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TRADE IN LOW-CARBON TECHNOLOGY PRODUCTS: MACRO AND MICRO EVIDENCE FOR ITALY

by Valerio Della Corte*, Stefano Federico* and Giacomo Oddo*

Abstract

The transition towards a carbon-neutral economy is poised to significantly impact on global trade flows. This paper presents new evidence on the evolution of these flows at both the global and European levels, with a particular emphasis on Italy. We combine a macro analysis of aggregate trends in the trade of low-carbon technology (LCT) products with a micro analysis of Italian firm-level data to examine the characteristics of Italian firms that actively export LCT products. The findings offer insights into how the shift to a carbon-neutral economy affects trade dynamics at a global level and into the role of Italian firms in this evolving landscape.

JEL Classification: F14, F18, Q56.

Keywords: international trade, green transition, low-carbon technology products, Italian economy.

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1 Introduction[1]

The Paris Agreement, signed in 2015, is a legally binding international treaty adopted under the United Nations Framework Convention on Climate Change (UNFCCC), where 194 countries committed to make the necessary efforts to limit the global temperature increase below 2.0° C above pre-industrial levels.[2] Its objective calls for policies aimed at reducing emissions of greenhouse gases, particularly carbon dioxide, which is a by-product of many essential processes, such as combustion and breathing. Therefore, the world economy has started transitioning away from the exploitation of energy based on fossil fuels, gradually adopting cleaner and/or renewable energy sources and more efficient production and transportation systems. The transition toward a carbon-neutral (or net zero emissions) economy requires a profound transformation of industrial processes and technologies. This shift will lead to a gradual decrease in the demand for polluting and carbon-intensive products and a corresponding increase in the demand for low-carbon or "green" products, creating both winners and losers among firms and countries.

In this context, we aim to assess Italy's position in the trade of green flows compared to other main countries. We follow a two-step approach: First, we report the main aggregate trends up to 2023 in world trade of low-carbon technology (LCT) products, as defined by the IMF, focusing on Italy's comparative advantages and those of its euro-area peers. Second, we complement these findings with a micro-level assessment, analysing Italian firm-level customs data to highlight the main characteristics of Italian exporters of LCT products.

Our paper is closely related to recent studies examining countries' production capabilities in the green economy (Fraccascia et al., 2018; Mealy and Teytelboym, 2022; Andres et al., 2023; Bontadini and Vona, 2023; Arslanalp et al., 2023). With respect to these studies, we provide a more updated perspective by analyzing world trade flows up to the end of 2023. This is a significant contribution given the recent acceleration of the green transition and the increasing share of LCT products in world trade, which has started altering traditional patterns of comparative advantage. To the best of our knowledge, this study is also the first to analyze competitiveness in green products at the firm level for the Italian economy.

Our paper contributes also to the debate on the implications of green transition and climate change mitigation policies for the Italian economy. Existing literature has primarily focused on various relevant aspects such as agriculture, business demographics, or the labour market (Alpino et al., 2022; Basso et al., 2023). However, it has generally overlooked the issue of Italy's competitive position in international markets, with a few exceptions (Intesa-Sanpaolo, 2021; SACE, 2023; Confindustria, 2024).

The rest of the paper is structured as follows. Section 2 introduces and discusses the various definitions of green products proposed in the literature. Section 3 describes the data sources used in this study. Section 4 presents macro evidence on the international exchange of green products, based on international trade flows, focusing on Italy in comparison with its European peers. Section 5 takes a micro perspective, analyzing firm-level data on Italian exporters of green products. Section 6 offers additional results from a complementary

[1] The views expressed in this paper are those of the authors and should not be considered as reflecting those of Banca d'Italia or the Eurosystem. While retaining full responsibility for all remaining errors and omissions, the authors wish to thank Silvia Fabiani, Alberto Felettigh, Simona Giglioli, Claire Giordano, Luciano Lavecchia, Michele Mancini, and Alfonso Rosolia for useful comments and suggestions on a previous version of the paper.

[2] More info on the Paris Agreement can be found on the United Nations website.

assessment of countries' competitive positions in the green transition, considering their specialization in brown products and their exposure to transition risk. Finally, Section 7 wraps up with concluding remarks.

2 Definitions of green products

The first key issue when assessing the competitive position of a country in the transition process to a low-carbon economy is of course the empirical identification of "green" products (i.e. products that are particularly relevant for the green transition). Historically, the first attempts to compile lists of green products have been made in the context of multilateral negotiations, to waive or reduce tariffs on selected goods that were deemed crucial for environmental protection or the low-carbon transition, leading to the formulation of multiple lists of green products by various international organizations (e.g. WTO list in 2001 and APEC list in 2012). Admittedly, these lists were to some extent biased by political economy considerations, as each country negotiates "green" tariffs with the natural intention to favor their comparative advantage (Balineau and De Melo, 2011; Bontadini and Vona, 2023).

There are also conceptual and practical challenges associated with the definition of green or environment-friendly products. Green products can confer environmental benefits either directly, such as the goods whose production process has a lower content of carbon dioxide or is associated with less pollution (also called "adapted" goods in the IMF terminology), or they can confer benefits indirectly, such as the goods that allow reducing carbon-dioxide and/or enhance the efficiency in the production of other goods or the supply of other services (also called "connected" goods in the IMF terminology). Moreover, once a definition has been put forward, the appropriate categorization of green products within existing trade and industry classification systems can also be challenging. For instance, some products, defined as green according to the current statistical nomenclatures (such as the Harmonized System, which is used for trade statistics at the international level), may have a dual use (for example, a turbine can be used in a green way, like in a hydroelectric power plant, and in a non-green way, like in a coal-fired power plant). The speed of technological innovation adds complexity to this challenge, making lists and taxonomies obsolete if not regularly updated.

Given the lack of a global consensus on which goods should be classified as "green", we take into consideration the following four different classifications:

1. Low Carbon Technology products (LCT), developed by the IMF (Arslanalp et al., 2023).

2. Combined List of Environmental Goods (CLEG) used by the OECD in their official data and publications (e.g. Trade in environmentally related goods.)

3. Environmental goods (EG), defined by the IMF in their *Trade in Environmental Goods statistics*, published in 2021.

4. Critical goods for the green transition, recently developed by the Trade Expert Network of ECB's International Relations Committee (IRC Trade Expert Network, 2024).

The LCT classification, originally proposed by Pigato et al. (2020), focuses on goods that lead to a reduction in carbon dioxide emissions, either directly (i.e. in their production) or indirectly (i.e. as they contribute as input in the production process of other goods). Hence, LCT goods are products that entail less pollution than their traditional counterparts and are going to play a pivotal role in the transition to a low-carbon economy.[3] The list includes renewable wind energy (offshore and onshore), solar energy (on- and off-grid, solar photovoltaic and solar thermal), energy-efficiency technologies used in buildings, industrial processes, vehicles, heating and cooling, lighting, and appliances, totaling 124 products at the 6 digit level according to the 2017 Harmonized System classification. We split LCT goods into seven categories, according to their relation with different dimensions of the green transition:[4]

1. REP: clean energy and renewables (products related to the production of energy from renewable sources and/or with low carbon emissions);
2. EPR: reduction of environmental impact;
3. MON: environmental monitoring;
4. SWM: solid and hazardous waste management;
5. EVX: sustainable mobility (including electric and hybrid vehicles);
6. BAT: batteries (including energy accumulators);
7. OTH: other LCT products not included in previous categories.

Among all the existing taxonomies of green/environmental products, the CLEG, originally proposed by Sauvage (2014), is the most comprehensive, as it builds upon the two previously mentioned lists from WTO and APEC, and it expands them further, including products from the PEGS - Plurilateral list of Environmental Goods and Services developed by the OECD. In its updated definition of the 6-digit level HS 2017 harmonised system classification, this list spans over eleven categories of very diverse green and environmental products: air pollution control, cleaner / resource efficient goods, environmentally preferable goods, natural resource protection, noise and vibration abatement, components of renewable energy plants, management of solid or hazardous waste, soil and water remediation, water management, heat and energy management, environmental monitoring and analysis, covering a total of 255 products.

