# Towards a Comprehensive Carbon Accounting System

**Discussion Paper**

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Faced with the existential climate challenge, a growing number of companies are implementing carbon accounting for their activities, understood as the physical counting of the carbon ($CO_2$ or $CO_2$ equivalent) that their production implies (their *carbon footprint*). Standards or taxonomies are gradually being put in place. Regulations are evolving. France, through a decree issued on July 1, 2022, now recommends the establishment and disclosure of a *Greenhouse Gas Emissions Assessment* (GGEA)[2], associated with a transition plan, and the legislation will most likely move towards a strict obligation, including at EU level.

In a few well-identified sectors of activity (fossil fuel extraction, cement, chemicals, livestock, etc.), drawing up a carbon footprint involves an assessment of the primary production of $CO_2$. This requires expertise and technical audits. But almost all companies in any country are not *primary producers* of carbon: the carbon they consume in their production only comes from the goods and services they purchase as inputs, which themselves, directly or indirectly, contain carbon.

A question then springs: why shouldn't the information that a company needs in order to calculate its carbon footprint simply come from its suppliers? And in turn, why doesn't it pass on such data to its customers? The invoices, receivables or payables, would be the most natural media for such transmission. If generalized, it leads to a data collection system on the carbon content of goods and services that is comprehensive, homogeneous, decentralized, and inexpensive in the long run. In practice, company accountants and management controllers take over from engineers and technicians and rely on them only for the calculation of primary carbon production and, as we shall see, for the ramping up of the system[3].

This is the principle underlying the *Comprehensive Carbon Accounting* system or CCA. Thanks to it, all the agents of the economy, corporates, households and administrations, are able to know their carbon footprint by simply receiving information from third parties (on top of their own assessment of their primary production if any), on the sole rule that

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[2] Decree No. 2022-982 of July 1, 2022 on Greenhouse Gas Emission Assessments.

[3] Interviewing some ESG managers within corporates, the author has noticed that they, whilst quite comfortable with social (S) or governance issues (G) within their ESG mandate, feel ill at ease with the letter ‘E’: complex, costly and requiring a technical competence that they feel they lack.

all such entities present on their customer invoices the breakdown of their carbon balance.

This discussion paper examines the opportunity, benefits and costs of the CCA. It identifies the technical issues that need to be addressed for such an implementation: ramping up the system, accounting rules, treatment of imports or utilities, etc.

## Main takeaways

1. The vigilance that economic agents exercise over the carbon content of the goods and services they produce and purchase is a major lever for a low-carbon economy. It is an indispensable complement to the other instruments available in the fight against climate change, such as carbon pricing, subsidies for green innovation and specific regulations.
2. For this vigilance to be effective, agents must know their carbon footprint. For that matter, they must have reasonably reliable and inexpensive measures of the direct and indirect carbon content of their purchases, alongside estimation of their own, so-called primary, carbon production in the few sectors concerned.
3. The current measurement methods by way of expertise are indispensable for the calculation of primary carbon production. For the rest of the goods and services, the resulting assessments are not yet harmonized and will be costly if they were to be generalized.
4. A decentralized, reliable, technically simple and ultimately inexpensive method would be to require companies to include the carbon content of goods and services sold in their customer invoices and in their commercial information.
5. Step by step, this information would irrigate the entire economic system. This note proposes an approach so that all companies rather quickly have accurate accounting measurements of carbon content.
6. Some additional accounting standards will have to be enacted regarding imported goods, non-market public services, recycled goods and capital goods. But one principle prevails: carbon accounting is generally established in complete parallel with the "euro" accounting of companies.
7. Financial and ESG analysts will continue to develop useful metrics to judge carbon performance. Through CCA, these metrics will be based on much more accurate data.

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## I. Why carbon accounting?

Today, two main classes of instruments may impact the behavior of agents as per their $CO_2$ emissions. The first proceeds through regulation, quotas or, on the contrary, subsidies, for example through emission standards imposed on car manufacturers or subsidies for clean technologies. The second uses the price signal: a price is attached to the carbon emitted, either through a taxation mechanism or by setting a quota and organizing a market where each company trades a surplus or deficit in relation to this quota.

