [123]. Given the country's reliance on raw materials, the German Government established a raw materials strategy in 2010 with the aim of ensuring a sustainable supply of raw materials for Germany's economy, reducing trade barriers, developing bilateral raw materials partnerships with countries, creating transparency and governance around raw material extraction [124].

FIGURE 4. Contribution of the EU countries to negative spillovers, driven by their demand for raw materials.



The figure is structured in the form of pie charts, with the contribution of EU countries reflected in their respective pie proportions, starting with the country responsible for the most impacts to the country with the least (in clockwise progression). Panels (in order): Modern Slavery; Accidents at work; Emissions.

Modern economies are vastly dependent on materials and minerals produced outside a country's borders. Whilst there are evident embodied social and environmental impacts of the EU's demand for products (both primary – minerals; metals; and secondary – electronics that rely on primary metals and minerals) (Fig. 1-3), these international trade connections are vital for economic and social development in many countries. According to the World Bank, "*Countries that are open to international trade tend to grow faster, innovate, improve productivity and provide higher income and more opportunities to their people…[which]…helps drive economic growth and reduce poverty*" [125]. However, these benefits come with negative social and environmental spillovers. As seen in recent global events, such as COVID-19 and the Russia-Ukraine War, supply chain disruptions (read: disruptions in international trade; e.g. ([126])) have much wider social impacts [127]. This is being felt in the European Union due to recent events, particularly in the context of raw material supply chains, as **Russia and Ukraine are major exporters of raw materials and energy** [127].

Decomposing the EU's negative spillovers in supply chains

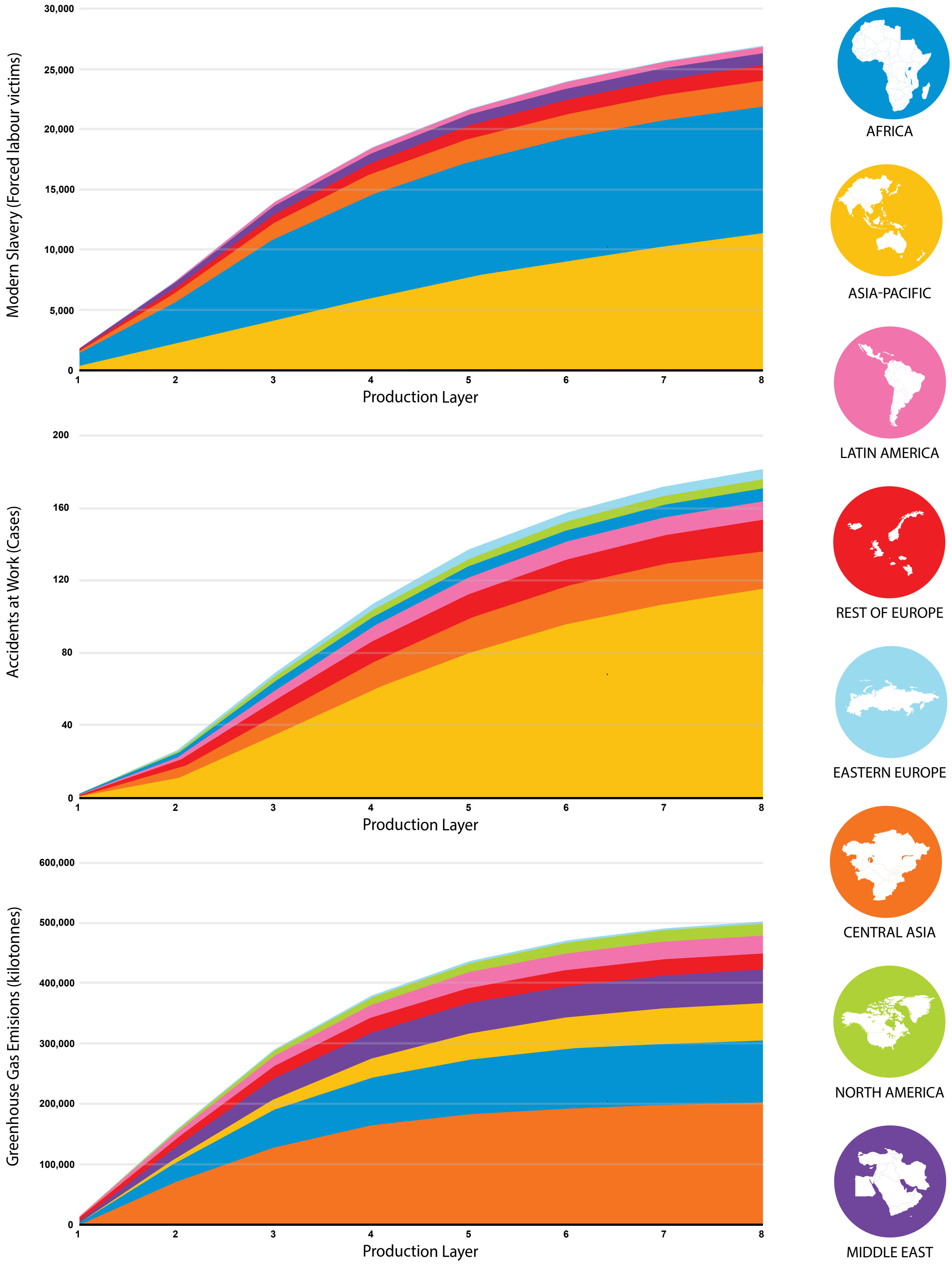
The EU's demand for raw materials in production processes is mostly met via imports. As such, most social and greenhouse gas impacts are embodied in international supply chains of the EU's raw material consumption (Fig. 2). Fig. 5 provides a breakdown of import-driven impacts into the EU according to upstream supply chains of production. It is well known that raw materials are used as building blocks in primary, secondary, and tertiary industries. Therefore, to quantify the full extent of raw material demand across all upstream supply chains, we tracked the impacts of mineral production driven by the import of raw materials directly by the EU; and processed imports, where the import-export of raw materials between countries outside of the EU eventually feeds into the EU's demand for processed electronic products, vehicles, infrastructure materials, and much more.