The IMF list of environmental goods is a list of 222 products at the HS 6-digit level. The list of environmental goods originally identified by the OECD (1999) was used as a starting point for identifying "adapted" goods (adapted to be more environmentally friendly or "cleaner") and "connected" goods (goods connected to environmental protection). Examples of connected goods include septic tanks, catalytic converters for vehicles, trash bags, bins, rubbish containers and compost containers. Examples of adapted goods include bio-fuels, mercury-free batteries, and hybrid and electric cars. To the original OECD (1999) list, an additional 108 codes were added by consulting the Amendments to the HS Nomenclature, which are published every five years by the World Customs Organization. Furthermore, six additional

[3]Generally speaking, these goods typically have lower emissions than their traditional alternatives or contribute to producing less polluting outputs. The assessment of their "carbon efficiency" should consider their entire life-cycle, not just the production phase. However, the selection of LCT products must remain unaffected by the technology used to power their production process in the specific country of manufacture, to ensure cross-country consistency. Therefore, a solar panel is classified as an LCT product regardless of whether it was produced in a factory powered by renewable energy or fossil fuel.

[4]The 7 LCT subcategories are derived from the 11 CLEG subcategories presented in Sauvage (2014) and listed in table 1. However, due to their differing numbers, the two sets of subcategories do not correspond exactly. Even when their three-letter codes match, they do not necessarily contain the same bundle of products.

codes were included to identify new items that have been added due to environmental and social issues and technological advances, which meet the definition of environmentally adapted goods, as well as the Combined List of Environmental Goods. The IMF list of environmental goods has a 60% overlap with the CLEG (134 out of 222 codes, see table 1).

Finally, we also considered the list of critical goods for the green transition (ECB) developed by the IRC Trade Expert Network (2024) in the context of analytical work carried out within the International Relations Committee of the European System of Central Banks. This list includes products identified in the Inflation Reduction Act by the US Administration (e.g. electric vehicles, electric batteries, and rare earth elements), as well as items highlighted by the European Commission as critical. This list includes 129 6-digit codes, and it has a very limited overlap with the other three lists (103 codes out of 129 are included neither in CLEG nor in any of the other lists, see table 1). Indeed, apart from a few codes related to electric and hybrid vehicles, the ECB list aims at identifying commodities, components, and raw materials (including rare earths) that are key for the green transition (e.g. lithium for batteries production, etc.).

As our baseline classification, we prefer to consider the list of LCT products. This classification has several advantages compared with the other three options: it is focused on goods that have a key role in the green transition and it strikes a good balance between consistency and comprehensiveness, taking into account all the main dimensions of the transition. Other classifications either miss some important groups of products or are too encompassing (for example, the CLEG leaves out batteries and electric accumulators, while it includes biodegradable plastics; the ECB leaves out goods for environmental monitoring and some of the products related to the production of renewable energy). Moreover, in contrast to CLEG and EG classifications, the LCT list includes a lower number of dual-use products (such as pumps/compressors, electrical static converters, lamps). Finally and importantly, it offers the empirical advantage of being coded directly in the 2017 vintage of the Harmonized System classification, which is the most appropriate, together with the subsequent vintage, for monitoring recent trends in world trade.[5]

[5]For instance, an important innovation introduced in the HS 2017 amendment is the separation of vehicles into subcategories that distinguish vehicles with exclusively an internal combustion engine from hybrid motors, plug-in hybrid motors, and fully electric cars.

Table 1: Comparison of classifications by CLEG category.

Notes: world trade data refer to 2023. "ECB" is the list of Critical goods for the green transition recently developed by the IRC Trade Expert Network (2024). "LCT" is the list of Low Carbon Technology products (LCT) developed by the IMF (Arslanalp et al., 2023). "Environmental goods" is the list of Environmental Good defined by the IMF in their *Trade in Environmental Goods statistics*, published in 2021. "CLEG" is the Combined List of Environmental Goods used by the OECD in their official data and publications (e.g. Trade in environmentally related goods.)

Subcateg.	Description	ECB	EG	LCT	CLEG	ECB	EG	LCT	CLEG
		number of HS codes				World trade (USD billion)			
APC	Air pollution control	0	11	6	12	0	101.4	35.8	117.6
CRE	Cleaner or Resource efficient	8	12	12	53	327.1	340.4	340.4	438.8
EPP	Environ. friendly products.	0	1	1	7	0	0	0	3.5
HEM	Heat & Energy Management	3	7	7	25	20.8	24.6	24.6	109.9
MON	Monitoring the environment	0	24	18	37	0	165	153.1	193.4
NRP	Natural Resources Protection	0	0	0	3	0	0	0	1.5
NVA	Noise or Vibration Abatement	0	2	0	4	0	69.6	0	71
REP	Renewable Energy Production	11	35	35	54	153.1	395.8	395.8	606.7
SWM	Sewage & Waste Management	1	17	15	26	19.3	128.7	124.5	153.1
SWR	Soil & Water Remediation	0	3	0	4	0	7.7	0	8.6
WAT	Water management	3	22	9	30	21.6	199.6	76.2	300
	Not included in CLEG	103	88	21	–	569.8	597	206.2	–
	Total	129	222	124	255	1111.7	2030	1356.7	2004.2

3 Data sources

Our analysis of the macro trends is based on trade in goods statistics reported by the Trade Data Monitor (TDM) for the years 2017-2023. We chose to start in 2017 because the introduction of the 2017 version of the Harmonized System introduced a break in LCT trade statistics between 2016 and 2017.[6] We include 123 countries, which account for 99 percent of world trade. For 14 countries that are not covered or stopped being covered by Trade Data Monitor (such as Russia), we use mirror statistics, combined with the BACI database provided by CEPII.[7] Data are broken down by reporting country and 6-digit product code.

For our micro (firm-level) analysis, we use granular data on trade in goods sourced by Italy's Customs Agency (*Agenzia delle dogane e dei monopoli*). These data include annual exports and imports by firm, 8-digit product code (Combined Nomenclature), and counterpart country, covering the universe of Italian exporters and importers, except sole proprietorship. We also collect balance sheet information on the universe of Italian incorporated companies from Cerved,[8] together with information on employees from INPS and Infocamere sources. Finally, we draw information on firms' foreign ownership from Bureau van Dijk's Historical Orbis database. We match the three datasets using unique firm identifiers (tax identification number and VAT code). We obtained a dataset with about 92,000 observations over five years from 2017 to 2021 (the last year for which customs data are available).

4 Trade in LCT products: macro evidence

4.1 Main players at global level

World exports of LCT products amounted to roughly $1.4 trillion in 2023 (Figure 1, left panel). They have been growing in the last two decades, with a substantial acceleration after 2017 (+70 percent since then), mainly driven by the soaring demand for products related to sustainable mobility (namely, electric and hybrid cars) and, to a lesser extent, batteries. World exports of electric and hybrid vehicles recorded a more than seven-fold increase, soaring from $45 billion in 2017 to $341 billion in 2023, while world exports of batteries went up to $158 billion, from $51 billion in 2017.[9]

The share of LCT on world exports has accordingly increased, reaching 6.1% in 2023 (Figure 1, right panel), up from 4.7% in 2017. This represents a remarkable acceleration: in the last five years, the share expanded as much as it did in the previous 15 years.[10] In 2023, the shares

[6]In particular, before 2017 electrical vehicles were not separately identifiable in trade statistics (Arslanalp et al. (2023)). For selected indicators, nonetheless, we also report longer time series based on aggregate statistics on trade in LCT goods reported by the IMF.

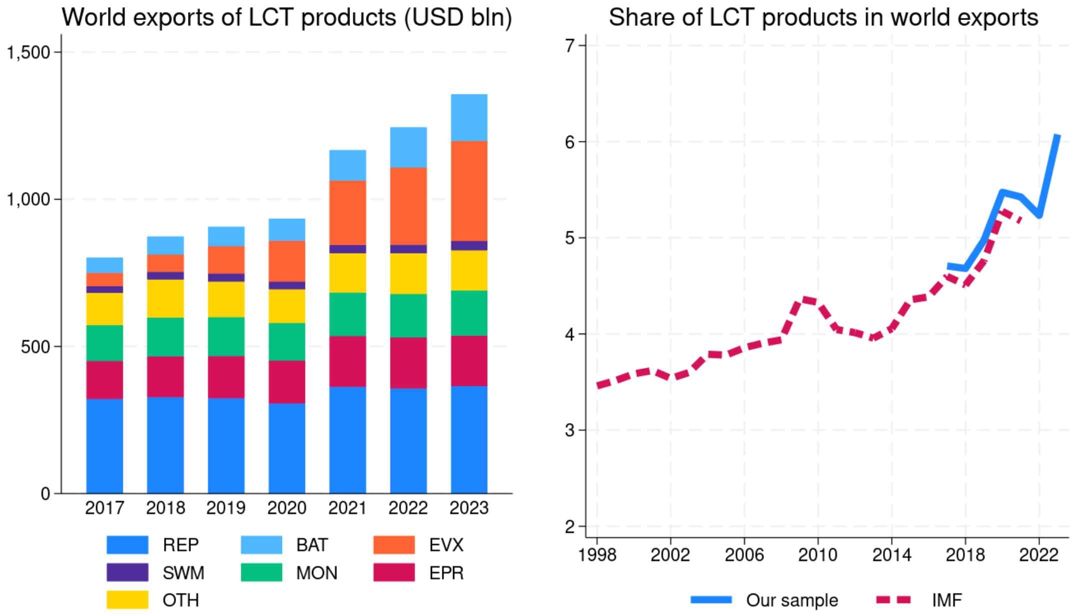
[7]In general, these 14 countries are scarcely relevant for exports of LCT products.