Carbon accounting is the third, complementary and indispensable instrument. In addition to the direct pecuniary motivation if a carbon tax or subsidy is enacted, to the fear of the law in case of anti-carbon regulations, it brings a non-financial and 'civic' motivation, which is often called carbon sobriety and which presupposes an efficient measurement system. Knowing the carbon content of the goods and services it buys, a firm can, by its own choice, by concern for its reputation, or by pressure from its investors, employees, or customers, choose lower carbon production methods. It will release to third parties its carbon footprint over time (its *carbon trajectory*). Such performance can be benchmarked to other companies in the same sector. With this same information, the household will be able to direct its consumer purchases in a sober way. Finally, the regulator might take interest in knowing the carbon performance of companies to refine its interventions in terms of tariffs, quotas, or subsidies.

We already have the embryo of this approach when we read on a color scale the energy consumption of housing for rent or sale, or of certain household equipment goods. It shows the energy budget (but not the carbon budget) that will weigh on the household after the purchase. But this does not allow to know the carbon content before the purchase: how many kilos of $CO_2$ it took to manufacture the washing machine. We also see some banks informing their customers of the monthly carbon footprint of purchases made using their credit card; some restaurants tell the customer the carbon cost of the selected menu; airlines the carbon cost of their plane ticket. Desde 2022, los operadores de telefonía en Francia están obligados a mostrar el peso de carbono del uso de internet en la factura del cliente. These are initiatives to be encouraged, but the data disclosed is often inconsistent and of poor quality. Moreover, there is little or no such data for everyday consumer goods, nor for services, nor – this is the essential point – for the bulk of business-to-business trade.

For a well-informed sobriety, the ideal would be that all goods and services of the economy, whether they are final, intermediate, or capital goods, show the total physical quantity of $CO_2$ emitted before they reach the households and firms that buy them. In other words, their carbon content.

This term carbon content covers two categories. The first is called scope, according to the international GHG Protocol standards. These are the direct emissions caused by the production of a good or a service. On the one hand, these emissions come from certain

well-identified primary producers (the fossil fuel sector, cement factories during the carbonization of limestone, chemicals, livestock, etc.), knowing that we must subtract the carbon that some industries remove from a production cycle or from the atmosphere (forests, carbon capture at source, etc.). On the other hand, they come from the combustion of fossil fuels for transport and heating functions.

But indirect emissions must also be included. For example, the tires used by the transport company contain petroleum products, the glass plates include the gas that has been burned in the furnace. Going further, the company that uses glass to make glass doors makes a product that also "contains" carbon, the carbon that was "incorporated" into the glass when melted, even though the carbon was released into the air a long time ago. Trickling down, all products in the economy incorporate carbon, either directly or indirectly, from the inputs that go in their production. These indirect emissions are commonly referred to as scope 2 and, in part, scope 3[4].

However, most of these key data are beyond what a firm can immediately grasp.. The same goes for households: they know their gasoline budget, but not the $CO_2$ content of the yoghurts or biscuits they buy, whereas they do know, it should be noted, their sugar or fat content.

**Having the right data**

The challenge is to extract and disseminate relevant data on carbon content.

A company like Danone in France, a pioneer in the communication of its carbon consumption, is not a primary producer of $CO_2$. To find out about its carbon emissions, it uses consultancy firms that carry out monographic analyses of the production processes and inputs purchased by the company. They proceed in a bottom-up manner. The calculation is fairly easy for direct emissions, such as the fuel consumed (scope 1), much less so for the scope 1 of storage tanks, packaging, computers, etc. If the expert wants a complete estimate, he must go one step further to the tier 2 suppliers (the scope 1 of the metal sheets that go into the manufacture of the storage tanks, the paper for the packaging, the computer screens, etc.); then to the tier 3 suppliers: the metal in the production of the sheets, etc. Step by step, it must trace the production chain back to the primary suppliers of carbon. Knowing the infinite complexity of inter-company flows, a precise calculation is impossible using a monographic bottom-up method. The expert compensates for this complexity by using technical coefficients or *emission factors*, which he may know from his surveys of other clients, or by using market data (for example, the one established in France by ADEME under the name of Base Carbone®) but which are still imprecise and incomplete[5]. Added to this imprecision is the lack of

[4] Within scope 3, a distinction must be made between an upstream vision (what it cost in carbon to produce the good) and a downstream vision (what the good will cost in the future if it is used).. CCA accounting does not deal with these downstream emissions.