Africa, Asia Pacific, and Central Asia experience the greatest proportion of social and greenhouse gas impacts of the EU's demand for raw materials (Fig. 5, Fig. 6). Russia is included in the category 'Central Asia' in Fig. 5. Prior to the Russia-Ukraine War, Russia was a key trading partner of the EU. In 2020, total EU-Russia trade was €257.5b. The EU's imports were worth €158.5b, featuring fuels (€98.9b, 62%), iron and steel (€7.4b, 4.7%), fertilisers (€1.78b, 1.1%), to name a few [128]. Kazakhstan also features in the 'Central Asia' category, which dominates the male and female employment indicators in terms of jobs generated in supply chains for raw materials production for the EU. Kazakhstan's biggest trade partner is the EU, with about 41% of exports from Kazakhstan destined for the EU, mainly consisting of fuel and mining products (€11.8b, 93.7% in 2020 [129]. In Eastern Europe, Ukraine exports iron and steel, ores slag and ash, electrical equipment and fuels to the EU [130]. The EU also trades with African nations, such as importing fuels, oils and distillation products from Nigeria [131], mineral products from Burkina Faso [132], fuels and mining products, machinery and transport equipment from South Africa [133], manufactured goods and mineral products from Ethiopia [134], and mineral products (including pearls, precious metals) from Angola [135]. In the Middle East, Turkey trades significantly with the EU, making it the sixth biggest trade partner [136]. The country has a high incidence of occupational accidents – in 2021, one worker died every four hours in work-related accidents [137]. The EU's imports of fuel and mineral products from Iraq [138] contribute to environmental impacts in the nation.

In Asia, China and India are key trading partners of the EU, with China's exports to the EU mostly featuring manufactured products where minerals are used as raw materials (hence appear in supply chains when all upstream impacts are accounted for). Key imports from China to the European Union include machinery & vehicles, manufactured goods and chemicals [139]. India also exports manufactured goods to the EU [140], such as iron, steel, aluminium, and granite [141]. Afghanistan has a history of labour exploitation [142], and the country exports mineral products to the EU [143]. Myanmar ranks 18 out of 167 on the Prevalence Index with a 65.92/100 vulnerability to slavery score [144] and is an exporter of textile products to the EU [145]. In Asia-Pacific, Indonesia is also a trading partner of the EU; for example, Germany and France imported US$ 156m of copper ore and US$ 5.6m of coal from Indonesia in 2020 [146], generating jobs (positive spillover) but also accidents at work (negative spillover).

