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255/1 RESEARCH

Estimating the carbon footprint of French subsidiaries abroad

We estimate the carbon footprint of the stock of French foreign direct investment (FDI) abroad at 130.7 million tonnes of CO_2 in 2014, the latest available data, equivalent to 56.7% of the emissions generated by production carried out in France. The increase in the stock of FDI in the most carbon-intensive destination sectors led to France's carbon footprint abroad peaking in 2006, before declining by 19.8%. Under certain accounting and economic assumptions, technology transfers within multinational firms could reduce the emissions of French subsidiaries abroad by up to 29%. The magnitude of these figures underscores the importance of more rapidly updated detailed sectoral-level international data, especially in light of the accelerating timetable for the ecological transition.

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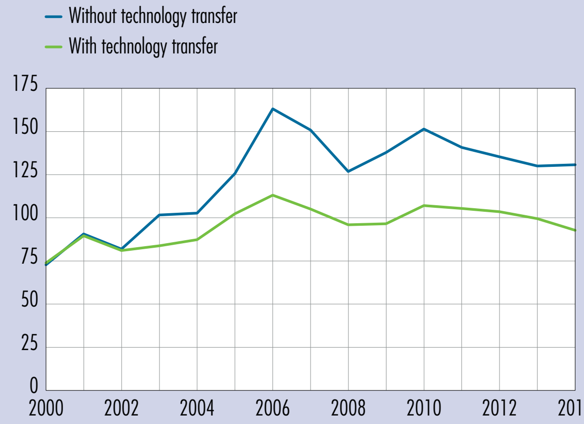
JEL codes
F21, F23,
F64

130.7 million tonnes of CO_2
carbon footprint abroad in 2014 (latest available data)

–29%
potential impact on the emissions of French subsidiaries of technology transfers within multinationals

Change in the estimated carbon footprint of French foreign direct investment abroad
(millions of tonnes of CO_2)



Sources: Banque de France; Groningen Growth and Development Centre, World Input-Output Database (WIOD).

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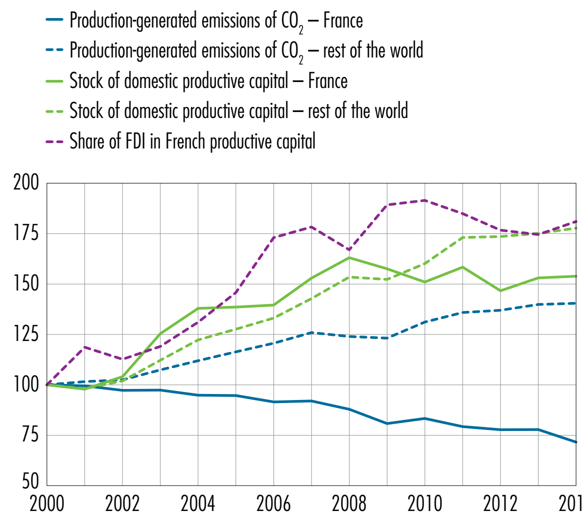
Production-generated emissions of CO_2 declined by 29% in France between 2000 and 2014 (year of latest available data, see Chart 1). This reduction was achieved **despite an increase in the stock of domestic productive capital of 54%**. Over the same period, the CO_2 emissions of the rest of the world rose (by 40%), although to a significantly lesser degree than their capital stock at constant prices (up 78%). The fall in French domestic emissions and their increase in the rest of the world also coincided with a sharp rise – of 81% – in the share of French foreign direct investment (FDI) abroad in the stock of productive capital. This growth in FDI is one of the most striking features of the internationalisation of the French economy (Cotterlaz et al., 2022).

C1 Comparative trends in CO_2 emissions and stock of productive capital in France and the rest of the world, 2000-14

(2000=100)



Sources: Groningen Growth and Development Centre, World Input-Output Database (WIOD) for emissions; Organisation for Economic Co-operation and Development (OECD), Structural Analysis Database (STAN) for domestic capital volumes; Banque de France for FDI.
Notes: For each variable, France is represented by an unbroken line and the rest of the world by a dotted line.
The volume of foreign direct investment (FDI) abroad is obtained from the implicit capital deflator of the host sector-country.
The stock of productive capital and FDI are calculated at constant prices, with 2010 as the base (green and purple lines); country emissions are calculated in tonnes, base 100 in 2000 (blue lines).

