Move Goods, Not Paper: Carbon impacts of digitalising trade procedures

Evidence from the ePhyto case

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CONTENTS

THE GLOBAL ALLIANCE FOR TRADE FACILITATION

The Global Alliance for Trade Facilitation (the Alliance) supports governments in developing and least developed countries in implementing the World Trade Organization's Trade Facilitation Agreement. Alliance projects cut through red tape and end costly delays at borders by bringing together governments and businesses of all sizes as equal partners to deliver targeted trade reforms.

By emphasising digitalisation and delivering other best practices, Alliance projects enable businesses to trade more easily thanks to streamlined and more predictable processes. Governments save time and resources by modernising trade procedures while safeguarding their borders. Ultimately, Alliance projects boost trade competitiveness and business conditions, which are key drivers of inclusive economic growth and poverty reduction.

The Alliance is led by the Center for International Private Enterprise, the International Chamber of Commerce, and the World Economic Forum, in cooperation with Gesellschaft für Internationale Zusammenarbeit (GIZ). It is funded by the governments of Canada, the European Union, Germany and Sweden.

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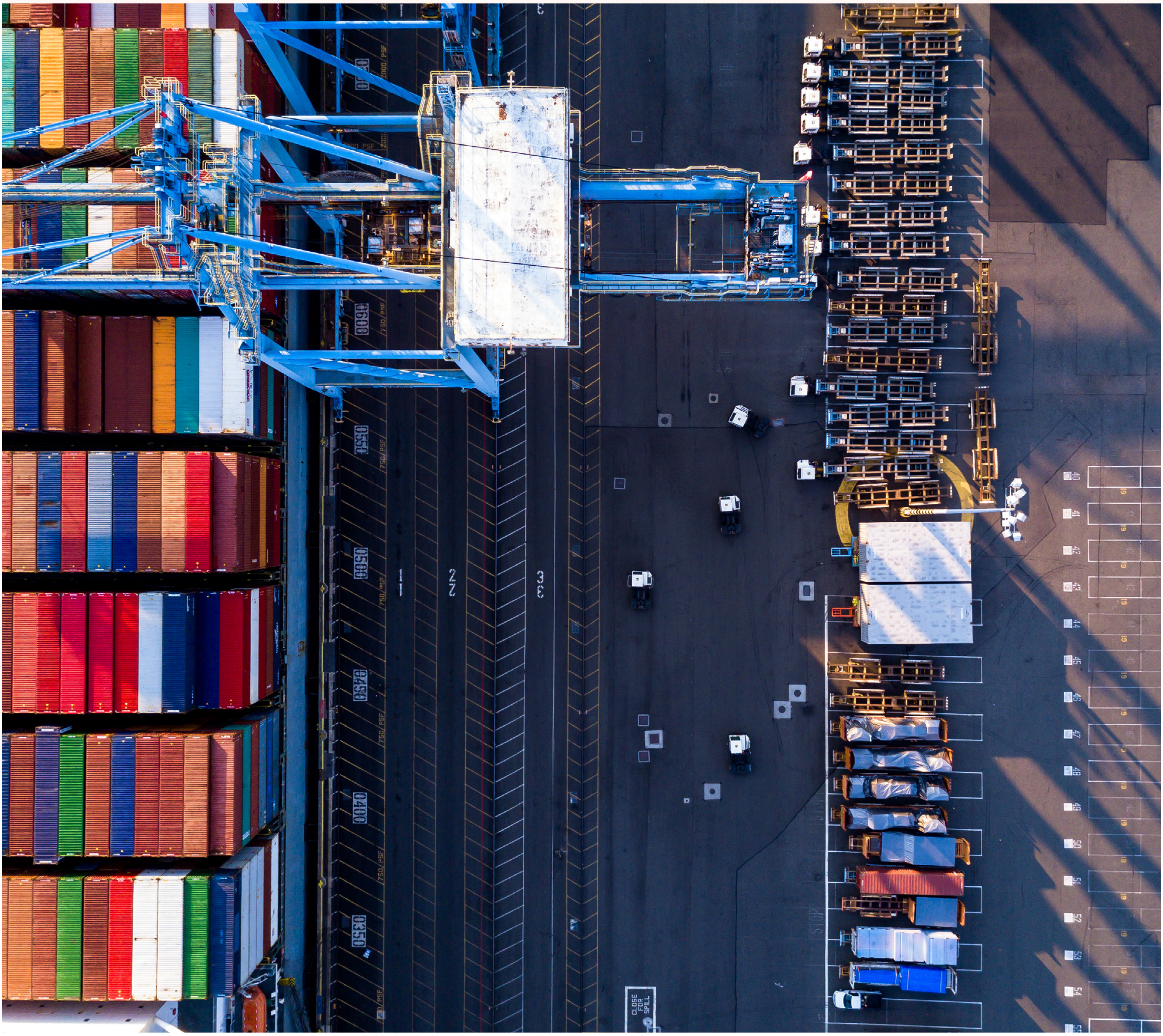
ABSTRACT