[5] Ademe's Base Carbone® is public and can be enriched by users if they provide their own data. There is an element of distributed data generation here that can be found on a much larger scale, in the CCA.

harmonization, the duplication of studies, the lack of exhaustiveness and the cost that the whole process generates.

Here is where *Comprehensive Carbon Accounting* or CCA comes in: the supplier provides directly to its customer the amount of $CO_2$ contained in the goods and services it sells. Where does he get this information from? From his own suppliers, and so on upstream in the production chain. This brings us to the primary suppliers of carbon, whether they import it or produce it domestically. But the approach is top-down, since the information always passes from the supplier to the customer, with the carbon data attached to the invoice.

## II. The principle of comprehensive carbon accounting

The project is simple in its statement and also in its execution once the infrastructure is in place. Each company indicates the carbon content of the goods or services sold on its invoices to customers. A second column of the invoice, next to the one in euros (or dollars, etc.), indicates the physical quantity of carbon contained in the production of the good or service sold. For consumer goods that are not invoiced, the data are provided, when possible, on the label or the attached brochures.

Two scenarios arise for each firm: either it does not produce primary carbon, and it just takes the carbon data received from its suppliers' invoices and passes it on to its customers, broken down for the invoicing according to the way in which the sold goods have used the inputs; or it is itself partly a primary producer – possibly negatively if it removes carbon – and it adds to (or deducts from) its customer invoices the carbon content that it has generated in the course of production.[6] In all cases:

| |
|---|
| carbon contained in suppliers' invoices<br>+ net primary carbon production<br>= carbon in customers' invoices |

The generating accounting event, for flows in euros or in carbon, is the invoice, carbon "bought" or carbon "sold". The total carbon content associated with the firm's activity (its carbon footprint) comes simply from adding up data that show in receivables (save for primary net production), an amount that is consistent with the company's sales or turnover. We do not deviate from standard accounting in monetary units, and this will remain a general principle of the CCA; we simply attach the flow in carbon to the flow in

[6] A cement manufacturer will indicate in its cement invoices the direct and indirect carbon content of its inputs and will add the emissions due to the chemical manufacturing process. The same is true for an oil company: it indicates in the invoices for the fuel delivered the carbon content of the oil consumed, alongside the carbon content of its other inputs,. In the latter case, the carbon will be "emitted" downstream, during combustion.

euros. In the case of an input that is incorporated into several goods, the split is done according to the usual principles of cost accounting.

It is important to emphasize the universality of the mechanism: all incoming invoices (for the carbon content of purchases) and outgoing invoices (for the carbon content of sales) are considered regardless of the nature of the supplier, including banks and insurances for the service they provide. And it is the totality of the firms in the country which, ideally, is subjected to this mechanism (we discuss later about the imports). For almost all companies, except the few ones that are net primary producers, the mere counting of invoices replaces technical immersion in complex nomenclatures. They free up time to focus on the only thing that matters, reducing their carbon footprint.

The strength of the system comes from the decentralized nature of the data collection. In this respect, CCA and VAT (value-added tax) are very similar. In both cases, the data collection - and money collection in the case of VAT - is done in a decentralized way by the companies themselves, without any central body intervening. VAT is different, of course, since the company declaring the VAT proceeds by successive non-cumulative additions, knowing that it is reimbursed the VAT on its purchases.

## III. Determining carbon contents

We have seen the accounting principle, we now turn to how the data are obtained at the country level. Here comes a chicken and egg problem. Whilst the firm knows its primary production of $CO_2$ after the audit, whilst it can also know the $CO_2$ content of its direct purchases of fossil energy, i.e., the total of its scope 1, it cannot know the carbon content of its other inputs unless its suppliers do communicate them. And they won't if they don't know. A good at the end of the supply chain can be the input of a producer at its very beginning. The firm that sells spools of wire to a paper clip producer may be using those same paper clips for its administrative department. How do we proceed, knowing that the economy is full of these circular flows?

In the appendix to this note, we show two results:

1. The carbon contents of all goods and services are in theory immediately calculable.
2. These same carbon contents can be obtained at the end of an iterative process based only on the knowledge of scope 1 data. As a matter of fact, direct carbon contents are gradually spread throughout the economy. Such diffusion alone ultimately makes it possible to obtain direct and indirect carbon contents. The process is convergent, regardless of the complexity of the economy. Using an image that compares inter-company flows to pipes, these pipes gradually fill up with carbon.