This pattern of internationalisation in France is also reflected in a negative balance of trade in goods and a positive balance of trade in business services (Bui Quang and Gigout, 2021) and of investment income. **The relocation of industrial production inevitably results in the relocation of its associated emissions.**

This paper aims to **quantify for the first time the contribution of French subsidiaries abroad to the CO_2 emissions of the rest of the world**. It reports on the basis of figures for 2014, the most recent year when sector account data were available. In the case of foreign direct investment (FDI) abroad, the French parent company has control or at least significant influence over the management of one or more foreign subsidiaries. The parent company can directly influence the production processes used, and can therefore intervene in the environmental efficiency of its subsidiaries. The aim of this exercise is thus to estimate the quantity of CO_2 emitted abroad as a consequence of the decision-making capacities of French residents (see Box 1). Such an assessment has implications for both economic and environmental policy. Encouraging companies to reduce their emissions abroad as well as domestically is a driver for the reduction of emissions globally. The new disclosure obligations introduced with the entry into force of the European corporate sustainability reporting directive[1] will allow better monitoring of foreign emissions. The gradual implementation of the European Union's Carbon Border Adjustment Mechanism, introduced in 2023, will also help to curb the carbon leakage associated with certain FDI and will help to limit concerns with regard to the risks of relocation when implementing greenhouse gas emission reduction policies (Parra Ramirez, 2021). This paper also aims to highlight the potential contribution that technology transfers within multinational firms can make to improving the carbon efficiency of their subsidiaries in host countries. Finally, we note that significant data gaps – both in sectoral economic data and in direct investment or environmental data – still exist, and that such data are essential to assessing the impact of current reforms.

1 Directive (EU) 2022/2464 *Directive - 2022/2464 - EN - EUR-Lex (europa.eu)*

BOX 1

Data and methodology

Unfortunately, as no specific data are collected on emissions generated by non-resident company subsidiaries, they can only be estimated on the basis of macroeconomic data. To do so, we combine emission and sector account data from the Groningen Growth and Development Centre's World Input-Output Database (WIOD; Timmer et al., 2012) with the Banque de France's foreign direct investment (FDI) stock data. However, we are limited in this approach by the unavailability of sector account data after 2014. We hypothesise that FDI in company shares corresponds to productive capital, which we then assume to be the source of emissions. We combine data on the carbon intensity of productive capital with data on FDI holdings to provide an initial estimate of emissions generated by French subsidiaries abroad. The sample obtained covers the emissions generated by 79% of French direct investments abroad in 2014.[1]

We use the amount of CO_2 emissions per unit of productive capital as the primary measure of carbon efficiency in the host country.[2] However, the study is again limited by the high degree of sectoral data aggregation. We make the implicit assumption that the composition of an aggregate sector in France is identical to its equivalent in the host country. However, a French subsidiary's position in the value chain, and therefore its carbon intensity, may differ from that of the average domestic company.[3]

Let FDE denote total emissions from foreign direct investment. Let τ be the carbon intensity, expressed in units of CO_2 emitted E per unit of capital K in current dollars. Let FDI be the stock of direct investment abroad by French residents in current dollars. We index the year, sector and host country by t, k and j respectively. FDE can thus be broken down as follows:

$$FDE_t = \sum_{k,j} \tau_{k,j,t} * FDI_{k,j,t} \tag{1}$$

With $\tau_{k,j,t}$ the carbon intensity of the destination sector:

$$\tau_{k,j,t} = \frac{E_{k,j,t}}{K_{k,j,t}} \tag{2}$$

Where necessary, to take account of the upward trend in the price of capital and price differences between countries, the capital of the host sector-country is measured in chained volume with 2010 as the reference year, after conversion into dollars, at purchasing power parity.

The main limitation of this type of exercise is that taking differences in CO_2 emissions technology between domestic and foreign industries into account is difficult. Equation (1) is based on the assumption that the stock of FDI in the host country uses the technology of the destination sector consistently in year t. However, direct investments are generally

1 See Appendix 1 for the content and treatment of these figures.

2 Alternatively, we could combine revenue by sector with investment income from French subsidiaries abroad. Furthermore, FDI income (reinvested earnings plus dividends paid to the parent company) is affected by multinationals' tax optimisation strategies.

3 In our classification, a subsidiary manufacturing engines and a subsidiary manufacturing body parts would both be classified in the automotive sector.

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made by companies that are more productive and therefore potentially less emissions-intensive per unit of capital than those in the host country-industry pair. For example, Borga et al. (2022) find that multinationals consume inputs that emit less CO_2, meaning that their carbon emissions are slightly lower than their domestic counterparts. However, they do not quantify this phenomenon. Rodriguez Clare et al. (2023) calculate the elasticity between the carbon intensity of subsidiaries and the carbon intensity of the parent company's home country: a 1% higher carbon efficiency in the home country is associated with 0.6% lower emissions in the host country. Conversely, the decision to locate in a host country may be motivated by the possibility of operating with poorer environmental efficiency.[4] A first approach consists in attributing to investor home sector-countries the efficiency of their host sector-countries. We thus obtain the most plausible value. We can then repeat the exercise by attributing to subsidiaries receiving direct investment the efficiency of their home sector-countries in order to obtain a lower bound. The difference between these two values also informs us as to the potential gains to be made from technology transfer within multinationals.

Another limitation of this approach is that complementarities may exist between the parent company's technologies and those available in the destination sector. Where complementarities exist, combining the two technologies may enable production with a lower carbon intensity than that of the home and host sectors. This can result in geographical specialisation effects: for example, a French company opening an IT server centre in Iceland to take advantage of the colder climatic conditions to make the server cooling process less energy-intensive. However, it is impossible to take this type of mechanism into consideration with the data at our disposal.