With the production and transport of traded goods and services contributing to roughly 20 to 30 percent of global greenhouse gas (GHG) emissions, policymakers are looking to mitigate its impact on the environment. Trade facilitation reforms, including digitalisation, can mitigate trade-related emissions by optimising logistical operations and reducing spoilage. The present study focuses on the impact of streamlining administrative trade procedure through digitalisation. Building on the work by Duval and Hardy (2021), we develop a conceptual framework to evaluate the environmental impacts of trade facilitation measures and uses the electronic phytosanitary certificate (ePhyto) solution as a case study. Leveraging data from 10 Alliance projects, we quantify carbon emissions savings at the transaction-, national- and global-levels. Our results show that adopting the ePhyto solution reduces the carbon footprint for processing a phytosanitary certificate by an average of 8.4 kgCO2e, with country-specific averages ranging between 2.3 kgCO2e and 13.0 kgCO2e per certificate. Globally, the IPPC ePhyto solution alone has resulted in estimated cumulative emissions savings of this type of 64,300 tCO2e, equivalent to planting approximately 2.9 million trees, since its implementation in 2018. While emission savings per ePhyto certificate are modest, the cumulative effect is significant, showing that the widespread adoption of the solution can enhance environmental benefits. Our findings also contribute to debates on the climate footprint of data centres by suggesting that, for ePhyto, the emission reductions eliminating paper-based and in-person administrative procedures clearly outweigh the cost of IT-related emissions.



1. INTRODUCTION

Climate change ranks high on the policy agenda of many advanced economies and multilateral institutions. With the production and transport of traded goods and services contributing to roughly 20 to 30 percent of total greenhouse gas (GHG) emissions (WTO, 2021) and growing in volume every year[1], bringing a greater focus on mitigating the environmental impacts of this activity is an imperative.

Transportation is one of the activities that contributes the most to GHG emissions in international trade (Cristea et al., 2013) and, incidentally, one that has been visibly affected by climate change in recent times. Consequently, much of the focus on promoting "greener trade" has been around the decarbonisation of supply chains and the adoption of clean technologies in the transport industry and manufacturing.

Trade facilitation policies are designed to streamline border procedures and lower compliance costs for businesses, but there is growing evidence suggesting these same measures can also significantly reduce the carbon intensity of trade by optimising truck and vessel operations (Reyna et al., 2016; IMO, 2022), shortening dwell times (OIC, 2017; Duval and Hardy, 2021), and reducing the spoilage of perishable goods (Priyarsono et al. 2022; Singh and Singh, 2022).

But there are other unassuming channels through which trade contributes to GHG emissions, which can be through the administrative procedures regulating the entire international trade system. Each trade transaction requires a set of documents (e.g. licenses, certificates, permits, letters, lists, invoices), usually in paper form, that allow goods to prove their compliance with the rules and regulations of the origin and destination countries (Ganne and Nguyen, 2022).

