The dissemination of the “Shell sentence” and compliance with the Paris Agreement

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The dissemination of the "Shell sentence" and compliance with the Paris Agreement

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Abstract

The extension of Shell's landmark sentence to all the foreign affiliates of multinational enterprises (MNEs) would imply a global emissions reduction of 2.76 $GtCO_2$. Between 28% and 43% of the total 2030 emissions reduction target of not exceeding 2 °C would be achieved. While 91% of multinational affiliates' output belongs to high-income countries, 54% of their emissions occur in low- and middle-income countries. Therefore, these commitments could crucially help emerging countries meet their mitigation targets.

We place a special focus on MNEs in the vehicle industry and find that the current targets disclosed in the sustainability reports of the leading automotive MNEs (such as Volkswagen, Toyota, Nissan, and Ford) ignore the upstream emissions of their production, as they consider only scopes 1 and 2. This biased approach would have them reducing only 8%-22% of the required reductions of their upstream emissions if the Shell sentence were to be extended to the automotive industry.

Main Text

"The Hague District Court has ordered Royal Dutch Shell (RDS) to reduce the CO_2 emissions of the Shell group by a net 45% by 2030, compared to 2019 levels, through the Shell group's corporate policy."[1] This is the summary content of the groundbreaking "Shell sentence". What if this sentence is extended to multinationals affiliates worldwide, and how would it help them comply with the Paris Agreement? Is there any relationship between the countries that own the multinationals and the countries where these reductions would occur? In which sectors are the MNEs operating that would have to reduce their emissions? What if we extended the Shell sentence to the motor vehicles industry and compared it with their own emissions reduction targets?

The importance of multinational affiliates (MNEs) in the CO_2 emissions embodied in global production chains has recently been well documented. Recent findings include the footprint of US MNEs operating in the world economy [2], the MNEs operating within the European Union (EU) [3, 4], or the affiliates of all MNEs whose combined carbon footprint reached 18.7% of total global emissions in 2016 [5]. MNEs must commit to becoming leaders in the fight against climate change due to their high level of responsibility [6], and technology transfers into parents and affiliates and the search for more efficient suppliers could have significant mitigation impacts [7]. Beyond corporate social responsibility issues and marketing campaigns, MNEs must be forced to set science-based emissions mitigation targets [8] aligned with the Paris Agreement throughout their global production chains.

The current context requires new policy choices to ensure a global reduction in emissions [9]. On the one hand, the targets proposed by countries to commit to the Paris Agreement are insufficient [10]. On the other hand, the temporary emissions reduction observed during the COVID-19 confinements will be reversed [11] by the rebound effects, as seen in China [12] and after the 2008 global financial crisis [13]. Moreover, the ambitious recovery plans announced by the EU within the framework of the NextGenerationEU [14] and by the Biden Administration [15] will imply a short-term increase in global emissions. However, they could mean emissions reduction in the medium term if all those plans adequately stimulate the energy transition [16]. The involvement of new players in the fight against climate change is essential to meet the set objectives, and MNEs could be the cornerstone of this change. In this context, the Hague Tribunal's sentence on Shell deals precisely with this. It obliges Shell to set targets for reducing its total CO_2 emissions by 45% by 2030, including all Scope 3 emissions (those associated with the inputs it uses) and those made by its downstream customers (for the products it sells) [1]. In practice, this implies an extraction-based accounting principle [17] but one that is applied to firms, in which emissions are reallocated from the combustion of all traded fuels back to the firms that extracted them. The sentence is aligned with the proposed European Commission's Directives to carry out actions toward sustainable corporate governance, supporting the increase of companies' obligations to comply with human rights and environmental standards in their supply chains [18].

To evaluate the global dissemination of Shell's sentence to MNE affiliates, we have used an environmentally extended MRIO model including firm heterogeneity according to ownership (domestic or foreign). We estimate the global CO_2 emissions reduction if all MNE affiliates set emissions reduction commitments to the level of Shell's sentence (45% emissions reduction by 2030), while differentiating between high-income countries (HICs) and low- and middle-income countries (LMICs). We propose that the reduction target be applied using three different allocation criteria: a) direct emissions, consistent with production-based accounting (PBA) and commonly adopted in international agreements [19]); b) producer footprint accounting [2] (PF) or total upstream emissions; and 3) the extended carbon footprints of the MNE affiliates by country [5], measuring total upstream and downstream emissions, which is compatible with Shell's sentence, as we account for the emissions associated with fuel production. However, we do not account for downstream combustion emissions to avoid double-counting and, parallelly, to engage all MNEs, not only the energy-related companies.

Our findings show that the extension of Shell's landmark sentence to the foreign affiliates of all MNEs in the world would imply a global emissions reduction of 2.76 $GtCO_2$, which represents 28%-43% of the total 2030 emissions reduction required to not exceed °C. While 91% of MNEs' affiliates' output belongs to HIC, 54% of their carbon footprint emissions occur in LMICs and account for an average of 26% of the respective national production-based emissions of LMICs (60% in Bulgaria and 10% in RoW). Regarding the motor vehicle industries, the dissemination of the Shell sentence to those industries shows a considerable gap between the mitigation targets of automotive MNEs and the reductions required by compliance with the sentence. Most of the company's emissions reduction targets for the production stages are set for scopes 1 and 2, which account for a maximum of 13% of the total carbon footprint in the production of motor vehicles.

Results

Global emissions reduction by dissemination of the Shell sentence. In the first scenario, in which the reduction target is applied to the MNE affiliates' direct emissions, the emissions reductions between 2020 and 2030 would reach 1.14 $GtCO_2$, or 3.6% of global emissions (Figure 1). This reduction represents 14% of the global emissions reduction needed to not exceed 2 °C by 2030 (7% of the amount needed to not exceed the 1.5 °C target) following the Climate Action Tracker data [20]. Higher emissions reduction would occur in high-income countries, such as the USA (19%, 0.220 $GtCO_2$), Germany (7%, 0.085 $GtCO_2$), and Canada (5%, 0.053 $GtCO_2$) (Figure 2). However, a considerable amount of emissions reductions would be required to take place in low- and middle-income countries (39%), such as China (15%, 0.168 $GtCO_2$) and India (5%, 0.054 $GtCO_2$).