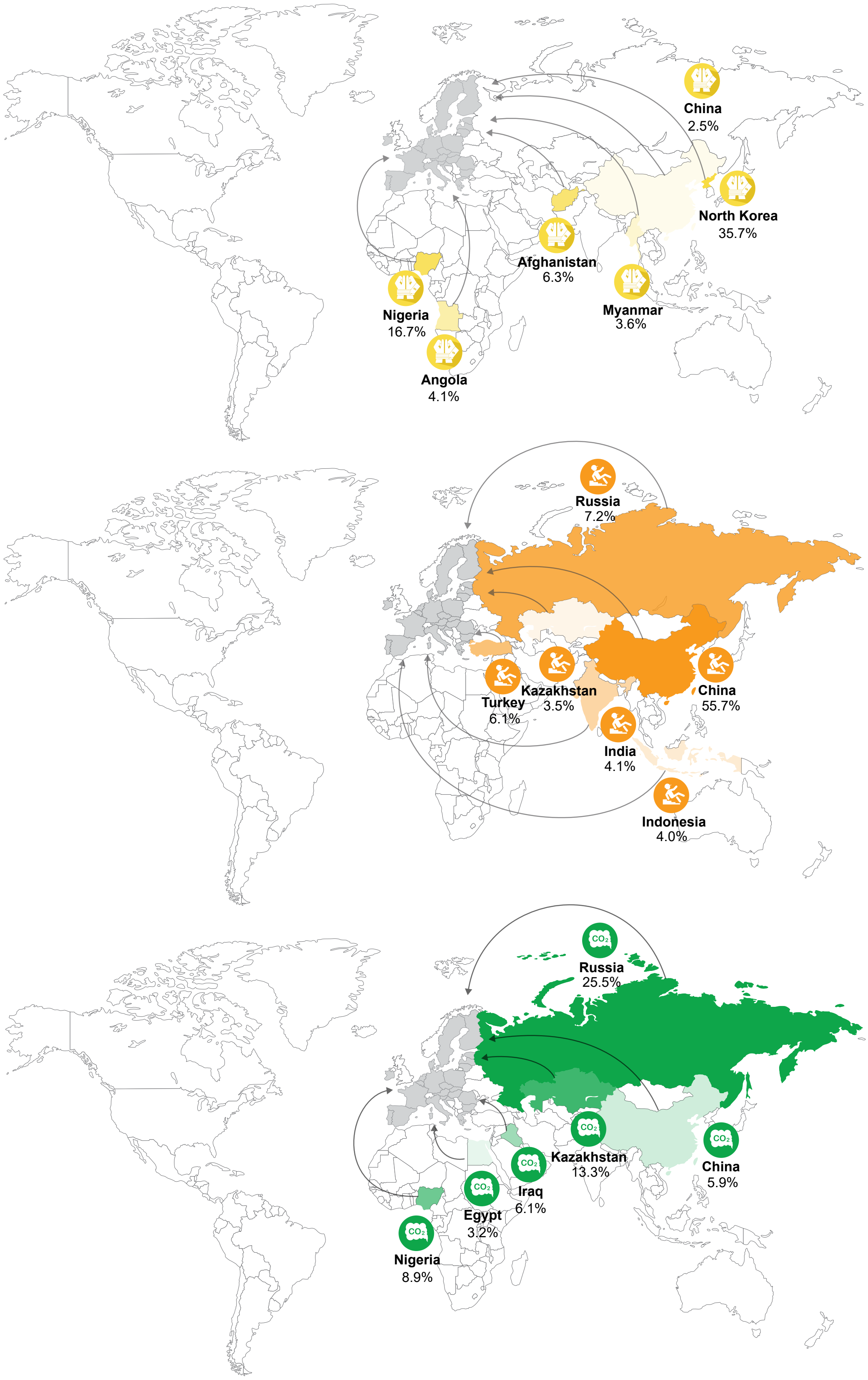
It is worth noting that Fig. 6 presents a world map of the primary producers and final consumer (EU). The graphs depict primary producers where raw materials are mined (thus resulting in spillovers), which are either sent directly to the EU (e.g., China to the EU) or sent to other countries for pre-processing before finally exporting mineral-embodied products to the EU (e.g., North Korea to China to the EU). The percentage contribution of various nations relies on the data-set used for sustainability assessment (see Section 2).

FIGURE 5. International trade-driven social spillover impacts of EU's demand for raw materials.



Production layer decomposition of total embodied social and environmental spillover impacts driven by EU's demand for raw materials. X-axis: Upstream supply chain tiers; y-axis: indicators (Greenhouse gas emissions, accidents at work, modern slavery). The figure represents international spillover impacts in eight broad regions outside the European Union, which produce raw materials for supporting the EU's final demand. The graph presents cumulative impacts up to layer 8, which cover all sectors of the global economy.

FIGURE 6. World maps of international spillovers that connect primary raw material production to consumption, i.e. mining (energy resources, ores and minerals) to final consumption by the EU.