[8]Cerved is a private registry containing balance-sheet information of incorporated companies in Italy. See the company's website `www.cerved.com` for more details.

[9]This increase did not simply reflect price dynamics. In the sustainable mobility segment, the growth in quantities exported was significantly higher than the growth in prices, which on average over the last two years were stagnant or declining in the most relevant products (electric vehicles and non-plug-in hybrid vehicles). In the battery segment price dynamics were more sustained throughout the period, but the jump in 2021 depended mainly on a strong increase in quantities exported, particularly of the product "electric accumulators; lithium-ion".

[10]The data for earlier years are however not perfectly comparable, due to breaks in the time series related to

Figure 1: World trade in LCT products



Note: LCT categories are defined as in Section 2. REP: clean energy and renewables. EPR: reduction of environmental impact. MON: environmental monitoring. SWM: solid and hazardous waste management. EVX: sustainable mobility (incl. electric vehicles). BAT: batteries. OTH: other LCT goods not included elsewhere.

of the fastest growing categories over world LCT exports, i.e. sustainable mobility products and batteries, were 25% and 12% respectively, the two largest ones after renewables (which have a share slightly below 30%).

Figure 2 breaks down world exports (left-hand-side panel) and imports of LCT products (right-hand-side panel) by geographical area. EU accounts for almost 40 percent of LCT exports. China and other Asian economies jointly account for an additional 42 percent of LCT exports. EU is also a large importer of LCT products, accounting for 36 percent of world imports. Apart from the EU, the US and other advanced economies account for the bulk of world imports.

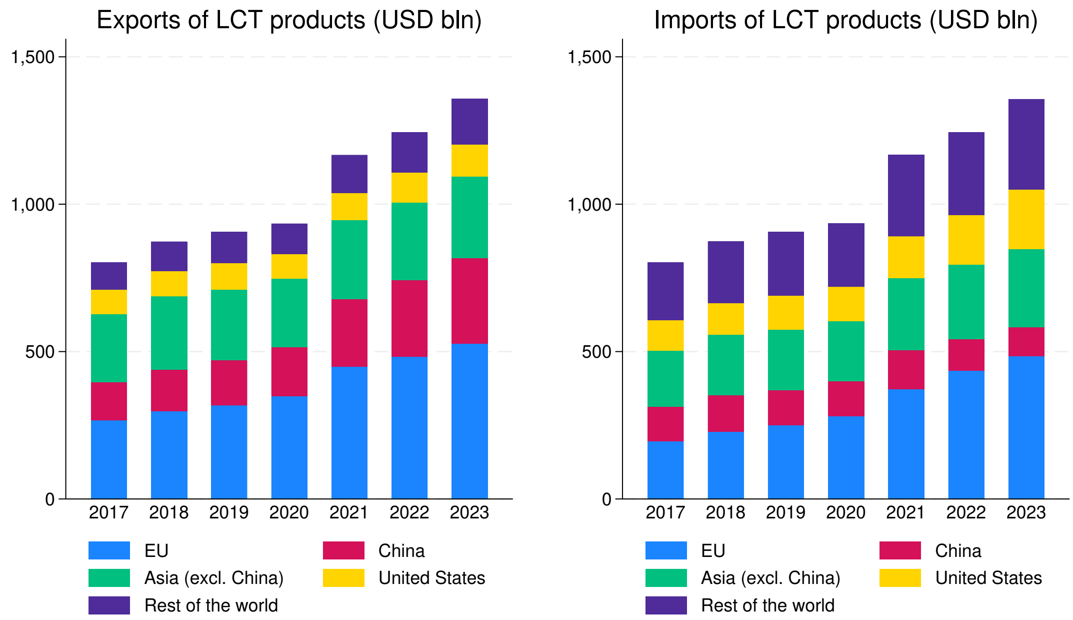
The trade balance in green products (i.e. the difference between LCT exports and imports) is a concise – yet informative – indicator of a country's competitive position in this market segment. The largest five net exporters and importers of LCT products are shown in Figure 3: China is by far the largest net exporter (193 billion in 2023), followed by Germany and Japan.[11] On the other side, the biggest net importer of LCT goods is the United States, followed at a distance by France, Australia, Canada, and Brazil.

Figure 4 illustrates the dynamics of the LCT balances for the four largest euro area countries, as well as for China, Japan, and the United States, and provides a breakdown by category for the year 2023. In line with the world average, the two most important contributors

amendments in the HS nomenclature.

[11]Germany's gross LCT exports are only one-third smaller than China's exports, but its imports are also quite large, as the country is the second largest importer of LCT goods at the global level; this explains why its net LCT balance is so smaller than China's balance.

Figure 2: Trade in LCT products by geographical area



Note: EU refers to external trade of EU member countries, so it includes intra-EU flows.

to China's growing surplus in LCT goods are the exports of batteries and sustainable mobility products (especially hybrid and electric cars), a market where the country has a well-established leading position (Baron et al., 2024).

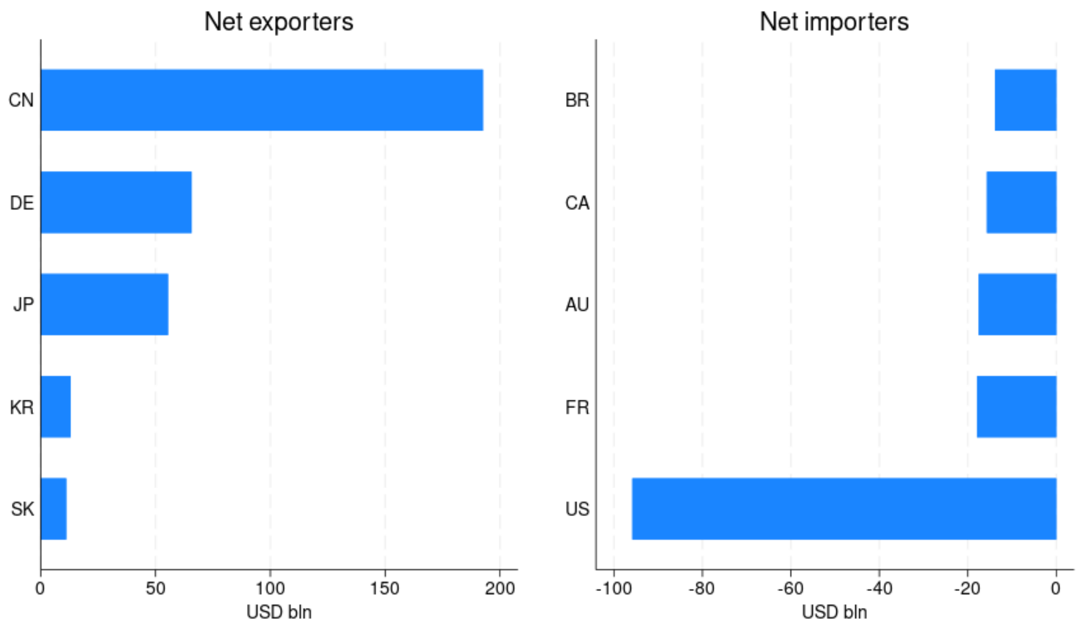
On the other side, the United States is associated with a structural and widening deficit in LCT goods (-96 billion in 2023), but this trend could eventually reverse if the industrial policy launched with the Inflation Reduction Act of 2022 and aimed at fostering investment in green transition technologies will unfold its effects in the medium term. The recent decision to increase tariffs and customs duties on imports of strategic goods from China, including some LCT products, such as batteries and electric vehicles, might also influence the future evolution of the US balance in LCT products.[12]

Focusing on the four largest euro area countries, Germany stands out as an exception, with a robust and growing surplus in LCT products ($66 billion, up from 49 in 2017). On the contrary, the trade balance of Italy in LCT products, which used to be positive until 2022, has gradually deteriorated, resulting in a slight deficit in 2023 ($ -3 billion). A gradual deterioration is observed also in France, which reached a significant deficit ($ -18 billion). Finally, Spain was a net importer throughout the period, although its balance deterioration was less pronounced if assessed against France and Italy.