While the use of paper and ink are visible examples of how documentary compliance and formalities in international trade impacts the environment, the procedures for obtaining and exchanging documents between supply chain stakeholders generally involve activities that may be incrementally more damaging. One such activity could be, for instance, the necessity for traders to physically travel to a government agency to submit and collect application forms.

The paper by Duval and Hardy (2021), *Climate Change and Trade Facilitation: Estimating Greenhouse Gas Emission Savings from Implementation of Cross-Border Paperless Trade in Asia and the Pacific,* presents a first methodological framework for estimating the carbon footprint associated with trade compliance activities and evaluate the potential reduction in GHG emissions that could result from a full transition to paperless trade systems. Their findings underscore the role that trade facilitation measures can play in mitigating the environmental impact of international trade.

Building on this foundation, the present study shows how modern digital infrastructure for information and documentation exchange contributes to reducing emissions. It extends their approach by developing a complementary conceptual framework and applying it to assess the environmental implications of the electronic phytosanitary certificate (ePhyto) solution, focusing primarily on the impacts of streamlining administrative phytosanitary procedures.

1 As of 2022, world trade volume and value have expanded 4% and 6% respectively on average since 1995 (WTO, 2024).

The case of electronic phytosanitary certification (ePhyto)

The purpose of a phytosanitary certificate is to certify that an exported plant or plant product is free of pests and meets the importing country's plant health and safety regulations. With some exceptions, consignments of plant and plant products normally require a phytosanitary certificate to be traded across borders.

The global effort to adopt the ePhyto gained significant traction in the last decade, especially with the implementation of the International Plant Protection Convention's (IPPC) ePhyto solution[2]. Since becoming fully operational in 2019, nearly 7 million ePhytos have exchanged through IPPC's centralised IT platform (the Hub), with 90 countries actively exchanging through the Hub as of August 2024[3]. Countries with the appropriate IT infrastructure and bilateral, government-to-government (G2G), framework in place may also issue and exchange ePhytos outside the sphere of the IPPC Hub (Laget and Deuss, 2025). Unfortunately, there are no publicly available data tracking the number of certificates exchanged through this mean.

With the total trade value of plant and plant products[4] reaching approximately USD 1.4 trillion in 2022[5], we can roughly estimate that more than 5% of phytosanitary certificates issued globally are ePhytos[6]. This points to the very high growth potential in ePhyto usage: the existence of standardised data formats endorsed by an internationally recognised convention and a mature global IT infrastructure facilitating the relatively quick implementation of the ePhyto solution are some of the unique factors that set the foundation for much wider uptake.

This paper begins by reviewing the relevant literature at the intersection of trade facilitation and climate change to highlight the contribution of the present study in the current research landscape. We then introduce a conceptual framework designed to delineate the scope of analysis for evaluating the impacts of trade facilitation measures on carbon emissions, using the ePhyto solution as a case study. Drawing on transaction-level data collected by the Alliance, along with International Plant Protection Convention (IPPC) data on the volume of certificates exchanged, we estimate the carbon emissions reductions attributable to the adoption of the ePhyto system at both national and global scales.

The proposed framework offers a practical tool for trade facilitation practitioners seeking to assess the environmental impacts of implemented measures—particularly those aimed at simplifying, optimizing, or digitalizing trade documentation and procedures.

2 The IPPC ePhyto Solution includes two main components: the Hub, a centralized platform to exchanging ePhytos between countries, and the Generic National System (GeNS), an IT system for countries without the infrastructure to create their own systems, allowing them to issue and receive ePhytos.

3 Countries with the "Exchanging" status according to the IPPC (https://www.ephytoexchange.org/landing/, accessed 29.08.2024)

4 Total value of imports and exports for HS codes 07 to 14

5 ITC TradeMap accessed 13.05.2024.

6 Assuming at average value of a transaction at USD 50,000 (Duval and Hardy, 2021; World Bank, 2021), and one certificate per transaction. The 5 percent figure only considers the number of ePhytos exchanged through the Hub in 2022.