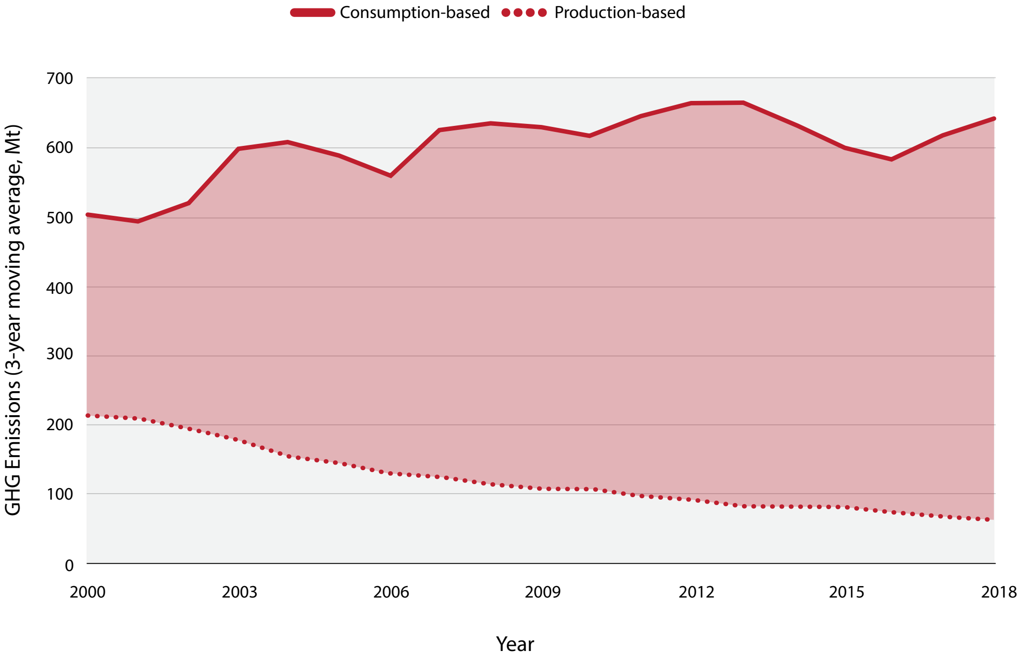


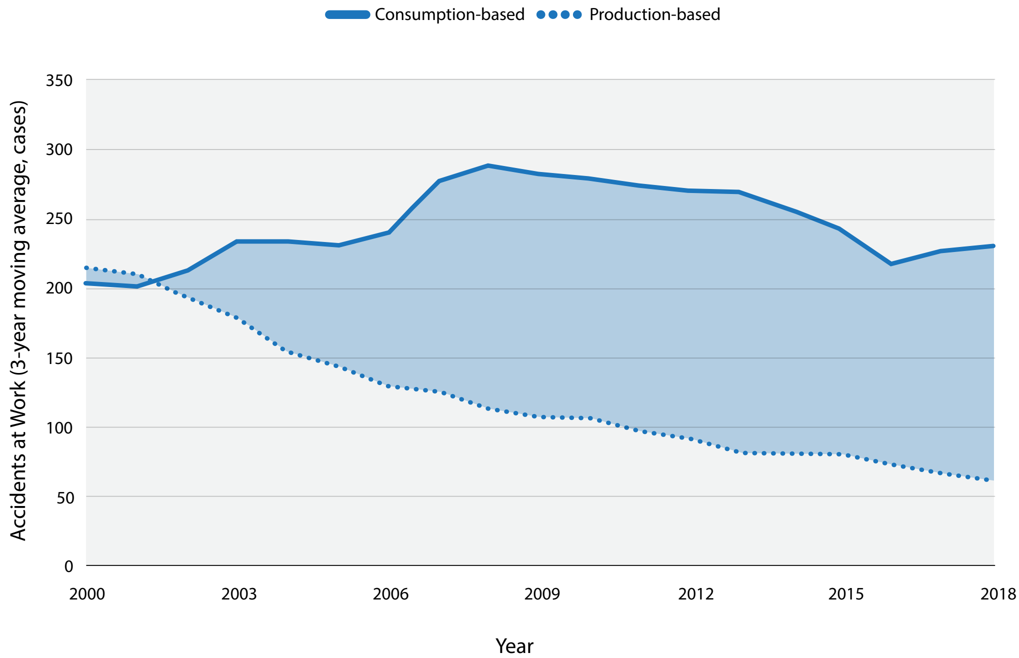
The graphs depict primary producers where raw materials are mined (thus resulting in spillovers), which are either sent directly to the EU (e.g., China to EU) or sent to other countries for pre-processing before finally exporting raw material-embodied products to the EU (e.g., North Korea to China to EU). The figure captures indirect supply chain impacts. *Note: The top regional supply chain interactions and percentages are based on the findings from footprint estimations based on the selection of the international trade database (See Methods).*