Germany's LCT surplus reflects a positive balance in all LCT categories, with key contributions in particular from sustainable mobility products and environmental monitoring. Italy shows positive balances in various categories, which are however offset by a large deficit in

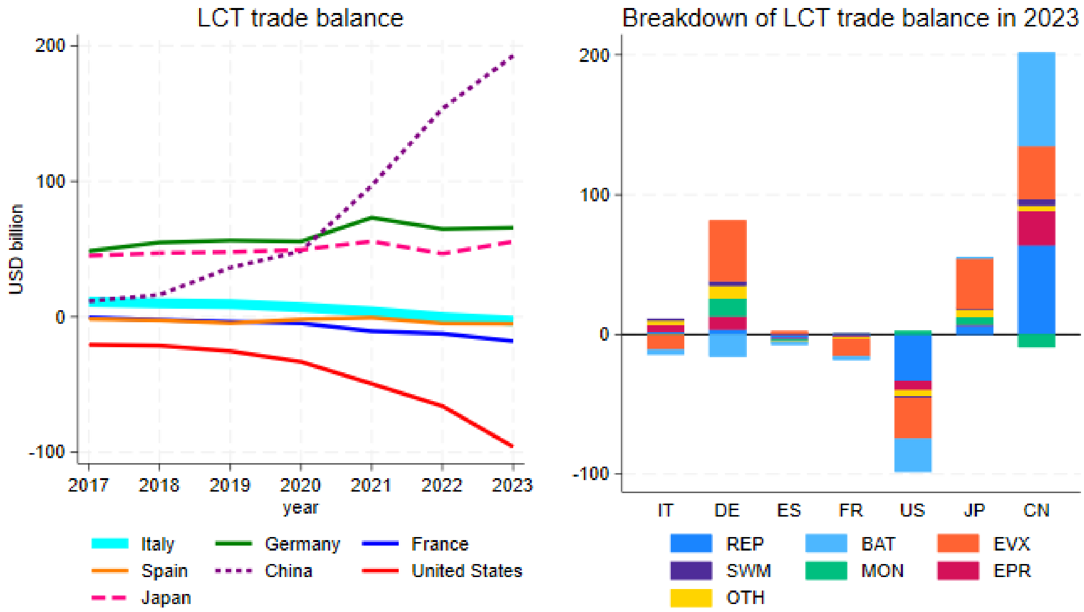
[12]On May the 14th 2024 the US President released a statement announcing the plan to increase tariffs on some selected imports from China, including relevant LCT goods such as electric vehicles, batteries, and solar cells, to protect American workers and firms from "unfair trade practices".

Figure 3: Largest LCT trade balances in 2023



sustainable mobility. The latter category also weighs on France's LCT balance, which in contrast to Italy is not offset by surpluses in other categories. Finally, Spain reports relatively small deficits in virtually all categories. As for the United States, also European countries' trade balances in green products could be affected by trade policies in the next years, such as the decision by the European Commission on June 2024 to impose duties on imports of battery electric vehicles ('BEVs') from China to countervail unfair subsidisation, as well as the continuation of financing renewable energy production and energy saving technologies under the European Green Deal.

Figure 4: Trade balances over time and by LCT category



Note: LCT categories are defined as in Section 2. REP: clean energy and renewables. EPR: reduction of environmental impact. MON: environmental monitoring. SWM: solid and hazardous waste management. EVX: sustainable mobility (incl. electric vehicles). BAT: batteries. OTH: other LCT goods not included elsewhere.

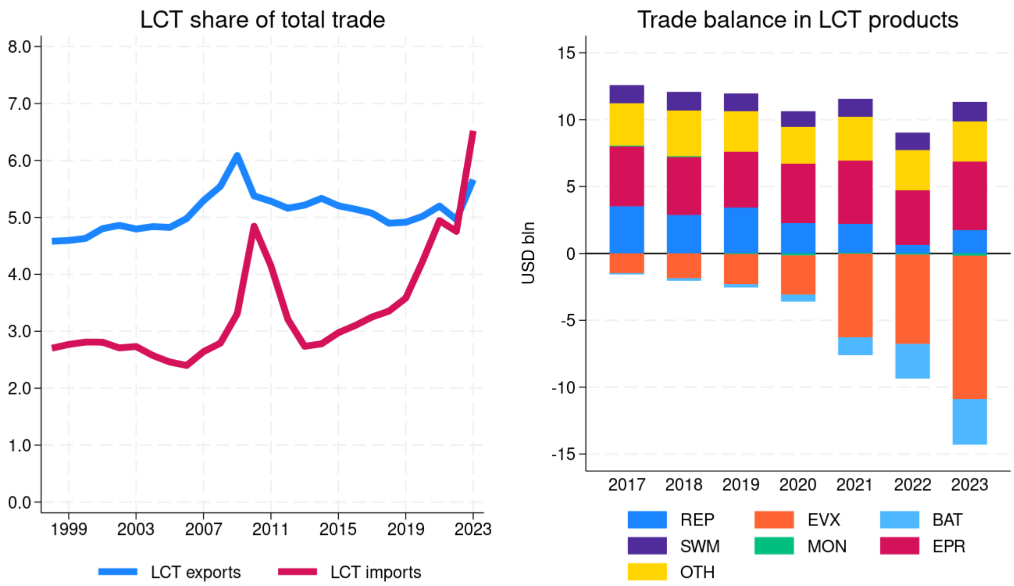
4.2 A macro view on the LCT trade of Italy

In 2023, Italian exports of LCT goods amounted to $ 37 billion, corresponding to 5.7 percent of total Italian merchandise exports (Figure 5, left panel). The share of LCT goods in total exports has remained relatively stable at around 5 percent in the last two decades, with the relevant exception of 2009, when world trade collapsed, following the great financial crisis. In such circumstances, foreign demand for LCT goods has proven to be less elastic than the demand for non-LCT goods, leading to a temporary increase in Italy's LCT share on exports. Finally, a small increase in the LCT share on exports was observed in 2023, reflecting a substantial increase in LCT exports (+13% year-on-year), in contrast to a substantial stagnation of non-LCT exports. All in all, almost 60% of Italian LCT exports are concentrated in only two LCT categories: clean energy production and reduction of environmental impact.

On the other side, the share of LCT goods on imports shows a clear upward trend, moving from slightly less than 3% at the beginning of this century, up to 6.5% in 2023, with a strong acceleration since 2019, driven by a more than sixfold increase in imports of electric and hybrid vehicles and by the quadrupling in the imports of batteries. This is largely in line with what was observed globally (see section 4.1). When considering the dynamics of the LCT share on Italian imports, a notable detail is the peak in 2010, when the share nearly doubled. This jump largely reflects the effect of an extensive program of public subsidies aimed at fostering renewable energy production, particularly through the installation of photovoltaic panels, which at the time Italy mainly imported from China and Germany.

Italy records a structurally positive balance in four of the LCT subcategories: namely, clean