Therefore, the methodology used in this study leans heavily on the attribution of destination sector technology to French subsidiaries. We relax this assumption to explore different counterfactuals in Section 2. Another limitation is the conceptual difference between the definition of FDI in the balance of payments methodology and capital in the system of national accounts. For example, capital in the national accounts does not include land acquisitions, which fall within the scope of FDI.

4 Or at least to operate in an institutional environment (regulation, taxation, labour costs, etc.) correlated with low carbon efficiency.

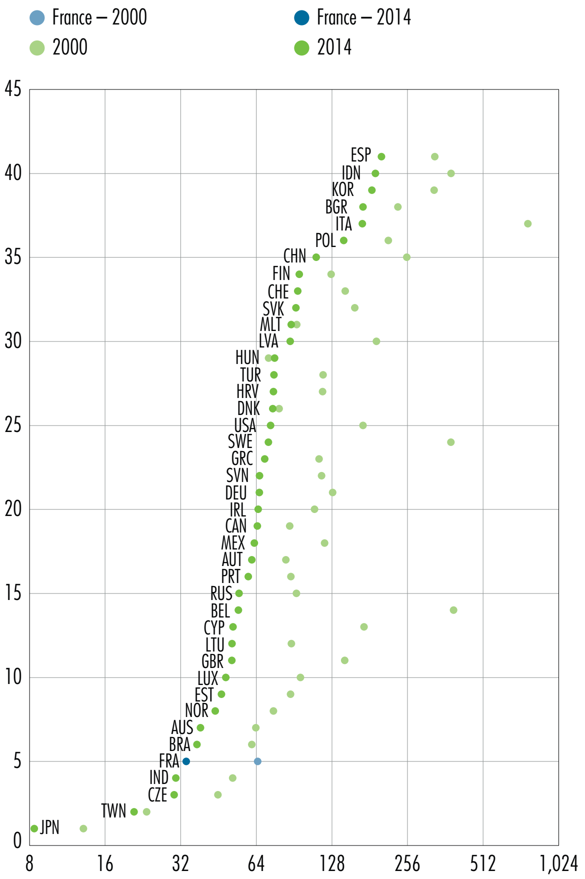
BOX 2

Improving carbon efficiency in France and worldwide

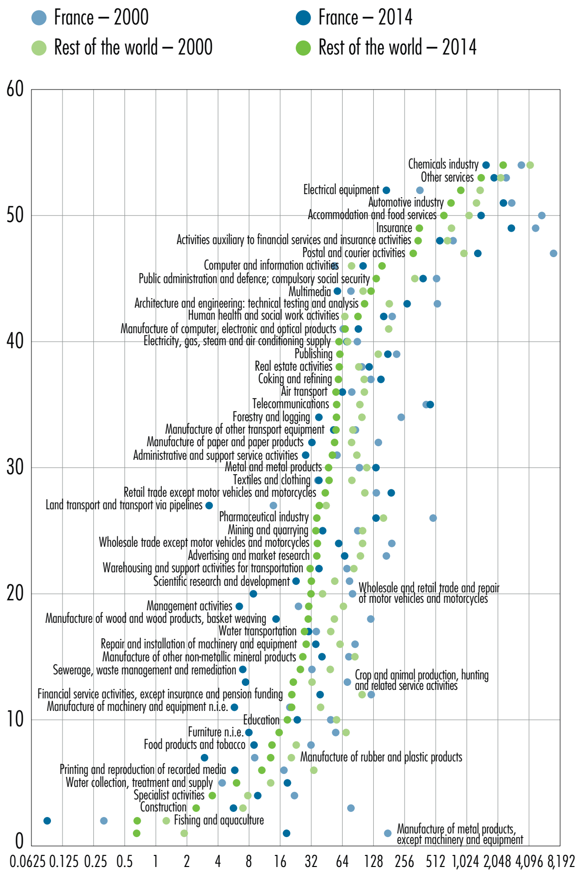
Carbon intensity by country and sector in 2000 and 2014

(in thousands of tonnes of CO_2 per unit of capital in constant dollars (purchasing power parity [PPP] exchange rate, 2010), logarithmic scale)

a) Carbon efficiency by country



b) Carbon efficiency by sector



AUS	Australia	CZE	Czech Republic	HRV	Croatia	LTU	Lithuania	RUS	Russia
AUT	Austria	DEU	Germany	HUN	Hungary	LUX	Luxembourg	SVK	Slovakia
BEL	Belgium	DNK	Denmark	IDN	Indonesia	LVA	Latvia	SVN	Slovenia
BGR	Bulgaria	ESP	Spain	IND	India	MEX	Mexico	SWE	Sweden
BRA	Brazil	EST	Estonia	IRL	Republic of Ireland	MLT	Malta	TUR	Turkey
CAN	Canada	FIN	Finland	ITA	Italy	NOR	Norway	USA	United States
CHE	Switzerland	FRA	France	JPN	Japan	POL	Poland		
CHN	China	GBR	United Kingdom	KOR	South Korea	PRT	Portugal		
CYP	Cyprus	GRC	Greece			ROU	Romania		

Source: Groningen Growth and Development Centre, World Input-Output Database (WIOD); author's calculations.
Note: "n.i.e." refers to all firms not included elsewhere.