Trends in spillovers – accidents at work and emissions

At this stage, there is no sign of decrease in imported GHG and accidents at work associated with the EU's consumption of raw materials. Fig. 7 demonstrates the trends over 3-year moving averages using MATLAB [147]. Across the time-series considered, production-based impacts (domestic production + exports) have decreased; and consumption-based impacts (domestic production + imports) have increased; and the gap is widening. Note here that Fig. 7 only considers mining supply chains. Many of the EU instruments to curb spillovers have either been adopted recently (over the past 2 years) or are in discussion and therefore the effects of these instruments and policies are not yet reflected in this study.

FIGURE 7. Trends in production-based and consumption-based and imports for the indicators: GHG emissions (units: Megatonnes) and accidents at work (units: cases).





The graph highlights that the EU's consumption-based impacts are much higher than production-based impacts (when plotted as a 3-year moving average), with imports of commodities that are associated with emissions and occupational hazards outside of the EU borders.

4. DISCUSSION

"Whether we talk about chips for virtual reality or cells for solar panels, the twin transitions will be fuelled by raw materials. Lithium and rare earths are already replacing gas and oil at the heart of our economy.[…]. This is where our trade policy comes into play. New partnerships will advance not only our vital interests – but also our values." Ursula von der Leyen, President of the European Commission, State of the Union address, 14 September 2022.

The estimates provided in this study show that the extraction and production of raw materials and products imported into the EU are associated with significant negative environmental and social impacts, including greenhouse gas emissions, accidents at work and forced labour. Globally, the ILO estimates that 27.6 million people are in a situation of forced labour and this number has increased since 2016, notably in Africa and the mining sector [148]. Increased demand for raw materials in the EU, renewable energy transition and other technologies may further increase negative impacts embodied in the EU's supply chains. Our study shows that forced labour happens everywhere, including the EU, yet the bulk of the EU's forced labour footprint happens abroad to satisfy the EU's demand for goods and services.

There is an ethical and economic case for the EU and rich countries to lead global efforts to curb environmental and social spillovers embodied in international supply chains, including raw materials. Historically, rich countries are responsible for the lion's share of greenhouse gas emissions that drive climate change. Extreme weather and environmental degradation worsen pre-existing socio-economic vulnerabilities, deepen exclusion and marginalization, drive population displacement and migration and, as such, are closely linked with increased vulnerability to forced labour and workers' exploitation [149]. Further, it is economically beneficial at the global and country level to curb greenhouse gas emissions [150] but also to reduce forced labour. Reduced forced labour tends to be associated with lower healthcare costs, higher tax revenues for governments and greater productivity [151]. Understanding the environmental, human rights, and economic benefits of preventing spillovers is exceedingly clear for companies, which can face reputational costs for their lack of efforts to curb impacts, such as forced labour or greenhouse gas emissions in their supply chains.

A three-pillar framework to curb environmental and social spillovers embodied in the EU's consumption of raw materials

Building on our previous work on measuring and addressing negative international spillovers in the context of the SDGs and Agenda 2030 [106], we introduce a three-pillar framework to curb environmental and social spillovers embodied by the EU's consumption of raw materials. The framework emphasizes the role of international cooperation and SDG financing to address the root causes of workers' exploitation and forced labour and support the transition in least developed countries towards more sustainable extraction and management of materials, including those minerals with high average GHG intensity, such as Neodymium oxide, cobalt, aluminum, and lithium hydroxide. The framework also recognizes the importance of the EU's trade policies and border controls, sound data and enforcement systems, responsible consumption, the circular economy and innovation to reduce the EU's environmental and social footprint embodied in raw material consumption. Notably, the framework can be adjusted to other supply chains.