Figure 5: Italy's trade in LCT products

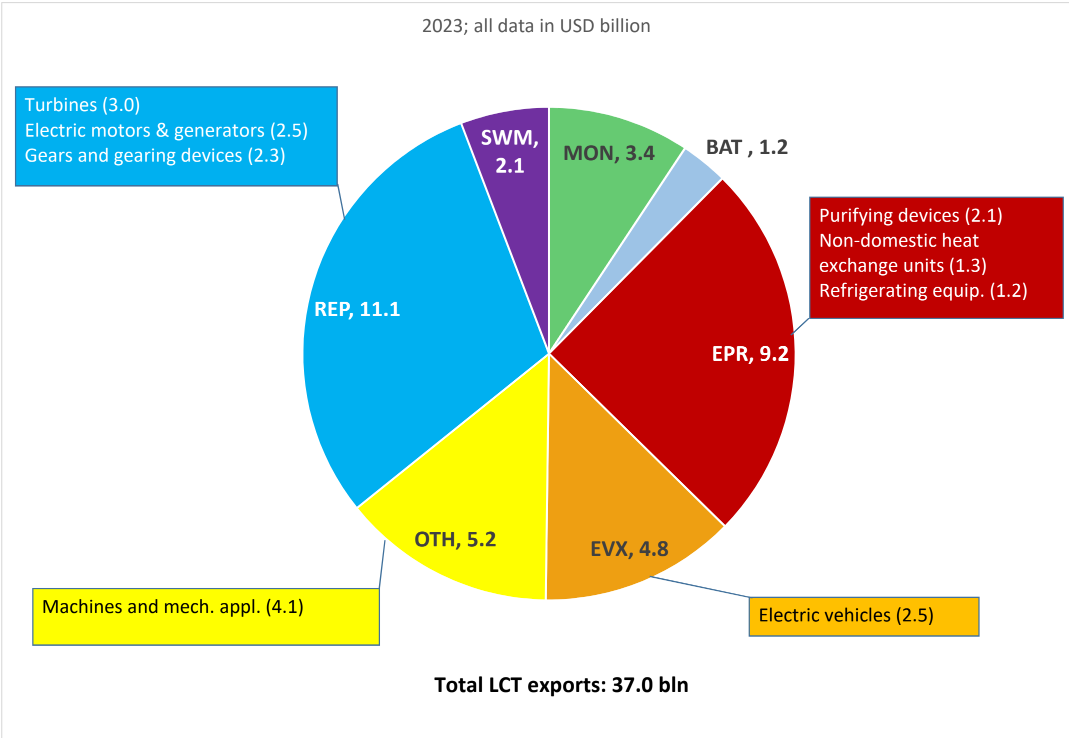


and renewable energy products (REP), reduction of environmental impact (EPR), and waste management (SWM, Figure 5, right panel), while it bears an increasingly negative balance in sustainable mobility (EVX) and batteries (BAT). The surplus in clean energy and renewables can be regarded as largely reflecting Italy's long-established industrial specialisation in industrial machinery (e.g. turbines), which manages to offset the lack of specialization in other renewable energy products, such as photovoltaic panels. The significant rise of imports of the latter kind has contributed to the reduction of the surplus in the REP subcategory, especially in 2022, when domestic demand of such products was boosted by the *super-bonus*, a tax credit scheme favouring interventions aimed at improving energy efficiency in real estate, which included residential photovoltaic systems.

As shown in Figure 6, the most relevant categories in Italian exports of LCT products are those related to clean energy and renewables (especially turbines,[13] generators and electric motors), and reduction of environmental impact. Sustainable mobility products have a lower share, slightly above 10%.

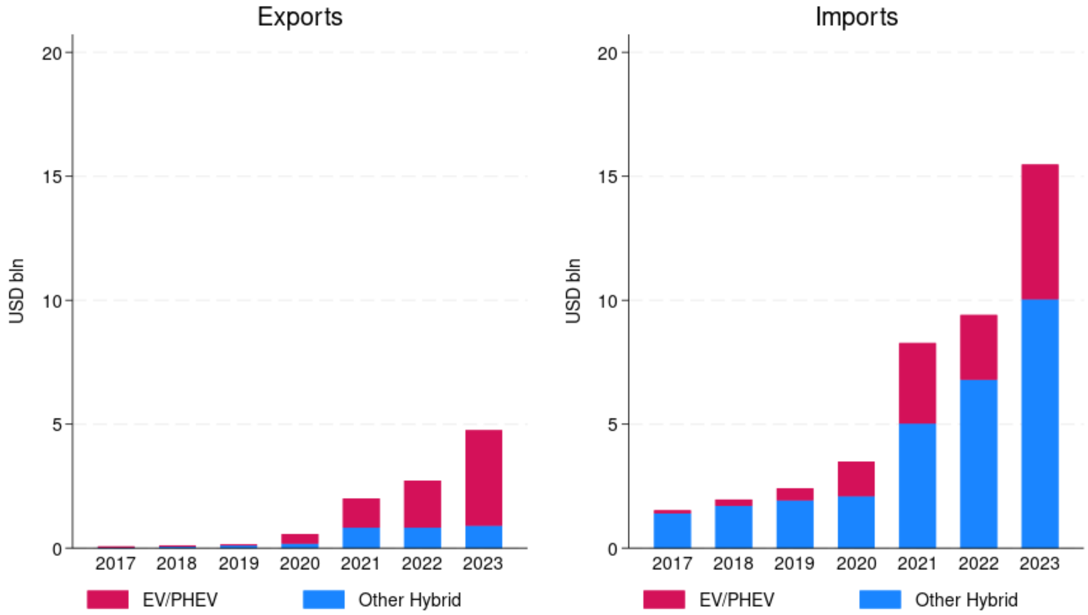
[13]Italy commands a global market share of nearly 9% in this specific segment. The turbine family, encompassing various types of turbines used in energy production, is quite diverse. There is a "core" subset of turbines, consistently categorized as "green" across all examined classifications (LCT, ECB, CLEG, and EG), which includes the 4-digit HS group 8410 of hydraulic turbines. These products are closely linked to renewable energy production, exemplified by their use in hydroelectric plants, and in water management facilities. The IMF's LCT list includes additional turbine categories, such as steam turbines (group 8406), which contribute to renewable energy in geothermal and solar thermal plants, and the miscellaneous group 8412, which includes wind turbines. A more debatable choice is the inclusion of gas turbines (group 8411), which incidentally make up more than three-quarters of Italy's turbine exports. While gas turbines are not used in the production of energy from renewable sources, they are employed in the production of electrical power from natural gas. Arslanalp et al. (2023) acknowledge the ongoing international debate about whether products related to energy production from natural gas or nuclear fuel can be classified as green goods. They motivate their decision to include these turbines in the LCT taxonomy by noting that power generation from natural gas produces significantly less carbon dioxide compared to traditional coal or oil-fired power generation methods.

Figure 6: Composition of Italian exports by LCT category



Note: LCT categories are defined as in Section 2. REP: clean energy and renewables. EPR: reduction of environmental impact. MON: environmental monitoring. SWM: solid and hazardous waste management. EVX: sustainable mobility (incl. electric vehicles). BAT: batteries. OTH: other LCT goods not included elsewhere.

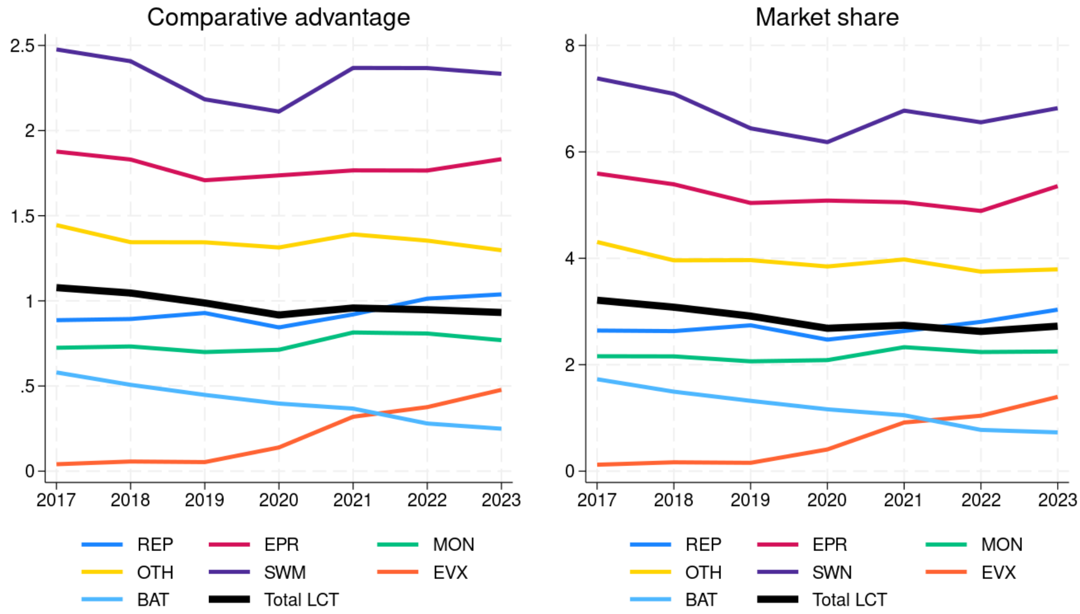
Figure 7: Italy's trade in sustainable mobility products



The deterioration of Italy's trade balance in sustainable mobility products reflects a very strong growth of imports, which more than offset the increase in exports. Figure 7 provides a further breakdown of Italy's trade in this category according to the three types of products included in it: (i) electric vehicles (a set of products including all vehicles devoid of an internal combustion engine, such as electric cars, but also e-bikes), (ii) plug-in hybrid vehicles (PHEVs, a subset including all vehicles with both a fully-fledged electric motor and internal combustion engine, capable of switching to fully electric propulsion with zero emissions over a medium-range distance) and (iii) hybrid non-plug-in vehicles (i.e., gasoline or diesel-powered vehicles, equipped with an auxiliary electric motor that improves the efficiency of the internal combustion engine and reduces its carbon emissions, but that does not charge by being plugged into an external electric charging source and cannot develop autonomous electric propulsion, unless over a short distance). After splitting sustainable mobility products into the three groups, we can observe that the composition of Italian imports and exports is markedly different: while imports are predominantly composed of non-plug-in hybrid cars, exports consist overwhelmingly of the first two categories. Therefore, if the LCT category of sustainable mobility were restricted to the more carbon-saving technologies of EVs and PHEVs, then Italy's LCT balance would significantly improve.