…/…

The global economy is becoming less carbon-intensive: the number of units of CO_2 emissions per unit of capital, in constant 2010 dollars (purchasing power parity exchange rate), is trending downwards. This is true for all countries and all sectors, with the exception of the "manufacture of rubber and plastic products". In 2000, in France, USD 1 billion of capital emitted 45 kt[1] of CO_2. In 2014, this had fallen to 30 kt (see panel a). In the rest of the world, USD 1 billion of capital emitted 161 kt of CO_2 in 2000, compared with 79 kt in 2014. Many Eastern European countries are among those whose carbon intensity has fallen most sharply, including Romania (down 86%), Latvia (down 64%) and Bulgaria (down 56%). Conversely, the least favourable trends were seen in Japan (up 6%), Denmark (down 5%) and Lithuania (down 6%). France was ranked third in the 2014 classification, behind Switzerland and Sweden. Russia (402 kt per EUR billion of capital) was ranked last.

France's good performance is not merely structural (linked to the expanding share of services in the French economy). France ranks better than the rest of the world average in 20 of the 54 economic sectors (see panel b), particularly in certain manufacturing sectors. For example, the rest of the world emits on average 4.7 times more CO_2 per unit of capital than France in sector 30 ("manufacture of other transport equipment") and 1.8 times more in sector 26 ("manufacture of computer, electronic and optical products"). The sectoral distribution of FDI therefore has an impact on its total emissions.

1 1 kt is the equivalent of 1,000 tonnes.

1 The carbon footprint of French subsidiaries abroad: contracting following a peak in 2016

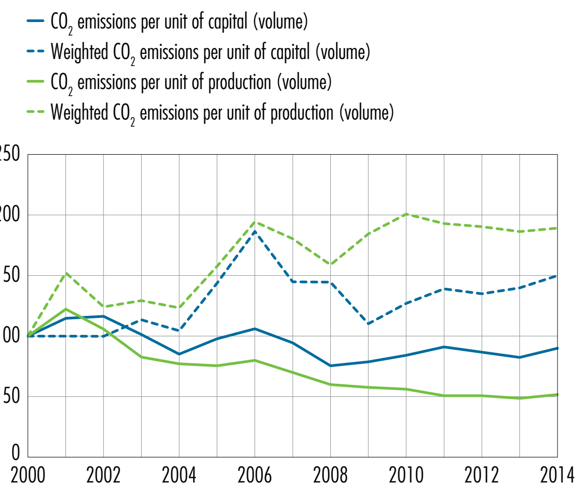
Between 2000 and 2014, the destination sectors of French investment abroad became less carbon-intensive on average (a 10% reduction; see Chart 2, solid blue line, and Box 2 for the geographical and sectoral details behind the trends). However, the average emissions of these sectors, weighted by their share of the total stock of FDI

$$(\tau_t^w = \sum \frac{FDI_{k,j,t}}{FDI_t} * \tau_{k,j,t})$$

increased by 50% (dotted blue line). This was due to the growth in FDI directed towards relatively more carbon-intensive destination sectors[2] between 2000 and 2006. However, the weighted carbon intensity has since declined, by 36 percentage points. This decrease is the result of a rebalancing of FDI stock in favour of less carbon-intensive destination sectors. We also note that the measure of CO_2 emissions per unit of revenue (blue lines) broadly correlates with the quantity of CO_2 emissions per unit of productive capital (a correlation coefficient of 0.68).

2 See Appendix 2 for details on the changing French FDI distribution.

C2 Change in unweighted and weighted carbon intensity
(constant prices, 2000=100)



Sources: Groningen Growth and Development Centre, World Input-Output Database (WIOD); Banque de France.
Note: The unbroken lines show the change (2000=100) in average unweighted CO_2 emissions per unit of production (green) or per unit of capital (blue), i.e. in the latter case the coefficients $\tau_{k,j,t}$ of Equation (2) in Box 1 in volume (price-adjusted values).
The dotted lines show the change in the average weighted by the stock of foreign direct investment (FDI) held in each host sector-country.

We estimate foreign direct emissions of CO_2 at 130.7 million tonnes in 2014 (see Chart 3, blue line). Emissions peaked in 2006 at 163.1 million tonnes and have been gradually declining ever since. We arrived at this estimate by extrapolating subsidiaries' emissions from the carbon efficiency of the destination sector (see Equation (1), Box 1). **It is therefore based on the assumption that French parent companies do not transfer their emission technology to their subsidiaries.** This assumption is empirically questionable. Aghion et al. (2024) find that setting up a subsidiary, as well as exporting goods to a subsidiary, goes hand in hand with technical knowledge sharing, as measured by patent citations (see Keller, 2021, for a review of this literature).