EU Domestic Instruments & Regulations	Green Deal/SDG Diplomacy & Financing	Responsible Consumption, Recycling & Innovation
Including due diligence regulations, accountability mechanisms, strong data systems and possibly border mechanisms such as import bans	*EU's leadership in promoting the "SDG Stimulus" internationally, investing in physical and human infrastructure via the Global Gateway and promoting SDG values internationally*	*Energy efficiency, circular economy, and sustainable innovations, including in hydrogen & energy storage, to reduce the EU's footprint embodied in its consumption of raw materials*

The EU Domestic Instruments & Regulations

The first pillar emphasizes actions the EU can take to reduce (and even eliminate) imports of materials, goods and services extracted and produced abroad that generate large negative environmental and social impacts. Trade is largely a responsibility of the EU. This can take the form of border adjustment mechanisms, tariffs and import bans but also stronger requirements for businesses to track these impacts and take actions throughout the full supply chains. These can promote the right level-playing field and incentivise businesses and partner countries to act. Overall, 86% of forced labour cases occur in the private sector (and the remaining 14% in the government sector) [148].

Still under debate, the EU's ***due diligence law*** may help address human rights violations and environmental degradation embodied in the EU's imports. The Corporate Sustainability Due Diligence Directive (CSDDD) presented by the European Commission in February 2022 may impose far more stringent requirements on companies operating in the EU to identify and address violations of human rights, biodiversity, and the environment in their supply chains. Companies would also need to establish a procedure for complaints and disclose publicly information about how they fulfil their due diligence obligations. Building on the experience of the French and German due diligence regulations, enforcement mechanisms and strong data systems will be key for effective implementation [152]. Despite the ongoing debates, notably on the scope of companies covered under the regulation, the CSDDD is likely to be adopted by the European Parliament in 2023 and may provide a real breakthrough to address the negative impacts of high-risk sectors, including textile and leather industries, agriculture and forestry, fisheries as well as minerals and mining. Additionally, the EU has announced due-diligence legislation specific to the extractive sector. This includes the EU Conflict Minerals Regulation [153] & the draft EU Battery Regulation [154]. Notably, a EU Critical Raw Materials Act is in the public consultation phrase [155]. The Act aims to monitor capacities and strengthen both the EU value chain and the EU external policies on Critical Raw Materials [155, 156].

The EU has also adopted and is currently discussing various ***border mechanisms to ban or impose tariffs*** on goods and services that are linked with environmental degradation and forced labour. In September 2022, the European Parliament passed a bill to ban imports of deforestation-linked commodities. That same month, the European Commission presented its draft proposal to ban forced labour products from entering the EU, mirroring existing legislation in the U.S. and Canada. Now, the European Parliament and Council of the EU needs to discuss and approve the proposal. The specificities of the Carbon Border Adjustment Mechanism (CBAM) are still being discussed to ensure economic efficiency, environmental integrity, and WTO compatibility. The generalized scheme of tariff preferences (GSP) - the unilateral tariff preferences in favour of developing countries - and the GSP+ mechanism, which provides preferential market access to countries that have ratified major international climate and human rights conventions, may be further leveraged and expanded in the context of the Green Deal and SDGs. The new GSP Regulation is expected to enter into force on 1 January 2024 [157]. Finally, the new Trade and Sustainable Development (TSD) Action Plan presented in June 2022 includes new measures to improve the monitoring of TSD chapters in Free Trade Agreements and stronger enforcement mechanisms, including sanctions, in case of non-compliance. While recognizing this progress, civil society also underlined some of the persisting blind spots of the new TSD, including the absence of "ratchet up" mechanisms to make TSD chapters more dynamic and increase environmental and human-rights ambitions of the EU's trade policy over time [158].

Both the due diligence regulation and increased border controls require strong ***data and information systems*** for effective implementation. More data-driven conversations are needed to reform the governance of global supply chains and to address their negative social and human rights impacts. Creating data systems that are fit for purpose should be an important priority of the EU at the national, industry, and business levels to curb negative spillovers embodied in imports of raw materials and mineral products. Spillover data should be more systematically included in official SDG reporting, including Voluntary National Reviews (VNRs). The EU-wide VNR to be presented at the United Nations in July 2023 (and other VNRs of the EU member states) could integrate a section on spillover effects in the context of the SDGs and Agenda 2030 [159], building, for instance, on the excellent work of Eurostat and other EU institutions [160, 161]. Transparent customs data can also help mobilize civil society and other stakeholders and help better connect trade policy and imports with human rights and environmental violations. Belgium announced the creation of an observatory on critical raw materials in 2023, which will provide evidence and formulate policy recommendations to promote more sustainable supply chains [162, 163].