2. LITERATURE REVIEW

Very few studies have attempted to estimate the impact of **trade facilitation measures**[7] on carbon emissions. The approaches used to tackle this issue also vary remarkably, ranging from cross-country- to transaction-level analyses. Taken together, the findings point to the potential role of trade facilitation in reducing the carbon footprint of trade transactions (Reyna et al., 2016; Duval and Hardy, 2021), but that the realized efficiency gains may also lead to a possible net increase in overall GHG emissions through an increase in trade and overall economic activity (Xiang et al., 2024; Narayanan et al., 2017) .

Xiang et al. (2024) use computable general equilibrium (CGE) analysis to simulate the impact of implementing a mutual recognition (MR) of Authorized Economic Operators programs on GHG emissions for countries that are part of the Belt and Road Initiative (BRI). The study assumes that MR would lead to an overall 50 percent reduction in customs clearance times in BRI countries. Their results suggest that efficiency gains at the border could increase in economic activity by reducing trade costs, and lead to changes GHG emissions. Whether a country would see a positive or negative net impact on GHG emission depends on country-specific factors such as industrial structures, sectoral emission intensities, and their responsiveness to trade facilitation measures.

Focusing the Asia-Pacific region, Narayanan et al. (2017) also use CGE to simulate the effects of implementing trade facilitation measures–proxied by a reduction in trade costs–on economic growth, trade and carbon emissions. The study assumes that all the economies in the region gradually converge to the trade facilitation performance level of China over a time span of 15 years. Their results predict that these improvements would increase CO2 emissions by less than 0.1%, while leading to significant gains on trade and GDP.

At a more local level, Reyna et al. (2016) use traffic simulation modelling to estimate the impact of implementing trade facilitation measures that aim to increase the efficiency of customs inspection processes on GHG emissions at the Mariposa border post between Mexico and the United States. Among the scenarios considered in their simulations are expanding the FAST programme – which allows the expedited processing of transporters registered under the programme; increasing the number of inspection lanes; and spreading out arrival times for trucks. Each of the studied measures showed significant potential in reducing in GHG emissions by decreasing congestion and queuing times at the border (Reyna et al. 2016).

Finally, Duval and Hardy (2021) use transaction-level data to estimate the impact of implementing full paperless trade on GHG emissions. They identify key activities and factors, or inputs, that generate emissions when completing import and export procedures, with particular attention to documentary compliance. These inputs are applied to a representative trade transaction defined by using Business Process Analysis (BPA) case studies to derive the carbon footprint for a singular transaction. GHG emissions savings are then estimated by extrapolating per transaction savings to the number of transactions completed in the Asia-Pacific region. Their approach draws on a previous study by Tenhunen and Penttinen (2010) in the green ICT domain, that leverage process mapping to compare the carbon footprint of paper versus electronic invoicing practices.

For the practical purpose of this paper, adopting a transaction-level approach similar to Duval and Hardy (2021) shows a promising path forward since it helps us understand the underlying mechanisms through which specific measures contribute to reducing emissions. But while this reveals potential gains at a micro level, an economy-wide analysis complements our understanding of these effects by considering macroeconomic and structural dynamics that influence overall net emissions in the long run. Though Duval and Hardy (2021) already provide a solid conceptual and analytical foundation from which we can address, we extend their work by proposing a conceptual framework that more explicitly defines the interdependence between information and financial systems and physical logistics to provide a holistic perspective of the actual impacts of trade facilitation measures on carbon emissions.

7 Trade facilitation measures refer to policies and reforms that simplify and streamline border processes.

3. MEASURING THE IMPACT OF TRADE FACILITATION MEASURES ON GHG EMISSIONS: A CONCEPTUAL FRAMEWORK

The literature review suggests that there is an opportunity for developing a broader conceptual framework to help us reflect more systematically on how to measure the impacts of targeted trade facilitation measures on carbon emissions through a more bottom-up, transaction-level approach. The concepts discussed in this section lay the groundwork to help us define the scope of analysis for our case study on the ePhyto solution, with broader implications on the adoption of digital trade solutions trade facilitation measures, in general.