2 The role of innovation and intra group knowledge sharing in the CO_2 emissions of subsidiaries abroad

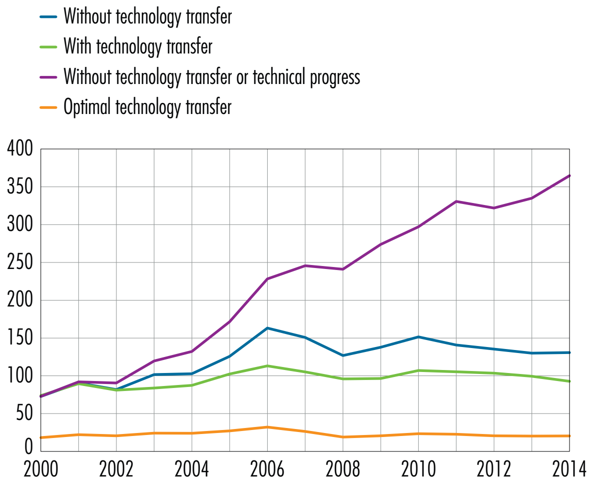
While it may not be possible, given the absence of more detailed data, to estimate the technological proximity between parent and subsidiary, it is instructive to simulate a scenario of perfect technology transfer. It allows us to estimate a lower bound for French CO_2 emissions abroad. In this scenario, the subsidiaries operate the same technology in use in their sector of origin in France:

$$FDE_t^{FRA} = \sum_{k,j} \tau_{k,j=FRA,t} * FDI_{k,j,t} \qquad (3)$$

In this, the most optimistic scenario, their emissions would amount to only 92.7 million tonnes of CO_2, that is, 29% lower (see Chart 3, green line). We set out the main sector-country pairs that would benefit most from French technology transfers in Table 1 below, in which two groups of countries are apparent. The first is made up of advanced economies (Belgium, the United Kingdom, etc.), where FDI stocks are significant, but differences in carbon intensity are minor. The emissions surplus associated with differences in technology represents 34.2% of total French emissions abroad. The second group includes emerging economies (China, Indonesia, etc.), where the positions of FDI stocks and carbon intensity differences are reversed. The second group's emissions surplus, on the other hand, accounts for only 8.7% of French emissions abroad.

C3 Change in the estimated carbon footprint of French subsidiaries abroad, 2000-14

(millions of tonnes of CO_2)



Sources: Groningen Growth and Development Centre, World Input-Output Database (WIOD), and Banque de France; author's calculations.
Note: The blue line shows the estimated total CO_2 emissions of French subsidiaries abroad if they had the same carbon intensity as the domestic companies in the destination sector. The green line corresponds to the case in which French subsidiaries have the same carbon intensity as their sector of origin. The purple line corresponds to the case in which French subsidiaries use the technology established in 2000 of the host country. The orange line corresponds to the case in which French subsidiaries use the best technology available at each date and in each sector.

In order to illustrate the role innovation plays in reducing carbon emissions, we also simulate a third, particularly pessimistic scenario, in which there is no technological progress and no spillover effects, and each destination sector is therefore assigned its 2000 carbon efficiency indefinitely.

$$FDE_t^{2000} = \sum_{k,j} \tau_{k,j,t=2000} * FDI_{k,j,t} \qquad (4)$$

If the technology of the rest of the world had remained unchanged at its 2000 level (purple line), **French emissions abroad would amount to 364 million tonnes of CO_2 per year, i.e. 2.8 times higher than our most likely estimate.**

Lastly, we simulate a final scenario in which French subsidiaries systematically use the best available

T1 Contribution of the top 15 sector-country pairs to emissions reduction in the event of perfect technology transfer in 2014

(stock in EUR billions, carbon intensity in millions of tonnes of CO_2/EUR billions of capital, surplus in millions of tonnes, share in %)

Rank	Country	Sector	Stock of foreign direct investment (FDI) abroad	Carbon intensity differential (between France and the host country) (2)	Carbon emissions surplus (3) = (1) x (2)	Share of emissions abroad (4) = (3)/total emissions
1	Belgium	Electricity, gas, steam and air conditioning supply	51.6	0.3	15.2	11.7
2	United Kingdom	Electricity, gas, steam and air conditioning supply	21.9	0.6	13.4	10.3
3	United States	Electricity, gas, steam and air conditioning supply	7.9	0.8	6.7	5.1
4	Belgium	Coking and refining	7.8	0.6	4.6	3.5
5	China	Electricity, gas, steam and air conditioning supply	1.7	2.3	3.8	2.9
6	Germany	Electricity, gas, steam and air conditioning supply	2.8	1.3	3.5	2.7
7	Indonesia	Coking and refining	1.7	1	1.6	1.3
8	Poland	Electricity, gas, steam and air conditioning supply	0.6	2.2	1.4	1.1
9	China	Manufacture of non-metallic mineral products	0.6	2.1	1.3	1
10	China	Chemicals industry	3	0.4	1.1	0.8
11	Italy	Electricity, gas, steam and air conditioning supply	6.9	0.1	1	0.8
12	Poland	Insurance	0.5	1.7	0.8	0.6
13	Mexico	Chemicals industry	0.3	2.6	0.7	0.6
14	China	Financial activities	4.4	0.1	0.6	0.4
15	United States	Insurance	19	0.1	0.5	0.4