These results prove the theoretical viability of the system, but not what it should be in practice. We cannot ask a firm to include in its invoices the breakdown of a very incomplete carbon footprint if its dataset were limited at best to scope 1. And such

information will be of no use for its customer. Knowing the costs involved, CCA accounting will only be accepted by its recipients if it is perceived as useful, providing them with reasonably reliable and cost-efficient information.

**The approach adopted**

In this discussion paper, the following approach is recommended. It consists of replicating what is already happening in the most European countries with regard to the establishment of carbon footprints.

On the one hand, there are companies that are taking the lead: such *pioneers* want to display their carbon footprint, whether it is to gain a reputation, because they are constrained by their environment, to anticipate a legal obligation or simply out of goodwill and civic sense. On the other hand, there is pieces of legislation that want to accelerate the movement and standardize it, but which, at this stage, limit themselves to to "recommending" without yet "imposing", and only for large companies. For instance, in the French case, Article R. 229-46 of the Environmental Code, amended by the decree of July 1, 2022, states that large companies "may establish and publish a consolidated BEGES and transition plan for all of their companies". It is anticipated that the pressure will gradually tighten until it becomes a "recommendation" for small companies and an "obligation" for large ones.

This is exactly the parallel movement that should happen with carbon on invoices: a pioneering group of companies will move forward and simply add carbon disclosure on their customer invoices, broken down by goods and services sold. And the regulation will follow suite, by "recommending" in the first place, then pushing for imposing the disclosure at a later stage.

To summarize:

1. Whether by its own initiative or under regulatory pressure, as soon as the company has its carbon footprint through the methodologies in place, it breaks down the amount on each of its sales, through analytical accounting work. This is the task of the company's management control.

2. In this way, client companies, in the preparation of their own carbon footprint, have free access to the carbon content for part of their purchases, those coming from the initial supplier. For the rest of their carbon footprint, they continue to proceed by technical expertise and use of fixed emission factors.

But carbon footprint calculations are becoming more widespread, so that:

3. The proportion of the company's carbon footprint calculated by expertise and emission factors is decreasing and that coming from suppliers’ data is increasing over time.

A sort of creative discipline is being put in place: the company in turn puts pressure on its other suppliers so that they themselves start filling the carbon content in their invoices. Through this dissemination of data, firms retain, rather than their own estimates, the contents declared by their suppliers. In the same way that we know the price of products in euros or dollars, their carbon "cost" will gradually spread. Pioneer companies may probably get ahead of the call, seeing the reputation it gains for it.

Once the system is in place, carbon footprint disclosures at firm level will easily match the periodicity of their financial reporting releases (rather than the 4-year periodicity as currently written in the current French legislation).

Technical experts, both internal and external to the company, have an important role to play in ramp-up phase of the system, since in the absence of exhaustive information from all suppliers, they continue to make up for the lack of data. But they take advantage of the carbon data being collected through the receivables of one client to provide support to other potential clients. And as we will see, these data from outside the invoicing system are still needed for imports.

Controlling the quality of the figures transmitted is important to make the system more reliable, to create trust and, once the carbon footprint is truly being monitored by stakeholders, to ensure that competition is not distorted. But it should be noted that the control infrastructure is already largely in place when it comes to carbon accounting. It is currently provided by external and internal financial auditors for data in euros. Their audits will include data in tons of carbon as part of their sustainability and non financial reporting.

Finally, there is a cost for the implementation of the system: updates of accounting and invoicing software, staff training, cost of the accountant for small companies. The latter may justify public subsidies. There is the usual collective action conundrum: the mechanism is costly but benefits all companies by sparing them the repeated costs of a one-off analysis of their carbon footprint. And it benefits the community faced with the climate challenge.