There are specific challenges related to estimating forced labour and child labour in supply chains. **Forced labour is particularly challenging to measure, considering that it can be harder to demonstrate the nature of the constraint imposed on workers and, therefore, may not be directly observable**. Due to the lack of regular national surveys on child labour and forced labour in many countries, the data available in upstream supply chains are often scarce or incomplete [148]. This is highlighted in a global study on modern slavery footprints [107]. Data gaps made it difficult to accurately measure cases of modern slavery and accidents at work in supply chains since national statistics on these indicators form the backbone of supply chain assessments. Significant progress has been made on MRIO databases for enhancing the timeliness and accuracy of footprint assessments; and for analysing the progress of world nations toward the UN SDGs [101]; however, gaps do remain for physical data (especially on social indicators). Uncertainties exist without robust information on these indicators, and they considerably hinder progress toward tracking spillovers in international supply chains.

Businesses should systematically include spillover information related to their supply chains in annual sustainability and SDG reporting. Ideally, businesses would identify relevant indicators and time-bound environmental and social targets for each of them [106]. Spillover data and information also need to be considered more systematically in standards and ratings for corporate social resfponsibility, as developed by the Global Reporting Initiative, the Science-Based Targets Networks, the World Benchmarking Alliance, and others. The four-pillar framework standard for SDG-aligned food [164] and textile companies [165] can be adjusted to help align corporate reporting of businesses involved in the mineral industry with the SDGs.

Besides data and information systems, guidelines, toolkits, and technologies must support companies' efforts to prevent and address forced labour in their supply chains. The EU's guidance for companies to combat forced labour in supply chains enhances companies' capacity to eradicate forced labour [166]. The OECD's due diligence guidance for responsible supply chains of minerals provides "*step-by-step recommendations endorsed by governments for globally responsible supply chains of minerals for companies to respect human rights and avoid contributing to conflict through their mineral or metal purchasing decisions and practices*" [167]. In France, Ressources Humaines Sans Frontières (RHSF) experiments with solutions and shares its expertise with private companies and other stakeholders to curb forced labour in supply chains, including via actions in the field [168]. Blockchain and other innovative technologies may be further leveraged to strengthen the sustainability of mineral supply chains [169].

Green Deal/SDG Diplomacy & Financing

Border regulations – especially import bans and tariffs – must be part of a larger package of efforts to support investment in cleaner production systems and digital technologies in developing countries in the Global South. Otherwise, the rest of the world may perceive domestic border measures as hidden protectionism, which could slow or stop bold efforts to achieve the SDGs and climate action in developing countries. They may also worsen living standards and poverty in certain communities. As emphasized by the Anti-Slavery group: "*Import controls should not be the only measure used to address forced labour in global supply chains. Instead, they should be introduced as part of strong legal, **trade and development framework** to address the root causes of forced labour – poverty, lack of legal protection, worker representation and discrimination*" [170].

Ultimately, the root causes of the lack of progress on SDG 8.7 (End Modern Slavery, Trafficking and Child Labour) in raw material supply chains (and other industries) are related to the lack of progress on other SDGs, including SDG1 (Zero Poverty), SDG2 (No Hunger), SDG4 (Quality Education), SDG7 (Clean and Affordable Energy) and SDG16 (Peace, Justice, and Strong Institutions) among others. Multiple crises – health, security, and climate – increase the vulnerability to forced labour. As such, urgent actions from the international community are required to invest in human capital and physical infrastructure needed to achieve the SDGs.

Recently, the EU and U.S. leaders have recognized the importance of international cooperation to curb negative spillovers. When announcing its agreement with the general approach of the CBAM in March 2022, the Council of the European Union also "*noted the importance of greater international cooperation with third countries*" [171]. It is also worth citing at length the remarks of Janet Yellen, Secretary of the U.S. Treasury, at the Center for Global Development in October 2022:

> "*Emerging markets and developing countries are often most acutely affected both by global shocks and by **spillovers from the policies of advanced countries** [...] Conversely, lack of development can magnify global challenges and increase vulnerabilities, with negative spillovers onto the rest of the world. [...] Without urgent and concerted action, the world is unlikely to meet the Sustainable Development Goals by 2030. [...] **We must also help developing countries transition their economies away from carbon-intensive energy sources** and expand access to clean energy. [...] If the global community benefits from investments in climate, then the **global community should help bear the cost.***"

The SDGs represent European values of a social market economy with environmental sustainability. Promoting the SDGs at an international level should be a key pillar of European diplomacy and development cooperation. In an increasingly multipolar world, where multilateralism is under unprecedented pressure, European partnership, diplomacy, and soft power will be vital to uphold the values incorporated in the SDGs [172].