Sources: Groningen Growth and Development Centre, World Input-Output Database (WIOD), and Banque de France; author's calculations.
Note: Contributions of the main sector-country pairs to carbon emissions reduction abroad, based on the difference in sector carbon intensity (CO_2 per unit of capital) between France and the host country.

technology, i.e. the technology used in the highest-ranking country for the sector and the year:

$$FDE_t^{OPT} = \sum_{k,j} \underset{i}{argmax}\, \tau_{k,j,t=2000} * FDI_{k,j,t} \qquad (5)$$

In this "optimal" scenario (orange line), **emissions would amount to only 20.6 million tonnes of CO_2, i.e. 6.3 times lower than in our main scenario**.

3 Conclusion

In this paper, we present a quantification of the CO_2 emissions of French companies' foreign subsidiaries. Their emissions amounted to 130.7 million tonnes in 2014, gradually declining after peaking in 2006. The composition of the stock of FDI has therefore become more virtuous in terms of CO_2 emissions. Moreover, the carbon efficiency of the destination sectors for French investment abroad has improved. We also demonstrate the role that technological progress and knowledge sharing can play in reducing greenhouse gas emissions. Without technical progress in host countries, the emissions generated by French FDI could have been up to 2.8 times higher. Without friction during the international technology transfer and adoption process, emissions could even be up to 6.4 times lower. However, these estimates are based on a series of restrictive accounting and economic assumptions, such as equivalences between FDI and productive capital and between the sector of the apparent FDI recipient and that of the ultimate recipient, or the absence of complementarity between technologies. The fact that these assumptions have to be made shows that significant data gaps still exist both in sectoral economic data and in direct investment or environmental data.

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Appendix 1
Data sources

1 WIOD

The data are taken from the Groningen Growth and Development Centre's publicly available World Input-Output Database (WIOD), version 2016 (*https://www.rug.nl/ggdc/valuechain/wiod/wiod-2016-release*). It covers CO_2 emissions, rates and related economic data in local currency up to 2014 for 54 two-position NAF (the French classification of activities) sectors, some of which are pairs of aggregated sectors, and for 41 countries, including the Organisation for Economic Co-operation and Development (OECD) countries as well as China, India and Russia (see the chart in Box 2 for the full list). Emissions data are, however, missing for the Netherlands. The sector accounts data are taken from the "Socio Economic Accounts" database and are converted into US dollars using the "Exchange Rates" database. The emissions data in the database come from the "CO_2 Emissions" database.

2 STAN

We round out the value data in the WIOD database with volume data for the domestic capital and production variables using the OECD's STAN (2016) database. These are available in local currency (2010 prices) and in chained volume measures. We follow Bergeaud et al. (2016) and convert them into US dollars at the purchasing power parity exchange rate using the World Bank's World Development Indicators.

3 Banque de France

The foreign direct investment (FDI) data are taken from the Banque de France's "French capital abroad" database. This database provides an almost exhaustive record of French residents' holdings of direct investment assets (i.e. providing direct control or indirect control of at least 10% ownership) abroad between 2000 and 2020. We select instruments coded F511, F512 and F519, which correspond to company shares (listed, unlisted and other), and which exclude intra-group payables and deposits (F2, F4 and F8). We only include companies whose head of group is French. Assets are expressed "at mixed value": the stocks of subsidiaries listed on the stock exchanges of the host countries are recorded at market value, while the stocks of unlisted subsidiaries are measured at book value. The host country corresponds to the country of the first recorded counterparty, which is not necessarily the country of residence of the ultimate owner. We convert the FDI stocks into constant dollars using WIOD exchange rates and implicit capital deflators from the STAN database.

Each non-resident subsidiary is classified according to its five-position NAF code. A difficulty arises when trying to correctly classify subsidiaries declared under sector 6420 ("holding activities"). Where possible, we give the same NAF code assigned to the parent company by the *Institut national de la statistique et des études économiques* (INSEE – the French National Institute of Statistics and Economic Studies) to the subsidiary. The data are then aggregated at the same level as the WIOD database (54 two-position NAF sectors with some pairs of aggregated sectors).

A limitation of direct investment data is that it indicates the sector and country of the "first level subsidiary". Suppose that a French company "A" acquired company "B" in the automotive sector in Japan. If company "B" owned a subsidiary "C" in the automotive repair sector in South Korea, the value of "C" would be well reflected in "A"'s cost of acquisition of "B", but "C"'s country-sector would be invisible in the data. This would mean that in the context of our study we would attribute the carbon efficiency of the automotive sector in Japan only to "B", whereas its true carbon efficiency would be a combination of the efficiencies of the automotive sector in Japan and the automotive repair sector in South Korea.