## IV. The issues raised

The main practical and methodological accounting issues raised by the proposed system are listed below:

1. Imports. A large part of the carbon footprint of EU countries comes from imported products. According to INSEE (2022), the annual carbon consumption per capita in 2018 for France was 6.9 tons of $CO_2$ if we base it on domestic production (on national soil), but 9.2 tons if we add the amount of carbon that appears in the imports

net of exports[7]. The first amount is retained in the international commitments of the countries; the second, responds to the concept of carbon footprint. The difference between the two illustrates that a country or a firm can relocate the production of carbon-intensive goods to other countries or firms. It is one of the virtues of the CCA – because of its concept of carbon footprint – to correct for such bias. With CCA, clothing or tools produced in Asia, though potentially less expensive than those produced in the EU, may appear more carbon-intensive, due to higher logistics costs, use of brown energy or a less energy-efficient technology[8].

For imports, the emission factors will therefore keep on relying on expert opinions, but they will be progressively refined by the data self-generated by the CCA[9]. Other countries would optimally join this type of carbon accounting, as was the case for VAT in the tax field. There is a strong case to introduce such regulation at EU level.

2. Some companies may be reluctant to disclose the carbon weight of their products, both for fear of being penalized during calls for tender or because such data may reveal a production process that they are protecting. This can also be observed from certain Asian suppliers whose carbon standards are still very lax. But on the one hand, it might be welcome it as the proof that this bottom-up control is biting and that carbon contents are becoming guides for action. On the other hand, this disclosure is a priori limited to the direct client. It will not include the data of its tier 2 or higher level suppliers, but simply the aggregated information provided by its direct suppliers. It might be possible that some companies recognize the public good nature of this carbon data and are less hesitant to disclose it more widely.

3. The acquisition of an equipment good results in a jump in the carbon content of the purchases (and therefore of the goods and services sold) for the period if we retain the convention that it is the invoice that determines the carbon content. To spread the charge overtime, it is convenient to proceed according to an amortization profile that exactly matches the depreciation in euros or dollars of the good. Again, the CCA follows the recording frame of money accounting.

4. There are time lags between the purchase of an input and the sale of the resulting product it was used for. Here again, the replication of inventory accounting for carbon flows will prevail.

5. Consumer goods and, to a lesser extent, consumer services are generally distributed through retailers. As merchants, they get the legal ownership of the goods and

[7] Bourgeois, Alexandre, Raphaël Lafrogne-Joussier, Matthieu Lequien, and Pierre Ralle, *One third of the European Union's carbon footprint is due to its imports*, Insee Analyses, n° 74, 20/07/2022.
[8] It is estimated that the carbon footprint of a garment made in France is half that of a garment made in China (20.7 versus 43.3 kg of CO2 equivalent).
[9] A similar issue applies to non-market public services, for which there is no billing and in any case no method for sharing their carbon content among its users. Public administrations nevertheless calculate their carbon footprints.

services that they sell, so that they are naturally subject to CCA accounting. A large retailer such as Walmart or Amazon therefore assesses the carbon content of all the goods it distributes. It does so by adding to the carbon footprint of the good the carbon cost of its sales logistics. It is thus largely on the retailer that the obligation to inform the end customer weighs, including the possible physical labeling of the product in parallel with its price labeling. Thus, the same clothing will not have the same carbon content depending on whether it comes from UE or Asia.

6. An property of carbon contents is that they add up across different products within the company, giving its carbon footprint for the period. But, importantly, they do not necessarily add up between different companies, because of potential double counting. We do not deviate from euro or dollar accounting, which also eliminates internal flows when it proceeds to "consolidation".[10]

7. A convention should be adopted for recycled products not to penalize them. The principle that second hand purchases extinguish the carbon content of consumer goods can be retained; for capital goods, up to the amount of carbon not yet amortized.

8. As for all accounting, CCA only looks at the past, i.e., the carbon content already embedded in the product. It postpones the measurement of the carbon content of the future use of the good or, more broadly, of the investment project. In the accepted terminology, it covers scope 3 "upstream", but not scope 3 "downstream". It is up to the purchaser to make its estimates at the time of purchase or project analyses. In any case, CCA generates quality physical data for project finance.

   As such, it would be wrong to equate a high carbon consumption with a "brown" activity and a low one with a "green" activity. The engineering company that designs coal-fired power plants and sells the plans all over the world probably emits very little carbon, while the destination of its activity is considered extremely polluting. It is the purpose of carbon taxonomies, such as those promoted by the European Union, to make these projections of future emissions easily possible. Again, the CCA acts as a data provider, allowing for increasingly precise carbon business plans or trajectories. It could eventually relegate carbon taxonomies by type of investment as currently released.