In scenario 2, MNEs apply their reduction targets over the total amount of emissions embodied in the upstream value chain of their final products. Emissions reduction would account for 1.21 $GtCO_2$ by 2030 (15% and 8% of the amounts needed to meet the 2 °C and 1.5 °C targets, respectively), an amount that is slightly higher than that determined in the first simulation (Figure 1). Regarding specific countries, the direct emissions related to the MNE supply chains are mainly released in the LMICs, increasing their reduction responsibility to 53%, especially in China (up to 26%) and India (up to 6%) (Figure 2).

The third scenario applies the reduction target to the total carbon footprint of MNE affiliates, accounting for those direct and indirect emissions embodied in the global production chain, both upstream and downstream, and avoiding double-counting [5]. Under this approach, MNEs directly generate only 41% of the emissions embodied in their extended carbon footprint, and the rest of the emissions (59%) are generated by domestic firms operating within the country. In this scenario, emissions reduction would reach 2.76 $GtCO_2$ in 2030, 8.6% of global emissions (Figure 1). This emissions cut would account for 28% to 43% of the reductions needed to meet the 2 °C target by 2030 (16%-18% of the amount needed to meet the 1.5 °C target).

A remarkable fact is that scenario 3 accounts for the highest emissions reduction under MNE responsibility and the highest share allocated to the LMICs: 39% in simulation 1, 53% in simulation 2, and 54% in simulation 3 (Figure 2). When considering all emissions of the global value chains of the MNEs, the responsibility of the HIC increases by 82%, while that of the LMICs increases by 233% compared to scenario 1.

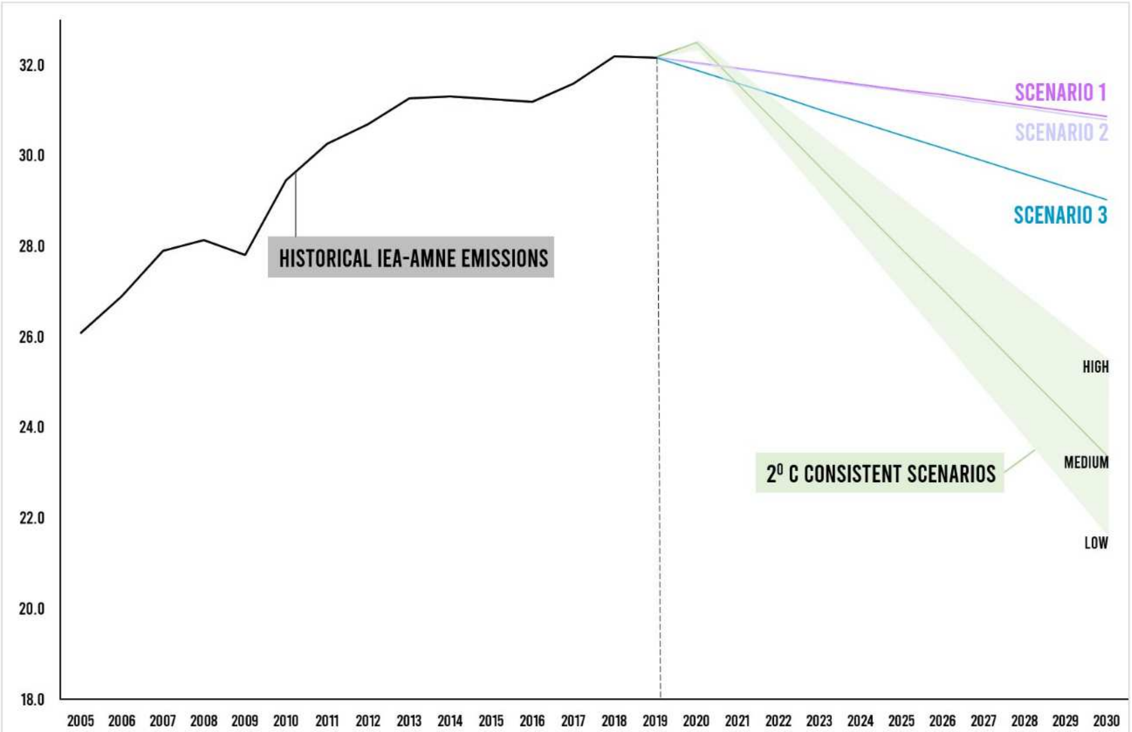

Fig. 1 | MNE emissions reduction scenarios ($GtCO_2$). (A) Fossil IEA-AMNE CO_2 historical emissions and the 2 °C consistent emissions path are shown to display the potential contribution of MNEs to the 2 °C target in each scenario. CO_2 emissions paths consistent with 2 °C scenarios are estimated following the Climate Action Tracker data [20].