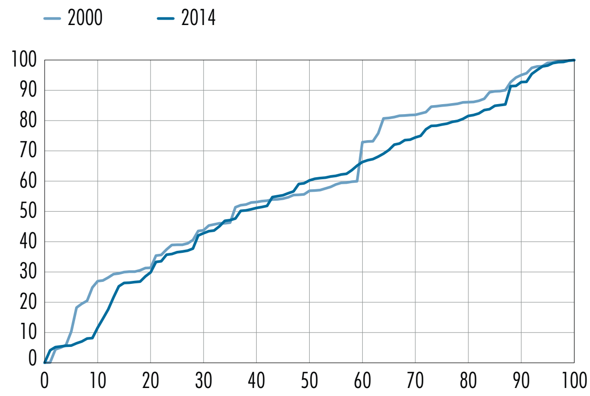
Appendix 2
Change in the distribution of the carbon footprint of French FDI

We note that in 2014 a greater proportion of foreign direct investment (FDI) was in more carbon-intensive destination sectors (see chart, top panel). This is reflected graphically by a shift to the right of the line of the cumulative distribution of FDI according to the carbon intensity of the destination sector. In 2000, 27% of French FDI was in the 10% least carbon-intensive destination sectors but by 2014, this had fallen to 11.6%. In addition, 17.9% of French FDI was in the 30% most carbon-intensive destinations in 2000, rising to 25.5% in 2014.

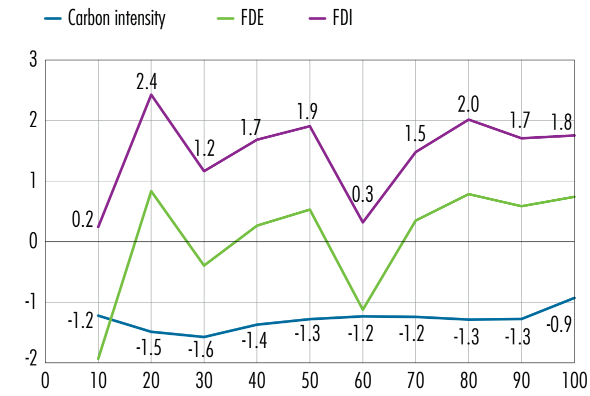
It is important to emphasise that progress in carbon efficiency is apparent and relatively uniform across the carbon intensity distribution brackets (see Chart b, blue line). The decline in destination sector carbon intensity offsets the growth in FDI (purple line) and stabilises emissions abroad for country-sectors below the seventieth percentile (green line). On the other hand, emissions from subsidiaries in the least carbon efficient sectors have continued to rise due to increasing direct investment inflows.

Cumulative distribution of FDI stocks according to destination sector carbon intensity in 2000 and 2014

a) Cumulative share of FDI
(%)



b) Growth rate per decile of the distribution of CO_2 emissions per unit of capital
(x-axis: in percentiles; y-axis: in log points)



Note: Each point on the curve represents the cumulative share of foreign direct investment (FDI) held in host countries ranked by increasing intensity on the x-axis (100 for the most emissions-intensive destination).
For example, in 2014, 11.6% of French FDI was held in the 10% of host countries with the lowest CO_2 emissions, compared with 27% in 2000.

Note: Each line represents the growth rate for each decile between 2000 and 2014 ($\Delta \log y = \log y_{t=2014} - \log y_{t=2000}$) of foreign direct emissions (FDE, in green), foreign direct investment (FDI, in purple) and carbon intensity (in blue) in the destination sectors (ranked by increasing CO_2 intensity).

Sources: Groningen Growth and Development Centre, World Input-Output Database (WIOD); Banque de France.

In order to isolate the heterogeneity of the contribution to emissions along the carbon intensity distribution, we carry out the following decomposition. Let $F(\tau_{k,j})$ be the cumulative distribution function of the carbon efficiency of the destination sectors $\tau_{k,j}$. Let the growth rate of a variable $Y = \{FDE, FDI\}$:

$$\Delta Y = \frac{Y_t - Y_{t-1}}{(½) * (Y_t + Y_{t-1})}$$

With $t = \{2000, 2014\}$. Thanks to this mid-point growth rate, we can separate the numerator into two components, that of the sector countries whose carbon efficiency is strictly less than the quantile q and that of the rest of the distribution of $F(\tau_{k,j})$:

$$\Delta Y = \frac{(Y_{t,q(\tau)<q} - Y_{t-1,q(\tau)<q}) + (Y_{t,q(\tau)\geq q} - Y_{t-1,q(\tau)\geq q})}{(½) * (Y_t + Y_{t-1})}$$

We note each of these components $\frac{(Y_{t,q(\tau)<q} - Y_{t-1,q(\tau)<q})}{(½) * (Y_t + Y_{t-1})} = \Delta Y_{q(\tau)<q}$ et $\Delta Y_{q(\tau)\geq q}$ respectively and note $C\Delta Y_{q(\tau)<q} = \frac{\Delta Y_{q(\tau)<q}}{\Delta Y}$ the cumulative contribution to the growth rate of Y in the sectors whose technology τ is below the q quantile.