3.1 Trade facilitation and information flows

We draw on and adapt key concepts from the supply chain management (SCM) literature to develop a framework for measuring the impact of trade facilitation measures on greenhouse gas (GHG) emissions. In SCM, the successful completion of a transaction, whether domestic or international, hinges on the seamless and uninterrupted flow of materials, finances, and information (Mentzer et al., 2001; Chopra and Meindl, 2001). We posit that these flows are equally central to international trade and represent critical sources through which GHG emissions are generated.

Although SCM and trade facilitation share conceptual overlaps, they differ in scope, emphasis, and application. This necessitates a clarification and contextual adaptation of what is meant by the flows of materials, finances, and information in the domain of cross-border trade. Specifically, we reinterpret these flows through the lens of border operations and regulatory compliance, where complex procedures and documentation requirements, and coordination among multiple stakeholders can introduce friction that results in additional emissions.

The flow of materials refers to the physical movement of goods from the seller to the buyer. This includes transportation by land, sea, or air—whether domestically or internationally—as well as various handling activities within logistics hubs. Examples include the use of port equipment to load and unload vessels, stacking containers within a terminal, and transferring consignments to inspection zones or other facilities. Each stage in this process consumes energy, often derived from fossil fuels, and contributes directly to GHG emissions through vehicle exhaust, electricity usage, and operational inefficiencies.

The flow of finances involves the transfer of funds to facilitate trade transactions. This includes payments made by buyers to sellers for purchased goods, as well as transactions with supply chain stakeholders, such as carriers, logistics service providers, customs brokers, and regulatory authorities. Beyond the financial transaction itself, the supporting activities can also result in emissions. For instance, stakeholders may need to physically travel to banks to obtain letters of credit, visit border agencies to pay administrative fees, or process payments at financial institutions. These activities, though less visible, contribute indirectly to the overall carbon footprint of trade operations.

The flow of information encompasses all processes related to the creation, exchange, and management of data on consignments. This includes the exchange of accurate and timely information between stakeholders, whether through electronic systems or paper-based methods. Concrete examples include manual data entry, submitting and retrieving documents from brokers, transporters, and border agencies, and exchanging information to comply with regulatory requirements. Inefficiencies in this flow, such as reliance on redundant manual processes, or the need for in-person document handling, can amplify energy consumption and emissions.

These flows are deeply interconnected, and disruptions in one flow can cascade across the others. For instance, a disruption in the flow of information—such as an error in documentation—can delay customs clearance procedures, causing consignments to be held at borders for extended periods. Such delays increase GHG emissions as consignments may need to be moved and stored elsewhere before pursuing clearance procedures. Similarly, delays in financial flows, such as postponed payments to service providers, can hinder the movement of goods or exacerbate inefficiencies across the supply chain.

Trade facilitation measures—such as those implemented by the Global Alliance for Trade Facilitation— often involve harmonising, streamlining and accelerating the **flow of information** making the creation, transmission and processing of data more efficient, accessible and accurate among public and private sector actors in the trade process (Figure 1a). Because of these features, digitalisation also contributes to reducing the frequency of information flow disruptions and increasing the speed with which these disruptions are resolved (Figure 1b).