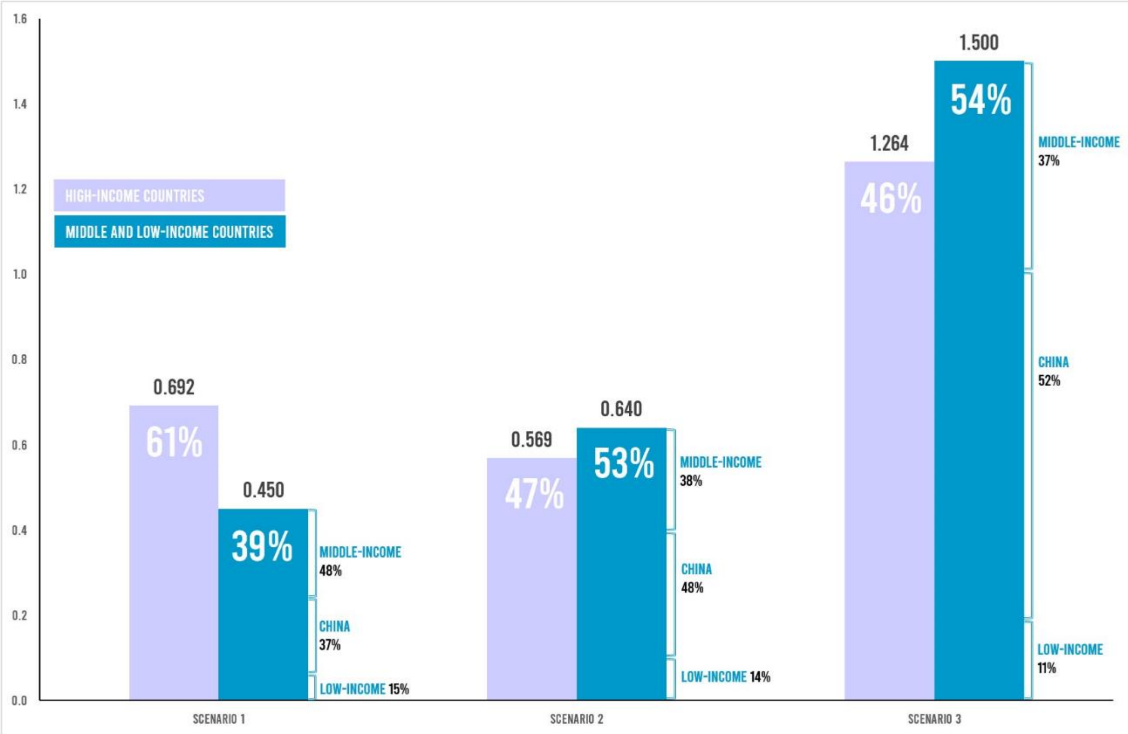

Fig. 2 | Potential MNE emissions reduction scenarios by groups of countries ($GtCO_2$). Bars show MNE global CO_2 emissions reductions according to each scenario, specifying whether these reductions affect direct emissions originally released in high-income countries (purple bars) or in low- and middle-income countries (blue bars). Percentages show the share of high-income countries and low- and middle-income countries on MNE emissions reductions.

The importance of the reduction in low- and middle-income countries (LMICs). LMICs' direct emissions embodied in MNEs' supply chains have reached 3.3 $GtCO_2$ and account for an average of 26% of the respective national production-based emissions of the LMICs. By country, the countries with higher direct emissions embodied in MNEs are China, with 1.729 $GtCO_2$, India (0.290 $GtCO_2$), Russia (0.238 $GtCO_2$), South Africa (0.171 $GtCO_2$), Mexico (0.127 $GtCO_2$), and the RoW (0.281 $GtCO_2$) (Figure 3). These direct emissions generated by MNEs in LMICs represent a significant share of national production-based emissions in each of the countries: 20% in China, 15% in India, 43% in South Africa, 34% in Mexico, and 18% in Russia.

Although there are LMICs that are not among the top countries in terms of direct emissions, it is worth highlighting some cases where direct emissions embodied in MNEs' supply chains represent a large share of their production-based emissions (Figure 3). Bulgaria is the clearest case in which 60% of its production-based emissions are due to the direct emissions of MNEs. In the second position, we find South Africa with 43% and Malaysia with 40%. These high shares inform us of the possibilities that MNEs have to apply mitigation strategies to reduce emissions along their global production chains, which would help LMICs alleviate their growing share of global emissions participation [21]. In these countries, MNEs can be real agents of change that allow them to fulfill the Paris objectives.

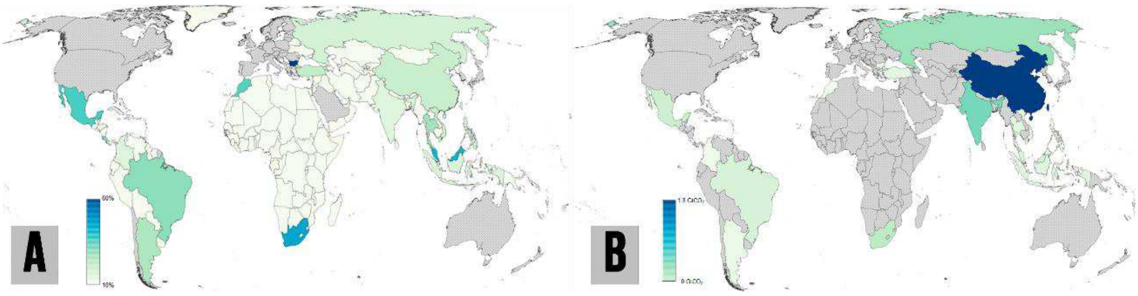

Fig. 3 | Direct impacts in the LMICs due to MNE production. (A). Share of national production-based accounting emissions embodied in the global MNEs' carbon footprints (excluding high-income countries). **(B)** Direct emissions embodied in the MNEs' carbon footprints (excluding high-income countries and the rest of the world, the RoW region). The RoW aggregate includes several countries in Panel A that are shown in the color corresponding to 10%. In Panel B, China is the LMIC with the highest direct emissions related to the MNEs (1.729 $GtCO_2$), followed by India (0.290), Russia (0.238), South Africa (0.171), Mexico (0.127), and RoW (0.281), which is not colored in Panel B.

The reduction of emissions by sector activities. In scenario 1, the reduction responsibility would fall on the MNEs operating in the following sectors: electricity, gas, and water (43%); transportation (12%); machinery and equipment (10%); and chemical products (8%) (Figure 4a). The difference between scenarios 1 and 2 is that the MNE affiliates are now responsible beyond the firm limits. Compared to scenario 1, the responsibility in scenario 2 is now transferred to the MNEs supplying the final demand. However, the electricity, gas, and water supply still appear at the top of the reduction obligations (17% of the MNE emission reductions). Hence, in scenario 2, MNE affiliates producing final goods and services in industries that are indirectly intensive in their use of fossil fuels increase their reduction responsibility, especially the MNEs producing machinery and equipment (26%, 0.312 $GtCO_2$) and vehicles (16%, 0.190 Gt CO_2) (Figure 4b).

In scenario 3, the sectoral distribution of the reductions is a mix of the two previous scenarios, with significant values in sectors typically providing intermediate inputs and those of final products: electricity, gas, and water (21%); machinery and equipment (19%); chemical products (11%); vehicles (9%); metal products (8%) and transportation (8%) (Figure 4c).