Two important aspects are needed to strengthen the EU's Green Deal / SDG Diplomacy: international financing for sustainable development and technical & research collaboration. Rich countries, including the EU and its Member States, need to lead in developing a global plan for financing the SDGs, one covering official development assistance, blended finance instruments, specific climate mitigation and adaptation funding, and others for safeguarding Global Commons. Countries (with and alongside Multilateral Development Banks and Public Development Banks) also need to deepen their technical cooperation and share know-how to better understand policies, investments, technologies, and pathways supporting SDG transformations in developing countries. The G20 Bali Leaders' Declaration adopted in November 2022, and especially the section on financing the SDGs, goes in the right direction.

Rich countries (especially those in the G7 and G20) should lead global efforts to implement the call made by UN Secretary-General António Guterres in September 2022 for an **"SDG Stimulus"** to address the limited fiscal space in low- and middle-income countries. Estimates vary, but recently the IMF estimated that, collectively, developing countries must invest at least US$ 1t in energy infrastructure by 2030 and US$ 3t to US$ 6t across all sectors per year by 2050 to mitigate climate change and a further US$ 140b to US$ 300b a year by 2030 to adapt to the physical consequences of climate change [173]. These efforts could build on positive moves made at COP26 in November 2021, including pledges by the United States and the EU to slash methane emissions and the EU's commitment of €1b to protect world forests or new forms of North-South Partnerships, such as the new Partnership for a Just Transition for South Africa. Large infrastructure projects led by the EU ("Global Gateway"), China (Belt and Road) and the U.S. (Build Back Better World) should work together to support cleaner energy and production systems globally. The U.S. worked closely with the EU (but also Australia and New Zealand, and other countries) in the design of effective import bans to curb forced labour, and similar cooperation could be expanded to major infrastructure projects in developing countries.

The G7 and G20 can also support international governance reforms, notably via the World Trade Organization, the World Bank, and the rest of the UN system. It is also crucial to reinforce the role of Multilateral Development Bank (such as the World Bank) and the IMF, to better connect access to financing and sustainable development policies. Recently, the U.S. and Germany lobbied for greater financial support from the World Bank to help developing countries deal with the consequences of climate change [174]. The ILO and other major international initiatives, such as the Alliance 8.7 and Pathfinder Countries, should be adequately supported to help strengthen social protection systems, workers' rights, collective bargaining and working conditions in cooperation with national governments as well as local authorities and communities. Finally, global taxation reforms should also help curb profit shifting and unfair tax competition so that governments have more revenues to invest in SDG transformations. As demonstrated with the adoption of the Green Deal – which was followed by numerous net-zero commitments all over the world - the EU can play a decisive role in the adoption and implementation of bold SDG commitments globally.

Responsible Consumption, Recycling, and Innovation

The war in Ukraine and energy crises in Europe and other regions have rebalanced public discussion and awareness, which was until recently overwhelmingly dominated by "production" side measures towards sustainable consumption and energy efficiency. This was emphasized in France by President Emmanuel Macron's call in September 2022 for increased "*sobriété énergétique*" ("energy savings"), followed by an action plan by the French government. This was also emphasized in the State of the Union address by Ursula von der Leyen (President of the European Commission) in September 2022, "*[…] putting forward measures for Member States to reduce their overall electricity consumption*". Transitioning towards more responsible consumption and the circular economy (including recycling electronic waste) can help reduce rich nations' global footprint embodied in raw material supply chains and other industries. Innovation, for instance, in clean hydrogen and energy storage, may also help reduce the consumption footprint of raw material extraction and other industries.

The European Green Deal and its focus on renewable energy and digital technologies will likely increase the EU demand for raw materials in the coming years. According to the IEA, "*solar photovoltaic (PV) plants, wind farms and electric vehicles (EVs) generally require more minerals to build than their fossil fuel-based counterparts. A typical electric car requires six times the mineral inputs of a conventional car, and an onshore wind plant requires nine times more mineral resources than a gas-fired plant*" [169].

Efforts to bolster energy efficiency, recycling, technology, social innovations, and sustainability standards can relieve the pressure and footprint of raw material supply. The IEA emphasizes the huge scope for progress in recycling metals, including many energy transition metals such as lithium and rare earth elements. In the context where EV batteries reaching the end of their first life is expected to surge after 2030 [169], innovation on the demand and supply side can also help make the raw material supply chains more sustainable. On the demand side, supporting Research and Development and innovations in energy storage and in the manufacturing and design of renewable energies (including solar panels) are key priorities. In fact, in recent years, innovations in Crystalline silicon panels have contributed to a sharp reduction in their material intensity [169]. On the supply side, innovations and emerging technologies can help lower material extraction and management emissions.

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