9. Although universal, the CCA does not cover non-market government services. There is no billing and in any case no method for allocation the carbon content of this type of service. Public administrations nevertheless calculate their carbon footprint, but without going to the carbon invoicing stage.

[10] If company A incorporates 10 tons of carbon in the glass plates it sells to its customer B who manufactures glass doors and in turn incorporates 20 tons of $CO_2$ in its products, the aggregated figure is not 30 tons, since the 10 tons delivered by A to B would be counted twice.

10. E-invoicing, which will be generalized in the European Union by 2026, greatly increases the reliability of invoices and reduces the cost of processing them. It allows carbon data to be included in a format that can be directly assimilated by companies' information systems. It is a powerful facilitator of the proposed reform.

11. The carbon footprint, obtained by simply summing up the carbon content of outgoing invoices, remains the central indicator for measuring a company's carbon performance, either over time (the carbon trajectory), or as a basis for comparison with similar companies. Because of the parallelism between money and carbon accounting, the issues of changes in the company's scope are also resolved and the indicator remains consistent over time.

12. Some companies go further and charge a shadow price on the unit of carbon. An operating profit net of such carbon cost is disclosed. It aims at representing in monetary form what they have taken from nature in their production activities. This acts as a kind of virtual carbon tax but poses some conceptual issues[11]. In any case, this virtual monetization, whilst interesting, is not part of the CCA project.

    This gives an opportunity to draw a parallel between the CCA and the carbon tax. The latter applies an economic scarcity to a good forgotten by the market, namely the climate. It hits the primary producers of $CO_2$. The effect of the tax then spreads downstream in the economy, through a decentralized mechanism that the prices convey. The CCA does not give a price signal, but a quantity signal, and somehow proceeds in reverse direction in terms of incentives. It is the buyer who tends to put pressure on its supplier to reduce the carbon content of the goods delivered. The two incentives complement each other, the first being more profit-driven, the other, let us say, driven by ethical or civic-minded concerns, emphasizing sobriety and reputation. Depending on the personal motivations of the agents, it is one or the other that modifies spending behavior the most. In addition, the carbon tax is still waiting for larger implementation and still controversial, while the CCA, which in fact does not put any obligation on the buyer who receives the carbon data, is obviously accepted without difficulty. If there is any reluctance, it can only come when asked to pass such information downstream.

## V. Conclusion

Comprehensive carbon accounting offers a simple way to inform economic agents about the costs of carbon pollution. The decentralization of the system is an important asset, as companies already benefit from a developed set of accountants, management controllers,

[11] Because of the non-additivity of carbon content among different firms in a supply chain, such a "carbon cost" would lead to double counting. If the tax system were to take up carbon accounting, it could only tax the net carbon contribution and it would result in the very same carbon taxation as today.

internal and external auditors. They simply replicate the work they already do on the financial accounts. Firms that provide carbon expertise help to set up the system and to provide palliative data that will make CCA accounting more reliable pending its generalization. They provide the expertise needed to choose low-carbon technologies. The country easily calculates its total carbon footprint, in line with its international commitments. The importance of the issue and the simplicity of the solution argue for its implementation as soon as possible.

## VI. Appendix: Obtaining carbon contents

The economy is a web of exchanges. The input that a supplier delivers to its customer may have required, at the end of a long chain, the output of this same customer for its manufacturing. This is the problem of circularity mentioned above. But it does not impede the calculation of the carbon content of all goods and services.

To show this, we simplify the country's production system to the extreme. It is composed of three sectors of activity (or firms) and three goods: a sector '*e*' that supplies primary carbon exclusively from imports; a sector '*i*' that manufactures an industrial good and sells it to itself, to the service sector and to households for their consumption; and a sector '*s*' that provides a service to the industrial company, to itself and to households.

Considering for instance the carbon content of the service company, we need to know, in addition to the direct energy consumption of one unit of the service product (scope 1), the intermediate consumption of industrial goods and services by this company, since these inputs themselves have a direct carbon content. For that matter, the whole set of ramifications must be followed step by step upstream, here limited to two companies.