The inner rings in Figure 4 show the distribution of the MNEs' emission responsibilities in each scenario between those hosted by high-income host countries (in purple) and low- and middle-income host countries (in yellow). From this perspective, the HICs become more relevant since the affiliates hosted by them generate more than half of the MNEs' global emissions in all scenarios; however, the participation of the HICs as the host countries across scenarios decreases as the emissions responsibility is charged to MNEs increases. That is, when MNEs' responsibility is restricted to their direct emissions (scenario 1), affiliates hosted by the HICs generate 61% of global MNEs' emissions. Nevertheless, this share drops to 52% when MNEs' responsibility includes their extended carbon footprints (scenario 3).

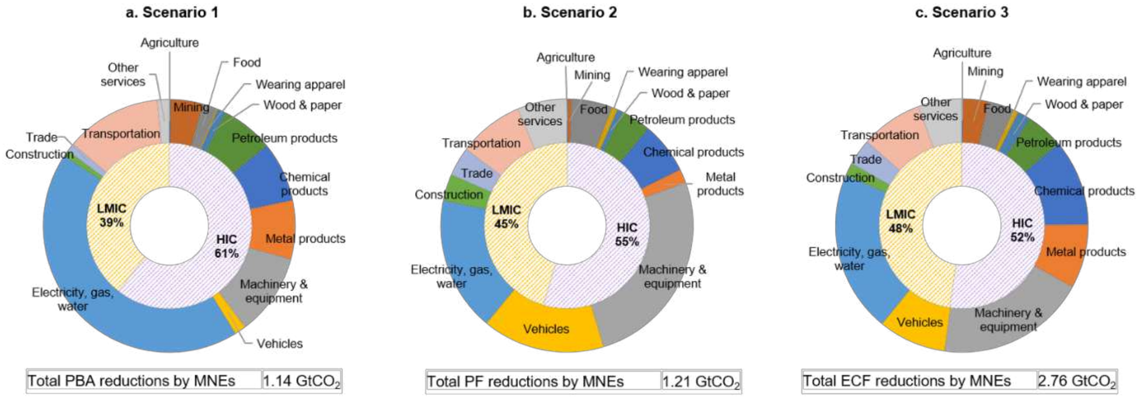

Fig. 4 | MNE emissions reduction by industry and host country. (a). MNE emissions reductions in scenario 1, **(b).** MNE emissions reductions in scenario 2, **(c).** MNE emissions reductions in scenario 3. The outer rings show the share of emission reductions by MNEs operating in each industry**.** The inner rings show the reduction share of MNEs located in high-income countries and in low- and middle-income countries.

The impact of the Shell sentence on the motor vehicles industry. The extended carbon footprints of the MNEs operating in the motor vehicles industry reaches 0.52 $GtCO_2$ (Figure 5), an emissions volume comparable to the total territorial emissions of large economies such as Germany (0.57 $GtCO_2$) and South Korea (0.54 $GtCO_2$). Among the vehicle-industry MNEs operating in the HICs, the US and Korea cases are noteworthy, accounting for extended carbon footprints of 0.08 and 0.02 $GtCO_2$, respectively (Figure 5). On the other hand, among the LMICs, we must highlight the cases of vehicle-industry MNEs operating in China (0.13 $GtCO_2$), India (0.03), and Mexico (0.03).

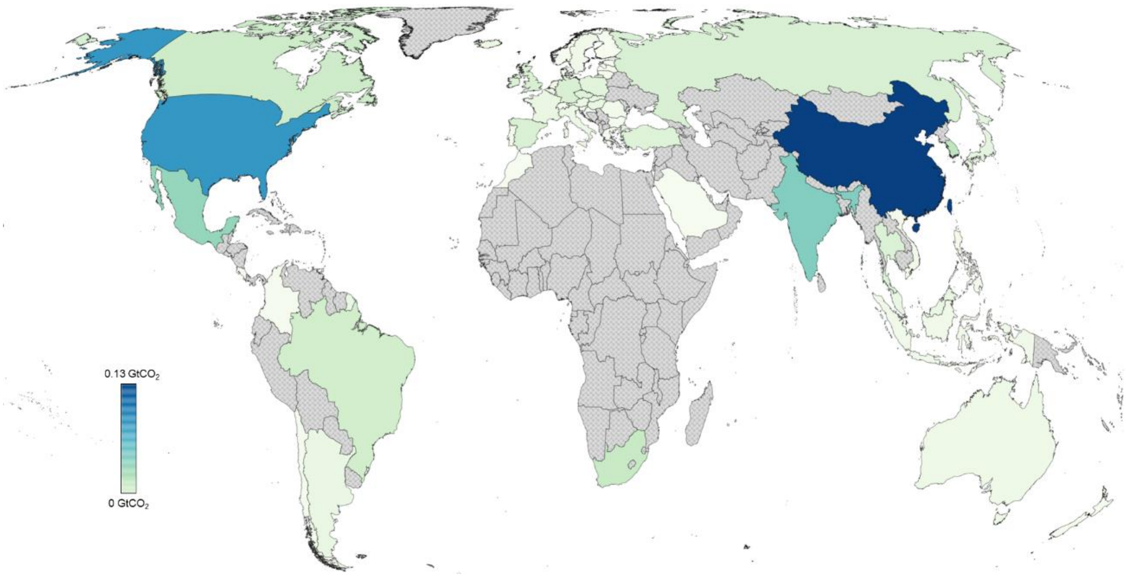

Fig. 5 | Extended carbon footprints of the MNEs in the vehicle industry by host country. The global extended carbon footprints of the MNEs in the vehicle industry reaches 0.52 $GtCO_2$. Affiliates located in all of the RoW countries (in gray) contribute 0.01 $GtCO_2$.

At the global level, the motor vehicle industry is dominated by US, European and Asian MNEs, such as Ford, Volkswagen and Toyota. At the country level, the foreign affiliates of these MNEs are among the main producers in the national vehicle markets in many countries. For instance, although the US vehicle manufacturing market is led by the US-native company General Motors with a 17% market share, the affiliates of Japanese automaker Toyota are in second place with a share of 14% [22]. Table 1 shows the foreign automaker with the largest market share in the vehicle industry of selected countries and presents details on the polluting emissions reduction targets of the corresponding automotive MNE's global activities.