This exercise demonstrates that destination sectors above the seventieth percentile accounted for 29.4% (100% minus 70.6%) of the increase in the stock of FDI, but contributed almost all of the overall increase in foreign direct emissions (FDE; see table). In fact, the contribution to the increase in FDE from destination sectors below the seventieth percentile is close to zero, or even negative, as the decline in their carbon intensity is enough to offset the growth in their FDI stock.

Cumulative contribution to FDE and FDI growth rates between 2000 and 2014

$C\Delta Y_{q(\tau)<q}$	q = 10	q = 20	q = 30	q = 40	q = 50	q = 60	q = 70	q = 80	q = 90	q = 100
FDI	5.9	27.4	41.2	49.6	60.1	66.2	70.6	78.7	90.9	100
FDE	-0.4	0.3	0.5	0.4	3.2	5	-0.7	6.4	33.7	100

Sources: Groningen Growth and Development Centre, World Input-Output Database (WIOD), and Banque de France; author's calculations.
Note: Breakdown of the cumulative contribution to the growth rates of foreign direct investment (FDI) and foreign direct emissions (FDE).
For example, 78.7% of the growth in FDI and 6.4% of emissions come from the 80% of sectors that have an intensity less than or equal to this level (and for 20%, their intensity is greater).

Appendix 3
Different ways to measure stocks of foreign direct investment abroad

Up to now, we have restricted our exercise to foreign direct emissions (FDE) generated by subsidiaries of French heads of group, and have not considered the subsidiaries of French companies that belong to foreign groups. Furthermore, our count is based on a "mixed value" measure of direct investment stocks (see "2 STAN" in Appendix 1). The value of these stocks can vary according to changing share prices of the invested companies listed on a stock exchange, for example. In this section, we will apply a range of scopes to measure foreign direct investment (FDI).

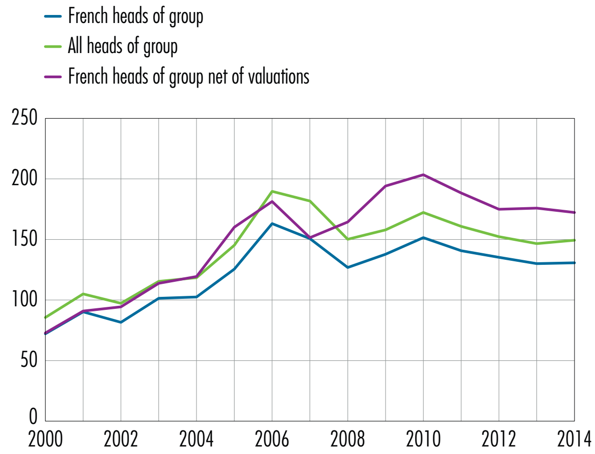
We broaden the measure of FDI to foreign subsidiaries owned or partly owned by a French company whose head of group may not necessarily be French. In this case, assessing a French company's decision-making power over its subsidiary's environmental choices becomes difficult. Airbus (with its head office in the Netherlands), Lafarge (Switzerland), Arcelor Mittal (Luxembourg) and Nestlé (Switzerland) all fall into this category. It is therefore instructive to apply a broader measure of FDI. Moreover, this measure is more suited to future international comparisons and any eventual carbon balance calculations. Carbon emissions abroad are mechanically slightly higher based on this broadened scope, amounting to 149.4 million tonnes (see green line in the chart) in 2014, compared with 130.7 million tonnes (blue line) for the subsidiaries of French heads of group. This exercise allows us to confirm that French heads of group account for the bulk (87%) of French carbon emissions abroad.

In order to check that the changes observed in our main measure are not an artefact of valuing the stock of FDI in mixed value, we also introduce a book value measure: CFDI. They are calculated as follows: for each company f in each sector country year, we obtain its initial stock at t0 and the cumulative total of FDI flows between this creation date and date t.

$$CFDI_{i,k,t} = \sum_{f} \left(STOCK_{f,i,k,t_0} + \sum_{t_1}^{t} FLUX_{f,i,k,t} \right)$$

The flow variable covers all investments (positive sign) and disinvestments (negative sign). The mixed value approach is only used to arrive at the initial value of the investment stock. Any fluctuations in CFDI can be attributed solely to the investment decisions of the French parent company. When we use this methodology to calculate the carbon emissions of FDI, the orders of magnitude of the emissions and their overall evolution remain unchanged. However, we find that these carbon emissions would have continued to increase after 2006 until 2010 (see chart, purple line) and that they culminate at a higher level than for our main measure (a 31.7% difference).

Estimated carbon footprint of French subsidiaries abroad, 2000-14
(millions of tonnes of CO_2)



Sources: Groningen Growth and Development Centre, World Input-Output Database (WIOD), and Banque de France; author's calculations.
Note: The blue line traces our main estimate based on the stock of foreign direct investment (FDI) of French subsidiaries of French heads of group in mixed value. The green line includes the stock of FDI of all heads of group in mixed value. Finally, the purple line corresponds to the stock of FDI of French heads of group at book value.

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