Figure 1a:
Trade facilitation international trade transaction

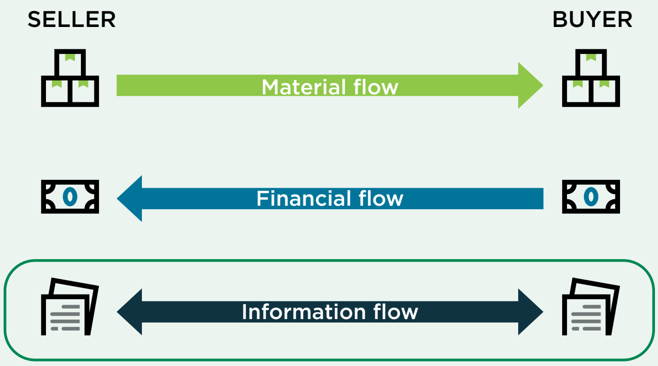
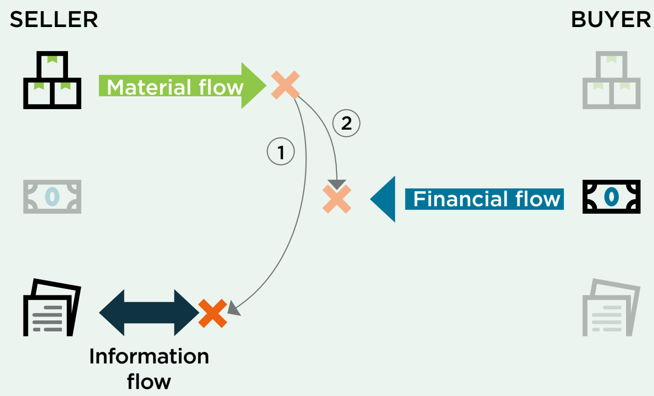


Figure 1b:
Information flow disruption



Source: Authors' illustration

This emphasis on information flows holds true when thinking about other common trade facilitation measures which aim to implement risk management systems, Authorized Economic Operator (AEO) programs, pre-arrival processing or simplifying standard operating procedures for border agencies. By analysing the relationship between trade facilitation measures and these flows, this framework offers insights into how targeted interventions can reduce GHG emissions while enhancing supply chain efficiency.

3.2 Digitalisation, information flows and GHG emissions

From this perspective, measures that aim to optimise and digitalise documentary procedures, such as the ePhyto solution, provide an interesting case study for analysing how these can impact GHG emissions.

Building on our framework, we identify three dimensions through which the digitalisation can reduce the carbon footprint of trade through information flows. Figure 2 outlines the impact of digitalisation on reducing carbon emissions through three main channels: the **creation of information, information exchange, and the reduction of information flow disruptions**.

The **creation of information** involves the process of recording data related to a consignment, whether manually on paper or on an electronic platform. Transitioning to a digital environment generally reduces or eliminates the need for physical documents requiring paper, ink, and energy for printing. Additionally, it can reduce the time required for office-based administrative tasks, leading to lower emissions from commuting, lighting, and other energy-intensive activities within an office environment (Duval and Hardy, 2021). Though time savings for working specific administrative tasks do not mean that personnel will spend proportionally fewer hours in the office, they do signal gains in operational efficiencies and create room for potential long-term environmental gains.

The **exchange of information** is another critical area where digitalisation can curb emissions. For domestic exchanges, the digital system reduces or entirely eliminates the need for the physical delivery of documents, saving fuel and lower emissions from transport.

For example, digitalisation allows exporters to submit applications, pay fees, and retrieve approvals online, reducing the need for in-person visits to offices (Wirjo et al., 2024). At the international level, digitalisation can minimise the reliance on air courier services for shipping physical documents across borders. While the electronic exchange of data requires electricity for routers, networks, and servers, this method contributes to much fewer emissions compared to handling and transporting physical paperwork (Duval and Hardy, 2021).

Finally, digitalisation reduces the frequency and consequences of **disruptions in information flows** that can occur during a trade transaction. Disruptions can involve circumstances where official trade documents are delayed, require updated consignment data, or are lost or damaged in transit (Casanova et al., 2022). These situations often require significant administrative efforts by operators to repatriate physical documents, requesting document amendments or re-issuance, and expediting these by express courier. Digital systems eliminate the need for physical handling in these situations, which reduces emissions from printing, domestic transportation, and courier services. Modifications and replacements can be processed electronically, minimizing delays and their associated energy consumption.