Table 1 | Leading foreign MNEs in the vehicle industry of selected countries and their global emissions reduction targets. The table shows the top 10 host countries with the highest ECF of vehicle-industry MNEs.

	Host country	Leading foreign MNE	Reduction Target	Notes	Emissions considered	Base year
1	China	Volkswagen	30% by 2030		Scopes 1 and 2	2018
2	United States	Toyota	35% by 2030		Scopes 1 and 2	2013
3	India	Suzuki	45% by 2030	Per unit sold†	Scopes 1 and 2	2016
4	Mexico	Nissan	80% by 2050	44% by 2030*	Scopes 1 and 2	2005
5	Korea	Renault	50% by 2030	Per vehicle	Scope 1, 2 and 3#	2019
6	Canada	Ford	76% by 2035	54% by 2030*	Scopes 1 and 2	2017
7	Brazil	General Motors	71.4% by 2035		Scopes 1 and 2[23]	2018
8	United Kingdom	Ford	76% by 2035	54% by 2030*	Scopes 1 and 2	2017
9	Russia	Hyundai	26% by 2030		Scope 1, 2 and 3	2016
10	Germany	Ford	76% by 2035	54% by 2030*	Scopes 1 and 2	2017

* Assuming a constant annual reduction rate.
† Suzuki also commits to reducing CO_2 emitted from new automobiles by 40% in the well-to-wheel base compared to 2010 by 2030[24]. The well-to-wheel method considers upstream CO_2 emitted from excavating and refining fuel as well as in generating electricity but overlooks upstream CO_2 emitted by nonfuel suppliers along the value chains.
# Renault measures average gross emissions per vehicle produced linked to upstream transportation and partially assesses the impacts of the production of materials and parts for each vehicle using LCA databases [25].

As shown in Table 1, none of the automotive companies identified would comply with the Shell sentence. In most of them, the emission reduction targets are limited to scope 1 and 2 emissions. Only Hyundai considers scope 3 upstream emissions, and only some consider scope 3 downstream emissions[26]. For instance, according to the Volkswagen Sustainability Report [27], scope 1 and 2 emissions account for only 8.6% of the total upstream emissions generated by Volkswagen vehicle production (83,343 ktCO_2 in 2020). Therefore, the emissions reduction target set by Volkswagen for 2030 (30% on scopes 1 and 2) overlooks 91.4% of the company's upstream emissions in the production phases. Volkswagen is not a unique case since the low relevance of scope 1 and 2 emissions is a common feature in the vehicle sector. According to our estimates, scope 1 and 2 of emissions of the vehicle-industry MNEs in the selected host countries of Table 1 account, on average, for only 13% of the total ECFs of the MNEs in the motor vehicles industry in each country. Therefore, upstream scope 3 emissions of the MNEs in the motor vehicles industry (not included in the targets of the leading automotive MNEs) represent on average 87% of the ECFs of vehicle MNEs. These results are consistent with those found for the US vehicles industry in 2013, ranging from 65% to 82% [28].

These MNEs set relative mitigation targets to improve the efficiency of vehicles they sell (downstream scope 3). These improvements are positive; however, they do not guarantee absolute decoupling if the use of vehicles is not reduced enough, and their improvement is associated with the progressive penetration of the electric car. This is expected in some developed countries to the extent that they limit or prohibit the sale of combustion vehicles and subsidize the sale of electric cars and charging stations [29]. Nevertheless, an alignment with the Shell sentence would require that companies also have to reduce emissions upstream to cover the scope 3 emissions of the manufacture of electric cars, which are typically more energy intensive than conventional vehicle manufacture, requiring approximately 70 % more primary energy [30], and this is not fully considered in sustainability reports.

Using the emissions reduction targets set by Volkswagen, Toyota [31], Nissan [32], and Ford [33] as benchmarks, we assess the potential reductions of vehicle industry emissions in those countries where these four companies are market leaders (China in the case of Volkswagen, United States for Toyota, Nissan for Mexico, and Canada, United Kingdom and Germany in the case of Ford). We assume that all of the foreign vehicle MNEs in the respective host county undertake the same target as the leading foreign MNE. In Figure 6, we evaluate the gaps between the reductions achieved through those targets (purple bars) and the 45% reductions potentially achieved by the dissemination of the Shell sentence to all the upstream emissions of the vehicle-MNEs (yellow bars). Our estimations show a gap between the targets of the automobile companies and the emissions needed to comply with the Shell sentence. If all vehicle-MNEs adopted Ford's target in Germany, the UK, and Canada, there would still be gaps ranging from 4,066 to 5,709 $ktCO_2$ to achieve the reductions aligned with Shell's sentence, and therefore, the Paris Agreement. Thus, hypothetical reductions of the automotive MNEs in those countries adopting Ford's target account for 20%-22% of the upstream emissions reductions demanded by the dissemination of the Shell sentence. In the case of Mexico, the gap would be 11,773 $ktCO_2$ if Nissan's target is adopted, 31,206 $ktCO_2$ in the United States with Toyota's target, and 53,501 $ktCO_2$ in China with Volkswagen's target; the emissions reduction reached by the automotive MNEs in those scenarios would account for 12%, 9% and 8% of the reductions required to be aligned with the Shell sentence, respectively.