We also considered two alternative indicators of Italy's competitive positioning in LCT products: The first is the Balassa index of comparative advantage, which corresponds to the ratio between the share of a country's LCT exports over total exports and the share of world LCT exports over global exports. An index above (below) one signals a comparative advantage (disadvantage). The second is the country's market share in world trade in LCT products. These two indicators provide a similar picture to the one based on trade balances (see Figure 8). Italy reports a comparative advantage in three of the four LCT categories with a positive balance. These are also categories in which Italy's market share on world trade is relatively

Figure 8: Italy's comparative advantage and market share by LCT category



Note: LCT categories are defined as in Section 2. REP: clean energy and renewables. EPR: reduction of environmental impact. MON: environmental monitoring. SWM: solid and hazardous waste management. EVX: sustainable mobility (incl. electric vehicles). BAT: batteries. OTH: other LCT goods not included elsewhere.

large, such as waste management (around 7%), reduction of environmental impact (around 5%), and other LCT mechanical products (around 4%), Considering all LCT products, Italy's share of world trade was equal, in value terms, to 2.7 percent, broadly in line with the share of total goods. All market shares have remained relatively stable throughout the period under scrutiny, except the two smallest shares, related to sustainable mobility and batteries: the latter recorded a modest decline (from almost 2% to less than 1%) while the former has been rising since 2019 (from near zero to more than 1%).

The geographical composition of Italian exports of LCT closely resembles that of total exports, with Germany, the United States, and France as the three largest destination markets, collectively accounting for $13 billion in 2023. These countries are also the three largest destination markets for all Italian exports. Indeed, considering the ten most important destination markets (see Table 2), we can observe that their market shares undergo few changes when we move from LCT to non-LCT exports. Only the shares of Spain, Switzerland, and Belgium present a noteworthy difference, as the relevance of these three markets for Italian LCT exports is lower than for total exports. The mix of LCT goods exported across main destinations is also quite similar (see Figure 9). Goods related to the production of clean and renewable energy and the reduction of environmental impact are about half of Italy's LCT exports in all main destinations (ranging from 45% in LCT exports to France, to 55% in LCT exports to the United Kingdom). Electric and hybrid vehicles are a relevant component of the LCT bundle exported to France and Germany, where they amount to about 27% and 23% of all LCTs, respectively; their weight is significantly less in the export toward Spain and the United Kingdom (between 12 and 13 percent).

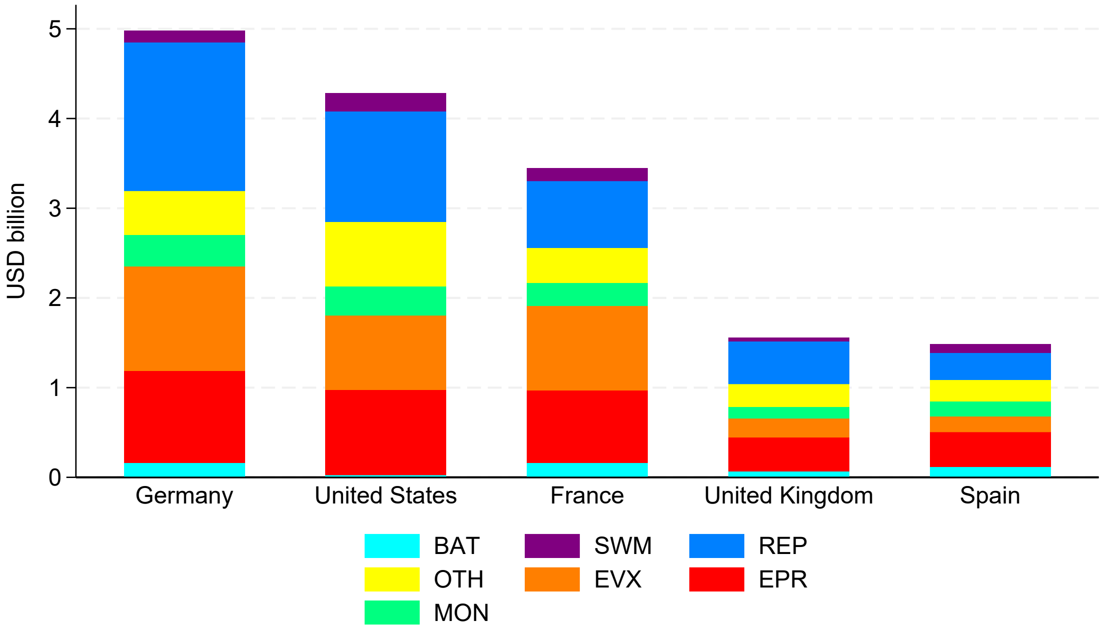
Table 2: Destinations of Italy's exports of LCT products

Top 10 destinations in 2023	value (USD bln)	Destination's share in LCT (%)	non-LCT (%)
Germany	5.0	13.6	12.2
United States	4.3	11.7	10.9
France	3.4	9.4	10.4
United Kingdom	1.6	4.2	4.2
Spain	1.5	4.1	5.5
Türkiye	1.2	3.2	2.3
China	1.1	3.1	3.1
Poland	1.0	2.8	3.3
Switzerland	0.9	2.6	5.2
Belgium	0.8	2.2	3.2
Other countries	15.9	43.2	39.8
All destinations	36.7	100	100

Destinations are ordered by decreasing value of Italian LCT exports in 2023.

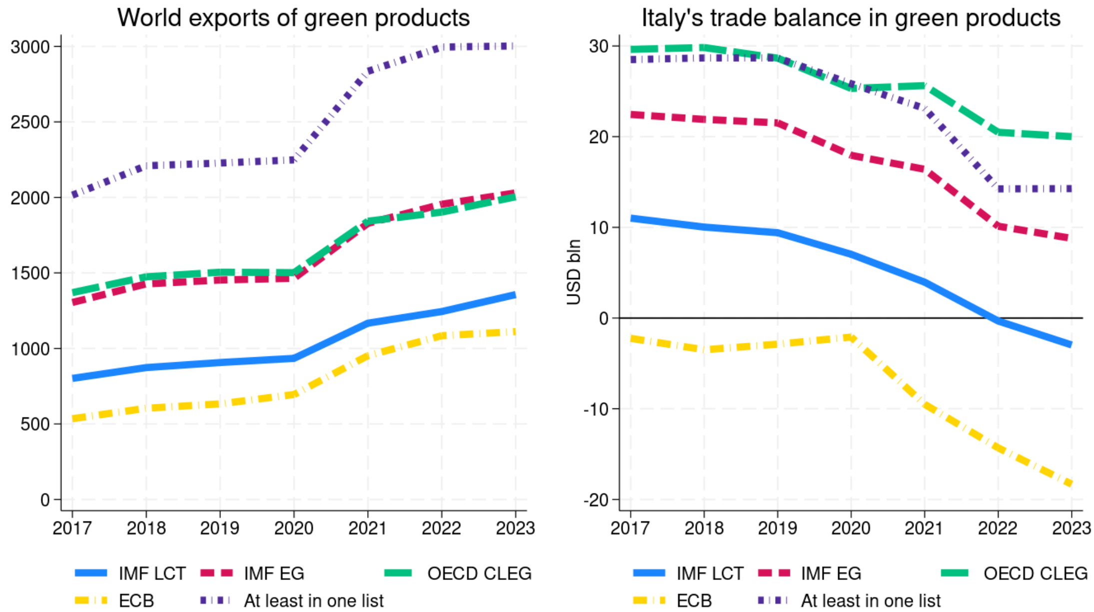
Finally, we performed a robustness check by comparing the dynamics and levels of "green balances" according to various taxonomies of green products. The left panel of Figure 10 presents world exports of green products based on the four classifications discussed in section 2 (LCT, IMF Environmental goods–EG, CLEG, and ECB) along with an additional classification that combines these four. The comparison indicates that using different definitions does not alter the main trends observed globally: world trade shows a broadly similar growth across each of the four classifications, although there are significant differences in terms of levels. Specifically, world exports are largest for EG and CLEG, lower for ECB, with LCT positioned in between. The global trade of products included in at least one of these classifications exceeds twice that of LCT products alone. Figure 10 (right panel) shows Italy's trade balance across the various classifications. While different bundles of green products result in different balances, their overall trends are generally similar.