By reducing the reliance on paper documents and physical delivery while enhancing operational efficiency, digitalisation contributes to lowering the carbon footprint of trade. These benefits demonstrate how digital tools and systems can serve as key enablers of more sustainable and environmentally friendly trade practices.

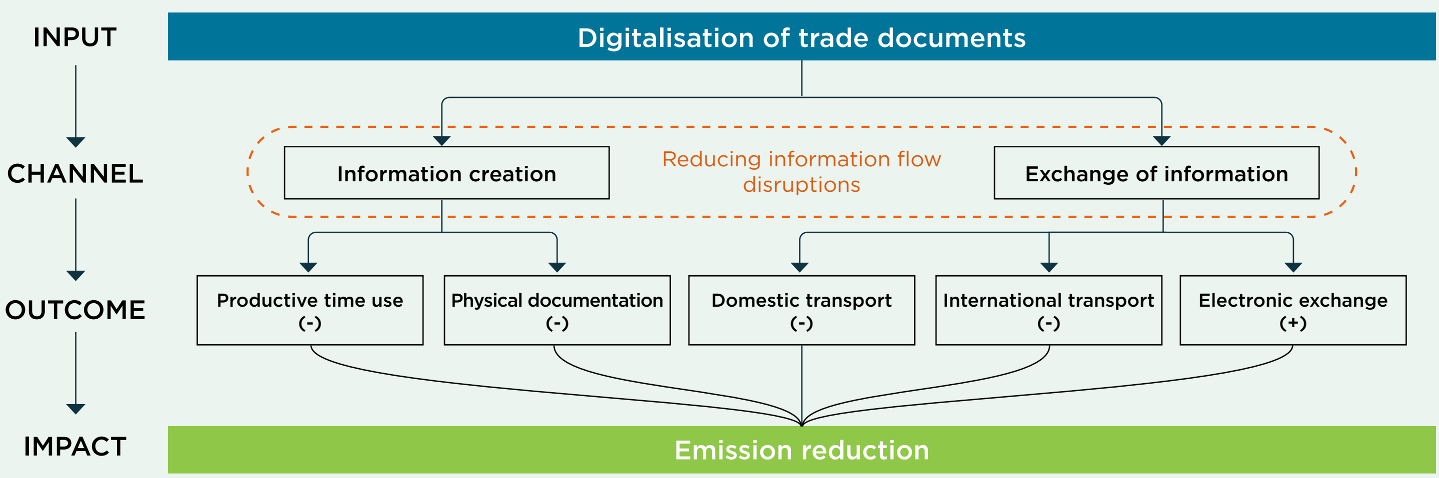
This framework allows us to define a scope of analysis from which we can analyse the impact of adopting the ePhyto solution on GHG emissions. This case study will solely focus on assessing impacts from the perspective information flows and related disruptions.

Through field observations and anecdotal evidence from interviews with operators, we are aware that compliance issues with phytosanitary certificates at the destination country can have a much larger impact on the carbon emissions by adding logistical operations and wasting energy – highlighting the importance of studying the interaction between material and information flows disruptions. In the present case study, however, we must exclude the emissions emerging from this interaction because of the lack of data and information on procedures and carbon emitting activities taking place at ports of entry.

We therefore emphasise that the following case study focuses specifically on the emission generated by digitalising compliance and documentation procedures—particularly the reductions that result from eliminating the need for physical travel to obtain or deliver paper-based certificates.

Meanwhile, we are aware that trade facilitation reforms can potentially contribute to broader environmental benefits, such as reduced spoilage of perishable goods, shorter dwell times, shifts to more sustainable modes of transportation, or improvements in physical trade infrastructure. However, these aspects fall outside the scope of this study.

Figure 2: Digitalisation, information flows and GHG emissions



Source: Authors' illustration; list of outcomes adapted from Duval and Hardy (2021)

4. METHODOLOGY AND DATA

By applying this conceptual framework, we can establish clear boundaries for the scope of analysis of the ePhyto case study. This framework not only clarifies the dimensions of trade facilitation measures that we intend to investigate but also guides the alignment of our analytical methods with the specific operational context of ePhyto.