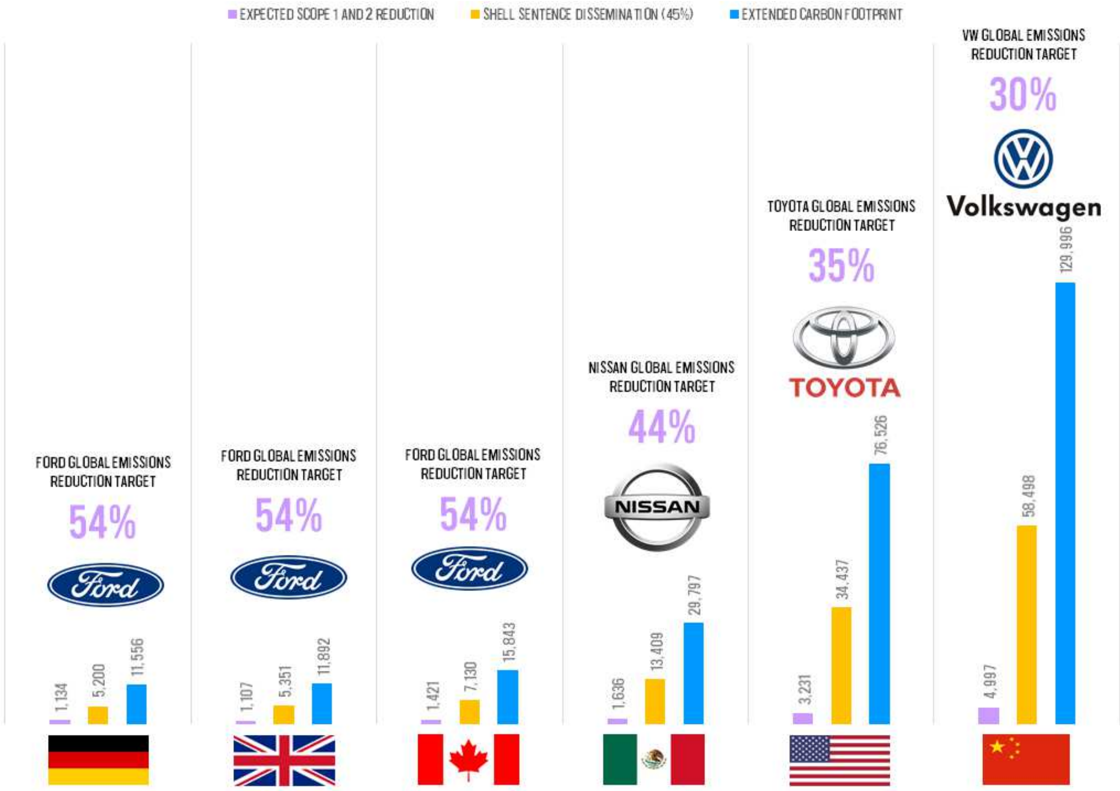

Fig. 6 | Emissions gap between vehicle MNE mitigation targets and the estimation of 45% established by the Shell sentence. The global extended carbon footprint of the MNEs in the vehicle industry reaches 0.52 $GtCO_2$. The firm's targets come from each company's sustainability reports. The dissemination of the Shell sentence proposed here would reduce the extended carbon footprints and direct and upstream emissions.

Discussions and Conclusions

There is a different emissions allocation criterion between the sentence and the one established by our simulations. The sentence obliges the Royal Dutch Shell company to reduce the downstream emissions associated with the combustion of the products it sells. In practice, this implies an extraction-based accounting principle [17] but applied to firms, in which emissions are reallocated from the combustion of all traded fuels back to the firms that extracted them. This allocation criterion has the advantage that if the responsibility is transferred to the rest of the extractive companies, it would be a reduced number of companies, 90 according to [34, 35], which have to reduce their emissions by 45%. Therefore, their compliance would be more easily controllable and monitorable (as with the Spanish and European legislation to reduce single-use plastics through a tax on domestic and imported production [36]). However, as shown in Elmalt, Kirti [37,] there is a weak relationship between emissions growth and the environmental, social, and governance (ESG) firm-level data for the largest worldwide emitters. This approach has the disadvantage that it offloads responsibility from energy-consuming companies and does not oblige them to set science-based emission reduction targets.

Conversely, our simulations assign the responsibility associated with the production and the consumption of intermediate goods to the affiliates. However, the last scenario is not related to downstream combustion to avoid double-counting and, parallelly, it engages all MNEs and not only fossil fuel extraction and processing companies but also, and especially those in the transportation, vehicles or machinery & equipment sectors. It would indeed be possible to adopt different criteria depending on the type of corporation. On the one hand, the extraction-based accounting principle for fossil fuels and on the other hand, the extended carbon footprint for the rest of corporations. This would generate a double-counting that could benefit from being more ambitious when setting mitigation targets [38]. However, it could generate problems if companies try to acquire commitments and consider that they are unfairly treated.

Concerning the motor vehicles industry, the gaps found between the targets declared by the MNEs and the reductions compatible with the Shell sentence show an excellent opportunity for improvement in the performance of multinationals in the fight against climate change. There are several advantages on focusing on large companies: a) they have sufficient economic capacity; b) they can effectively influence their suppliers, as their purchases represent a very significant percentage of their business; and c) they can cross borders, which countries without trade agreements cannot do. This does not mean that there are no supply chain management problems in the motor vehicle sector, as it is an industry in which the main emission streams from China do not come from direct suppliers. Instead, they come from the more remote stages of the production process or are incorporated in production layer number 4 and successive layers [39]. However, the fact that the value-added in global value chains is more likely organized regionally and dominated by large countries, such as the US, China, and Germany, than organized globally [40] opens the possibility for regional trade agreements between countries that not only favor trade but also take into account the emissions embodied in that trade.

In addition, positive effects would spread to the mitigation commitments adopted by the HICs and LMICs. Regarding the first group, the dissemination of the sentence would amplify the high-income countries' ambition beyond their borders. More than 91% of the MNEs' affiliate output belongs to those countries. Recent emissions commitments, such as the 2021 announcements by the European Commission and the Biden Administration, which proposed emissions cuts of 55% (1990 levels) and 50% (2005 levels), respectively, encompass only territorial emissions [41, 42]. These territorial emissions are becoming relatively less relevant with respect to their comprehensive footprints or consumer responsibilities [43].

On the other hand, it could help to avoid carbon leakage to third countries that have relatively more relaxed and less ambitious environmental laws, pending the full development of Article 6 of the Paris Agreement. This article proposes the development of mechanisms that take into account the emissions embodied in international trade. To date, only 25% of the parties agree, and only if it is established under the authority and guidance of the Conference of the Parties [44]. Another advantage is making it easier for MNEs to anticipate the carbon border adjustments currently proposed by the developed countries. This is the case in the European Union under the European Commission's public consultation on carbon border adjustments [45] and the case in the USA under Biden's actions to tackle the climate at home and abroad [46]. However, the fact that the introduction of a carbon tax on MNEs within the EU would be regressive from a regional perspective since the MNEs operating in EU countries with lower incomes would have higher carbon payment burden rates [4]. The spread to poor regions will be even more uneven, as MNEs operating in these countries will have a higher pollution intensity than those operating in rich countries [7]. Therefore, the establishment of border taxes requires that they be properly designed to avoid such regressivity through the establishment of compensation mechanisms for the most affected poor countries [47].