Figure 9: Composition of Italian export markets by LCT category



Note: LCT categories are defined as in Section 2. REP: clean energy and renewables. EPR: reduction of environmental impact. MON: environmental monitoring. SWM: solid and hazardous waste management. EVX: sustainable mobility (incl. electric vehicles). BAT: batteries. OTH: other LCT goods not included elsewhere.

Figure 10: Robustness checks across different taxonomies of green products



5 Trade in LCT products: firm-level evidence for Italian exporters

In this section, we exploit highly granular customs data and investigate the activity of Italian exporters of LCT products at the micro level. The contribution of this analysis, which relates to the literature assessing the role of firm heterogeneity in export performance (Melitz, 2003; Mayer and Ottaviano, 2008), is two-fold: on one hand, it allows us to assess Italy's export potential in LCT products; on the other hand, it provides a characterization of the market structure of the various LCT categories.

We start by focusing on two micro-based metrics of export potential. First, we look at the number of exporters of LCT products. This provides an indication of the firms that are already actively engaged in foreign sales of LCT products, and might therefore be well placed to benefit from an expansion of world trade in this segment as the world makes the transition to a low-carbon economy. Table 3 reports that in 2021 (the last year for which data are available) there were about 23,000 exporters of LCT products.[14] This amounts to about 25% of the overall number of Italian exporters.[15] Since 2017, the number of LCT exporters has increased by 1.5%, and the share of LCT exporters has increased by 1.1 percentage points.

Second, we consider the number of LCT exporters for which LCT products account for at least half of the exporting company's foreign sales in a given year. We define these firms as "LCT-intensive exporters". The intuition behind this breakdown is that products with the largest shares in firms' sales are generally products that are closer to firms' core competence and in which firms tend to be more successful (Eckel and Neary, 2010; Bernard et al., 2011). We find that roughly 5,400 exporters are LCT-intensive exporters, which corresponds to 5.9% of total exporters (up 0.4 percentage points since 2017). Despite representing only a quarter of LCT exporters, LCT-intensive exporters account for two-thirds of the total exports of LCT products. This suggests that firms for which LCT products are part of the firm's core business activity play a leading role in aggregate LCT exports.[16]

Table 4 shows in column (1) that the number of LCT exporters is larger for four categories: clean energy and renewables, reduction of environmental impact, environmental monitoring, and other LCT products.[17] Column (2) reports the distribution of LCT-intensive exporters by category, confirming that their main specialization lies in the four above-mentioned categories.[18] Column (3) shows that LCT-intensive exporters account for the majority of exports in all categories, except for sustainable mobility. In this sector, the bulk of LCT exports is concentrated in a few large players, whose majority of sales comes from non-LCT exports. Finally, column (4) shows that the degree of concentration of LCT exports varies significantly

[14]Almost half of LCT exporters also import LCT products, accounting for almost 80 percent of the value of LCT imports in 2021

[15]We restrict the analysis to incorporated companies, excluding therefore sole proprietorship. We also exclude companies that Cerved classifies as real estate or financial companies (including financial holding companies).

[16]We check the robustness of our findings to an alternative definition of LCT-intensive exporters, in which we look at whether the core product exported by each company (i.e. the HS6 digit product with the largest share on the company's portfolio of HS6 exported products) is an LCT product or not. According to this alternative definition, the number of LCT-intensive exporters would be equal to 5,960. Their share in total LCT exports would be equal to 68 percent. Both values are broadly in line with what was found adopting the baseline definition of LCT-intensive exporter.

[17]An LCT exporter may export products belonging to more than one category.

[18]LCT-intensive exporters have been assigned the category with the largest sales.

Table 3: Exporters of LCT products

Year	LCT exporters	of which: LCT-intensive
	Number of exporters	
2017	22871	5270
2018	22234	5154
2019	22323	5157
2020	21723	5178
2021	23204	5415
	Share on total exporters	
2017	24.0	5.5
2018	23.8	5.5
2019	23.7	5.5
2020	24.2	5.8
2021	25.1	5.9
	Share on LCT exports	
2017	100.0	69.7
2018	100.0	69.2
2019	100.0	68.9
2020	100.0	67.2
2021	100.0	66.3

across the various LCT categories. Exports are known to be often concentrated in a handful of "superstar exporters" that drive their countries' aggregate dynamics of trade (Mayer and Ottaviano, 2008). The share of the top 10 exporters is especially high in sustainable mobility and batteries, while the other categories report much smaller levels of market concentration.

Given the relevance of LCT-intensive exporters, we further investigate the main characteristics of this subset of firms (Table 5). In terms of the main sector of activity, 70 percent of these firms are in manufacturing, while 27 percent are in the services sector. Among the manufacturers, machinery firms make up more than 40 percent, while metal products and electronics each account for 20 percent. In the services sector, LCT-intensive exporters are primarily engaged in wholesale and retail trade, as well as business services. Geographically, LCT-intensive exporters are predominantly located in the North-West and North-East regions of Italy, with the North-West alone accounting for almost half of the firms. Only 7 percent of LCT-intensive exporters are situated in the South of Italy. In terms of size, the majority of these firms are either small or very small (micro) firms, with only 6 percent classified as large firms.

Table 6 investigates whether LCT-intensive exporters differ concerning the population of exporters. For each of several firm characteristics that we take into account, we run a regression in which a given firm outcome is regressed on a dummy that identifies LCT-intensive exporters, controlling for 3-digit industry fixed effects.[19] Panel (a) shows that, in terms of size, LCT-intensive exporters are smaller in terms of sales but similar in terms of employ-

[19]The regression is run on a cross-section of exporters in the year 2021. The results are robust to a pooled specification over the years 2017-21

Table 4: Structural indicators of LCT exporters by category in 2021

Year	LCT exporters	LCT-intensive exporters	% LCT-intensive share on exports	share on exports of top 10 firms
EPR	7,934	1,256	63.6	18.3
MON	6,533	867	52.8	25.7
REP	8,144	1,001	70.3	35.2
SWM	2,265	411	62.7	25.1
BAT	1,674	112	80.3	75.0
EVX	594	156	12.8	84.1
OTH	15,079	1,854	55.5	17.2

Note: All data refer to 2021. LCT category are defined as in Section 2. REP: clean energy and renewables. EPR: reduction of environmental impact. MON: environmental monitoring. SWM: solid and hazardous waste management. EVX: sustainable mobility (incl. electric vehicles). BAT: batteries and energy accumulators. OTH: other LCT goods not included elsewhere.

Table 5: LCT-intensive exporters by industry, macro-area and size

Industry %		Macro-area %		Size %	
Manufacturing	70.2	North-West	48.7	Large	6.1
Services	26.5	North-East	34.1	Medium	20.5
Construction	2.7	Center	11.6	Small	42.4
Other	0.6	South & Islands	5.7	Micro	31.0
Total	100.0	Total	100.0	Total	100.0

ment. LCT-intensive exporters are less intensive in tangible capital and have a slightly larger share of white collars. They generate a slightly larger value added per employee, pay higher wages per employee but are not more profitable than other exporters. LCT-intensive exporters also tend to be slightly younger than other exporters, while no difference is found in terms of foreign ownership propensity.

Panel (b) replicates the regressions replacing the single LCT-intensive dummy with separate dummies according to the prevailing specialization of LCT-intensive exporters. The results reveal substantial heterogeneity in the characteristics of LCT-intensive exporters across the various categories of LCT products. For instance, LCT-intensive exporters tend to be larger than other products when they specialize in sustainable mobility, batteries, and clean/renewable energy, while the opposite applies to the categories of waste management and other LCT products. We also find that the higher share of white collars and lower intensity of tangible products is largely driven by LCT-intensive exporters in environmental monitoring and waste management categories. Finally, differences in companies' age also arise, as LCT-intensive exporters in sustainable mobility tend to be younger than other exporters, while the opposite is true for environmental monitoring.

Table 6: Characteristics of LCT-intensive exporters

The table presents ordinary least squares (OLS) regressions of firm-level variables on a dummy for LCT-intensive exporters (panel a) and on separate dummies according to the prevailing specialization of LCT-intensive exporters. Regressions include industry fixed effects (at the 3-digit level). ***, **, and * indicate statistical significance at 1, 5, and 10 percent, respectively.