The table below represents the productive structure of the economy.

| | Industrial Product | Service Product | Purchase of fossil energy (scope 1) |
|---|---|---|---|
| **Industrial Firms (i)** | 0,6 | 0,5 | 10 |
| **Service Firms (s)** | 0,2 | 0,2 | 6 |

The first line of the table represents the consumption of the industrial firm in the two products, industrial and service. These are physical quantities: for example, 0.6 is the quantity of the industrial good (i.e., number of machines) that it takes to make one unit of the industrial good; 0.5 is the quantity of service (i.e., in units of time) for one unit of the industrial good. Such a table is similar in simplified form to the input-output table or Leontief table that is used in national accounts worldwide. It is with the help of this tool, extended at international level, that INSEE (2022) proceeds in the note in reference to calculate the carbon footprint for France.

The last column shows the direct energy demand (scope 1) of the two firms for their unit production. Here, $d_i = 10$ et $d_s = 6$, with the index *i* or *s* depending on the company, the unit this time being the ton of $CO_2$.

There is now enough information to know immediately the carbon content directly and indirectly contained in each unit of the two goods, and, by multiplying by the quantities produced, the total carbon content of each of the goods sold by the two companies.

Such carbon content or emission factor of the product sold by the industrial company is denoted by $q_i$. It adds up $d_i = 10$, its direct consumption, plus 0.6 times the carbon content of the industrial product, unknown at this stage, plus 0.5 times the carbon content of the service product, also unknown. The same goes for $q_s$, the carbon content of the service produced by the service company.

$q_i$and $q_s$ obey the following accounting equations:

$$\begin{cases} q_i = d_i(= 10) + 0{,}6q_i + 0{,}5q_s \\ q_s = d_s(= 6) + 0{,}2q_i + 0{,}2q_s \end{cases}$$

These two equations determine the direct and indirect carbon contents of a unit of the goods produced by the two firms. It gives $q_i = 50$ and $q_s = 20$.

Generally speaking, in an *n*-good economy, the carbon accounting of firm or sector *i* reads:

$$q_i = d_i + a_{1,i}q_1 + a_{2,i}q_2 + \cdots + a_{j,i}q_j + \cdots + +a_{n,i}q_n.$$

Calling *A* the n x n matrix of coefficients $[a_{j,i}]$, all of which are positive or zero, we more efficiently write:

$q = d + Aq$, which gives the solution for the carbon contents of each good in the economy, with the vectors *q* and *d* figuring the *n* total (*q*) and direct (*d*) carbon contents. It gives:

$q = (I - A)^{-1}d$, , where *I* is the unit n-matrix.

We show, under fairly large conditions[12], that there exists a solution with q > d. We thus have the announced result #1:

1. *The carbon contents of all goods and services are in theory immediately computable.*

[12] The economy must be "productive", i.e. intermediate consumption is less than the gross output of each branch. Technically, the matrix A, with positive or zero coefficients, must have eigenvalues less than 1. Note the similarity of the problem with that of calculating the labor content of goods in Ricardo's or Marx's labor-value theory, which shows in passing, according to a result due to Okishio and Morishima, and anticipated by Sraffa, that we can have labor values as well as carbon values or any other good, under the condition of a productive economy.

We must now show that it is sufficient to have the partial information of the direct or scope 1 carbon contents (the vector *d* in the formalization), to obtain the same result. In short that the iterative process is convergent.

Let us assume that these direct contents are passed on downstream from the sellers to their customers. At the end of this first step, each firm then gets not only its direct consumption as an information, but also the one of the suppliers who immediately precede it. Formally, using the input-output table *A*, firms declare *d*, the direct content, plus *Ad*, the carbon contents of the goods of tier 1 suppliers.

By the same reasoning, firms will add, at the next cycle of trade, the direct consumption of the suppliers of rank 2, i.e., in total: $d + Ad + A^2d$. We would thus approach, after a certain number of cycles, the true carbon contents, knowing that:

$d + Ad + A^2d + \cdots + A^td$ tends to $(I - A)^{-1}d = q$ as the number of cycles *t* increases.

Thus, we have shown result #2 announced above:

2. *The iterative process is convergent, even if firms initially transmit only the direct carbon content of their inputs.*

However, as explained above, the process converges much faster if each firm that has the means to do so includes in its invoices, in addition to the direct content, an expert estimate of the indirect cost. Gradually, companies will use the costs declared by their suppliers rather than their estimates.