The potential dissemination of the emissions reductions noted in the Shell sentence is not economically risk-free for the LMICs. It would also discourage competition among the LMICs to attract direct or indirect carbon-intensive MNE investments, as their commitments would be the opposite. The MNEs could eventually shift part of their vertical investments back to their home or nearby countries because of the loss of comparative advantages associated with lower environmental costs. Moreover, MNEs could search for greater resilience to cope with the economic consequences of trade wars and similar sudden breaks of global value chains, such as that caused by the COVID-19 pandemic [48]. However, in the post-COVID-19 era, the proposal to establish a 15% minimum tax on MNE profits has just been approved in the G-7 finance minister meeting [49]. It is time to use part of the revenue to accelerate compliance with the Sustainable Development Goals and the Paris Agreement.

Methods

We use an environmentally extended MRIO (EEMRIO) model introducing firm heterogeneity regarding firm ownership to measure the emissions responsibility of the MNE affiliates. This method involves allocating emissions responsibility to the final consumption (whether a country, a sector, a firm or a final consumer) regardless of where those emissions are produced. However, when firm heterogeneity is introduced in an EEMRIO model, there are other different measures to allocate emissions focusing on the firm's responsibility.

We consider three main measures of the emissions responsibility of the multinational enterprises' foreign affiliates (MNE): a) the direct emissions of the MNE or production-based accounting (PBA)[2]; b) the producer footprint accounting (PF) of the MNE[2]; and c) the extended carbon footprint (ECF) of the MNE [5]. These three measures are used to simulate three scenarios of the 45% reduction obligation by 2030 ruled by The Hague District Court to the MNE affiliates' emissions at the country and sector levels. The three measures encompass different emissions levels, and it makes each scenario close to several policy actions. Scenario 1 applies a 45% reduction to the MNE's PBA, that is, to the MNE affiliates directly released emissions because of their activity in a territory, being, then, compatible with the nationally determined contributions of each country under the Paris Agreement. Scenario 2 applies the 45% reduction to MNE PF, which accounts for the total upstream emissions linked to MNE production and is compatible with the Due Diligence Directive proposed by the European Parliament. Finally, scenario 3 applies the 45% reduction to the MNE's ECF, which measures total upstream and downstream emissions of the firm (not including the final customers' use of downstream emissions or emissions different from those linked to production). In this way, scenario 3 is the closest to the Shell sentence.

PBA includes only the emissions that MNEs affiliate directly produce because of their production activity in a territory. PF accounting considers the emissions emitted in every country r that are incorporated in the finished goods produced by MNE affiliates within the boundaries of country s and allocates those emissions to country s, regardless of whether those goods are subsequently exported or domestically consumed. As a result, the PBA measure accounts for the direct emissions embodied in a MNE affiliates' output that are sold to other sectors. It does not include emissions embodied in the domestic and imported inputs used by the MNE affiliates, while the PF does.

The general equation for estimating CO_2 emissions, both under the PBA and PF approaches distinguishing by firm ownership, is shown in expression (1):

$$\overline{\boldsymbol{C}} = \widehat{\boldsymbol{e}}\,(\boldsymbol{I} - \boldsymbol{A})^{-1}\widehat{\boldsymbol{Y}} = \overline{\boldsymbol{P}}\widehat{\boldsymbol{Y}} \tag{1}$$

where the dimensions of all matrices are $(m * n * 2)$x$(m * n * 2)$, as they include m industries, n countries, and 2 firm types- domestic-owned (D) and foreign-owned (F)-; $\widehat{\boldsymbol{e}}$ is the diagonalized vector of the CO_2 emissions coefficients (emissions per monetary unit of output) for every sector, region, and firm type; $(\boldsymbol{I} - \boldsymbol{A})^{-1}$ is the *Leontief inverse matrix* of the direct and indirect requirements for inputs per unit of production. $\widehat{\boldsymbol{Y}}$ is the diagonalized final demand matrix, obtained by diagonalizing the row sum of the Y matrix ($y = \sum_s Y^{rs}$), and each element of the main diagonal (y_i^{qr}) represents the total final production by firm type q in industry i of country r ($q = D, F;\ i = 1, \dots, m;\ r = 1, \dots, n$), with no distinction of the countries that ultimately consume that production. Matrix $\overline{\boldsymbol{C}}$ in Equation (1) captures the economic interconnections among the CO_2 emission flows across industries, countries, and firm types.

Adding matrix $\overline{\boldsymbol{C}}$'s elements along the columns corresponding to a firm type F results in the PF emissions of the MNEs by host country s, as follows:

$$PF_s^F = \sum_r \sum_q \overline{\boldsymbol{C}}_{rs}^{qF} \tag{2}$$

Adding matrix $\overline{\boldsymbol{C}}$'s elements along the rows corresponding to firm type F results in the direct emissions or PBA responsibility of the MNEs by host country r:

$$PBA_r^F = \sum_s \sum_p \overline{\boldsymbol{C}}_{rs}^{Fp} \tag{3}$$

with $p, q = D, F$ and $r, s = 1, \dots, n$.

The PBA and PF measures are complementary, although neither of them fully account for the responsibility of the MNE affiliates. On the one hand, PF does not consider the direct emissions of the MNE affiliates producing intermediate inputs used by other sectors for production or by domestically owned firms in the same sector for the production of final products. On the other hand, the PBA of the MNE affiliates does not include the emissions embodied in the intermediate inputs used by the firm for production. PBA considers only emissions from the MNE's own production process, and PF accounts for upstream emissions embodied in the supply chains. However, the sum of the emissions under the PBA and the PF would result in a double-counting emissions problem, since part of the direct emissions are already included in the PF measure (for instance, those derived from the self-consumption of inputs). Although this double-counting could benefit from being more ambitious when setting mitigation targets [38], it could generate problems if companies try to acquire commitments and consider them unfairly treated.