	Empl	Sales	VA prod. per worker	Wages per worker	ROA	% White collars	Tang. K/L	% Intang.	Age	Foreign
Panel (a)										
LCT-intensive dummy	-0.02	-0.07***	0.02**	0.04***	0.25	0.02***	-0.09***	0.00	-0.02*	-0.00
3-digit sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		
No. obs.	84,443	92,378	81,991	84,443	92,415	84,443	80,703	87,449	92,365	92,415
Panel (b)										
... × Batteries	0.21	0.53***	0.15*	0.05	0.18	-0.00	0.20	-0.01	-0.07	0.00
... × Red. env. impact	0.03	0.14***	0.04*	0.04***	0.08	0.01*	-0.03	0.00	0.01	-0.00
... × EV/Hybrid	0.28**	0.47***	0.00	0.09**	-3.77***	0.02	-0.19	0.08***	-0.16**	0.01*
... × Env. monit.	0.06	0.00	0.08***	0.11***	2.02***	0.10***	-0.14**	0.00	0.08***	-0.00
... × Other	-0.24***	-0.44***	-0.04*	-0.00	0.05	0.01*	-0.15	0.00	-0.08***	-0.00**
... × Renewables	0.15***	0.08	0.04*	0.06***	0.48	0.01*	0.02***	0.00	-0.00	0.00
... × Waste manag.	-0.18***	-0.17*	0.02	0.04*	-0.75	0.03***	-0.19**	0.01	-0.02	-0.00
3-digit sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. obs.	84,443	92,378	81,991	84,443	92,415	84,443	80,703	87,449	92,365	92,415

6 Exposure to brown products and transition risks

The concept of "brown products", which can be regarded as a natural counterpart of the concept of "green products", is meant to refer to goods that generate significant greenhouse gas emissions during their production, distribution, and/or utilization. Typical examples of brown products include fossil fuels, such as coal, oil, and natural gas, and fossil fuel-based energy; vehicles with high carbon-dioxide emissions, such as cars with only an internal combustion engine, but also airplanes, and ships; and certain industrial processes with high carbon footprints, such cement and concrete production (Barcelo et al., 2013). Some experts include in the concept also agricultural activities characterised by large amounts of net carbon emissions, in particular cattle farming.[20]

In our analysis, we considered the list of brown goods from Andres et al. (2023), which includes 189 6-digit product codes in the Harmonised System.[21] They can be grouped into three broad categories: (i) fossil fuels and derivative products; (ii) internal combustion engines and related products (including vehicles relying entirely on it, excluding air and naval transportation); (iii) cattle, bovine and lamb meat, and related products (excluding dairy and leather products). While this list may not be exhaustive, it is useful insofar as it includes all brown products that are relevant in the merchandise trade.[22]

According to the Paris Agreement, countries pledged to gradually move away from fossil fuels and adopt cleaner technologies, expanding both consumption and production of energy from clean or renewable sources (see Section 1). Policy-makers are also increasingly aware of the GHG emissions potentially embedded in imports, and making plans to limit "carbon leakage" from production om locations with less stringent climate actions. To this aim, the EU introduced in October 2023 the Carbon Border Adjustment Mechanism (CBAM), which put a price on the carbon emitted during the production of carbon-intensive goods that enter the EU.

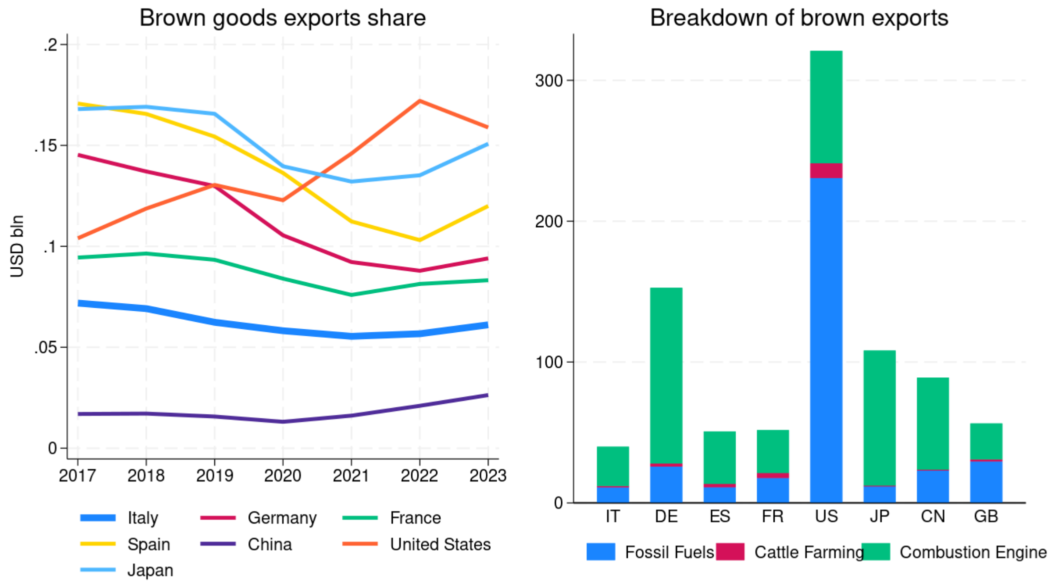
Exporters of brown goods are therefore expected to meet a downward pressure on their market shares, which they could countervail by expanding their export capacity of green products. The left-hand side panel of Figure 11 shows the incidence of brown products on goods exports for the countries considered in the previous section, i.e. for the most relevant countries in LCT trade. In four of them, the brown share is larger than 10%: namely, the United States and Japan, and, to a lesser extent, Germany and Spain. In the latter two countries, the brown shares have been declining until 2022. In all four countries, the bulk of brown exports is made up of combustion engines (Figure 11, right panel), except the United States, where fossil fuels are a sizeable part of brown exports. For Italy, the brown share of exports is between 6 and 7%, and it is composed mainly of combustion engine vehicles and related components. Finally, cattle farming has a negligible weight in brown exports, reflecting the fact that in many advanced countries meat production is mainly oriented toward satisfying domestic demand.

[20]It is estimated that about a third of all human-caused GHG emissions in 2015 were linked to the food system, primarily from agriculture and land use (Crippa et al., 2021). In Italy, GHG emissions from the food system were estimated to be 23% in 2018 (Crippa et al., 2022). Animal-farming, particularly the production of red meat, is associated with highest GHG emissions (FAO, 2021; Intergovernmental Panel on Climate Change, 2022), while plant-based food entails significantly lower GHG emissions per Kcal (Poore and Nemecek, 2018; Scarborough et al., 2023).

[21]We are very grateful to the authors for sharing their list of brown goods with us.

[22]For example, cement and concrete have a large environmental impact in terms of carbon emissions, however, they are scarcely exchanged across borders, hence their exclusion is irrelevant to our analysis.

Figure 11: Brown goods in the exports of relevant countries



If we abstract from the effects of the policies adopted with the Inflation Reduction Act, we could conclude that the United States is the country most exposed to transition risk, as its relatively weak position in LCT trade (the United States is the largest net importer) is coupled with a sizeable share of brown products in exports. On a middle-ground position, we find Germany and Japan, countries that are counterbalancing their large shares of brown exports with their strong competitive position in LCT exports, whose share of total exports has been constantly growing in the period under scrutiny. Italy is also somewhat in a middle-ground position, due to a modest deficit in LCT trade but also a small share of exports of brown products. If we ignore the large weight that fossil fuels have in domestic energy supply, the country whose trade is less exposed to transition risk appears to be China, characterised by a very small brown share of exports and a large and growing share of LCT exports, a sector where it is the global leading exporter.

7 Concluding remarks

This paper has provided new evidence at the macro and micro level on trade flows associated with the green transition. Our macro analysis points to a growing demand for LCT products worldwide. In particular, products related to sustainable mobility and batteries have recorded a very strong expansion. A few countries, China *in primis*, have been able to satisfy this still-increasing demand, contributing to a significant shift in overall comparative advantage patterns for LCT products. Italy has seen the progressive erosion of its LCT trade surplus, due to increasing imports of hybrid vehicles, while it maintains a comparative advantage in a few subcategories of LCT products. Our micro analysis complements the macro approach, providing a battery of indicators on the export potential of Italian firms and pointing to significant differences in market structure among the various segments of LCT products. Along this line, detailed analyses of countries' market structures in LCT products are essential for a better calibration of public incentives, as industrial policies aimed to support production capabilities in green industries are increasingly widespread worldwide.

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