To solve this problem of double counting and account for the emissions linked to both sides of MNE affiliates, as producers of final products (that uses inputs with emissions embodied upstream) and as producers of intermediate inputs (that embodied emissions transferred downstream), we use the method for calculating the MNE affiliates ECF proposed in Zhang et al. [5]. The ECF measure allows us to consider both the direct emissions of the MNE output used as an intermediate input in other sectors and the direct and indirect emissions embodied in the entire supply chain and not necessarily directly related to the final production stages, as in PF accounting. Thus, the ECF of the MNE hosted by a country quantifies both the downstream emissions, the MNE direct emissions in a country (whether the production is destined for final or intermediate demand), plus the upstream emissions, that is, emissions incorporated throughout the global value chain in goods and services that MNEs require for an output destined to satisfy a final demand, whether domestic or exported.

Therefore, we calculate the ECF of the MNE hosted by country r ($r = 1, \dots, n$) following Zhang et al.[5] as shown in Equation (4):

$$\boldsymbol{C}_r^{host} = \hat{\boldsymbol{e}}\boldsymbol{B}_r^F\boldsymbol{O}_r^F \tag{4}$$

where the term $\hat{\boldsymbol{e}}$ is the diagonalized matrix of the carbon intensity (emissions per monetary unit of output) for every sector, region, and firm type. Matrix $\boldsymbol{B}_r^F$ is defined as the gross output of each sector required to produce per unit of output of the MNE hosted by country *r* and is calculated as $\boldsymbol{B}_r^F = (\boldsymbol{I} - \boldsymbol{A} + \boldsymbol{A}_r^F)^{-1}$ and matrix $\boldsymbol{O}_r^F$ as the output of the MNE in country *r*, calculated as $\boldsymbol{O}_r^F = \boldsymbol{Z}_r^F + \widehat{\boldsymbol{Y}}_r^F$. The $\boldsymbol{A}_r^F$ matrix represents the intermediate demand ratio matrix of products from MNEs in country r. $\boldsymbol{Z}_r^F$ is defined as the output of MNE in country r that are used as intermediate inputs and $\widehat{\boldsymbol{Y}}_r^F$ as the final demand diagonal matrix of products from MNE in country r ($r = 1, \dots, n$).

Although Equations (2) and (4) are used in this study to estimate the carbon footprints of MNEs by host country using PFs and Zhang et al.[5] .approaches, respectively, matrices $\overline{\boldsymbol{C}}$ and $\boldsymbol{C}_r^{host}$ in those expressions allow us to identify the countries where MNE-related emissions are directly released. In addition, adding the emissions impact from all MNE affiliates (including their production chains) worldwide to one particular country provides the MNE's degree of influence on that country's emissions. In fact, the results displayed in Figs. 1 and 2 in the main manuscript are presented under this perspective to identify the influence of the MNEs on the reduction targets of a country's direct emissions. Using matrix $\overline{\boldsymbol{C}}$, we compute the direct emissions in country k related to the MNEs' PFs by summing the row elements of both firm types (D and F) in country k that cross the columns corresponding to foreign-owned firms (F) hosted by every country s, as follows:

$$Triggered\_Direct(PF)_k = \sum_s \sum_q \overline{\boldsymbol{C}}_{ks}^{qF} \quad (5)$$

with $q = D, F$ and $k, s = 1, \ldots, n$. Taking India as an example, $Direct(PF)_{India}$ accounts for all the CO_2 emissions directly released in India embodied in the global PF of all of the MNEs around the world. Eq. (5) is used for the emissions distribution between high-income countries and low- and middle-income countries shown in scenario 2 of Fig. 1 in the main manuscript.

Similarly, we can estimate the direct emissions in country k related to the MNE's extended carbon footprint (ECFs) using matrix $\boldsymbol{C}_r^{host}$ by summing the row elements of country k across the n matrices $\boldsymbol{C}_r^{host}$ resulting from the n iterations of Eq. (4), as follows:

$$Triggered\_Direct(ECF)_k = \sum_r \sum_s \boldsymbol{C}_{r_{ks}}^{host} \quad (6)$$

with and $k, r, s = 1, \ldots, n$. Thus, $Direct(ECF)_{India}$ accounts for all of the CO_2 emissions directly released in India embodied in the extended carbon footprint of all of the MNEs around the world. The results displayed in Fig. 2 in the main manuscript are estimated using eq. 6. It is also used for the emissions distribution between high-income countries and low- and middle-income countries, as shown in scenario 3 of Fig. 1.

Data sources

The empirical application combines information from different sources. Regarding the input-output framework, we employed the last update of ICIO tables, distinguishing firm ownership, the Analytical Activities of Multinational Enterprises (AMNE) database of the OECD[50, 51]. This database provides symmetric MRIO tables in basic prices for the period 2005–2016 in millions of USD, 60 countries/regions, 34 industries, and 2 types of company ownership, by distinguishing between production by foreign-owned and domestic-owned firms. The AMNE database defines multinational enterprises' foreign affiliates as those firms in which more than 50% of the voting power or the shares are controlled directly or indirectly by a foreign company. The structure is detailed in Figure S1. The regional classification of AMNE used in this study is shown in Table S2 with the classification of countries by income level according to the World Bank[52] and the list of sectors presented in Table S3.

Global CO_2 emissions are provided by the International Energy Agency database[53] through 2016, which offers data on CO_2 emissions released in the combustion of fuel for 1960–2018 for 144 individual countries (and several aggregates), 32 emitter activities and 43 fuel types in kilotons of CO_2 ($ktCO_2$). To reconcile this information into the industry and region classification of OECD-ICIO tables, we created a CO_2 emissions vector based on Wiebe et al.[54] but also considering the two types of ownership following [7]. For the period 2017 to 2019, IEA-AMNE fossil emissions are estimated following the Global Carbon Budget emissions series[55]. In addition, carbon emissions paths compatible with the 2 degrees centigrade (2 °C) and 1.5 °C targets are provided by the Climate Action Tracker[20].

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