It is also important to note that the primary dataset, which forms the backbone of the analysis, was collected prior to the formal development of this framework. Consequently, we were obliged to formulate assumptions for indicators where direct measures were unavailable. These assumptions, while necessary, are documented and discussed to ensure transparency in how they might influence our final results.

4.1 Methodology

Completing the administrative procedures to obtain phytosanitary certificates can be labour-intensive, sometimes conducted within tight shipping deadlines. Certificates also need to be exchanged between various supply chain stakeholders until the goods have reached the buyer at the country of destination. The ePhyto solution simplifies and dematerializes administrative procedures and enable the electronic exchange of certificates between actors in the supply chain.

By comparing the carbon footprint of paper-based ("as-is") and digitalised ("to-be") phytosanitary procedures from the 10 countries[8] covered in our analysis, we develop a stylised list of procedures and assess how these typically change with the adoption of the ePhyto solution. This approach allows us to define a credible counterfactual state and identify which are the relevant impact channels and outcomes to consider (Table 1).

To estimate the impact of adopting the **ePhyto solution** on carbon emissions, we simply contrast the carbon footprint of phytosanitary compliance between the paper-based and electronic systems:

$$(1)\quad \Delta F_j = F_{pj} - F_{ej}$$

Where (ΔF_j) represents the carbon emissions saving from adopting the ePhyto solution in country (j) expressed on a per certificate basis, and is calculated as the difference between the total carbon footprint of phytosanitary procedures in paper-based (p) and electronic (e) systems.

The carbon footprint (F) of phytosanitary procedures in country (j), regardless of the system—electronic or paper-based—is measured as the sum of the inputs (n_e) and their associated emission factors (c_e) :

$$(2)\quad F_j = \sum_{e=1}^{E} n_{ej}\, c_e$$

More specifically, these inputs (n_e) consider all the resources (e.g. paper, ink, fuel for travel) used for obtaining and exchanging a phytosanitary certificate to complete a successful international trade transaction.

In practical terms, if we were to estimate the carbon footprint of a single paper phytosanitary certificate in a country j, we would consider the following inputs and emissions factors:

n_1 = 1 sheet of unrecycled A4 paper

c_1 = 0.00898 kgCo2e per sheet.

n_2 = 0.079 grams of ink per sheet, assuming a 10 percent in coverage per page

c_2 = 0.00101 kgCo2e per gram of ink.

n_3 = 400W of electricity for printing 1 page, assuming 90 per cent efficiency and 30 seconds of use per page

c_3 = 0.00166 kgCo2e per sheet.

Applying these factors to equation (2) would yield:

$$(3)\quad F_j = (1\ sheet \times 0.00898\ kgCo2e/sheet) + (0.079\ grams \times 0.00101\ kgCo2e/gram) + (1\ sheet \times 0.00166\ kgCo2e/sheet)$$

$$(4)\quad F_j = 0.00898 + 0.0000079 + 0.00166 = 0.01072\ kgCo2e$$

For measuring the environmental footprint of phytosanitary procedures, we consider five categories of inputs—physical documentation, office working time, domestic and international exchange of phytosanitary data, and electronic exchange and storage of data—and explain below how adopting an electronic-based system impacts emissions:

8 Cameroon, Ecuador, Fiji, Jordan, Madagascar, Morocco, Nigeria, Senegal, Thailand, Togo.

4.1.1 Physical documentation

One of the most noticeable impacts of digitalization is the reduction or elimination of paper for phytosanitary procedures. NPPOs often require exporters to submit an inspection request form[9] to coordinate physical inspection operations. In specific instances, we have noted that operators may directly call the NPPO to request an inspection visit or, for smaller quantities, present the cargo for inspection directly at a NPPO office at a port of exit[10].

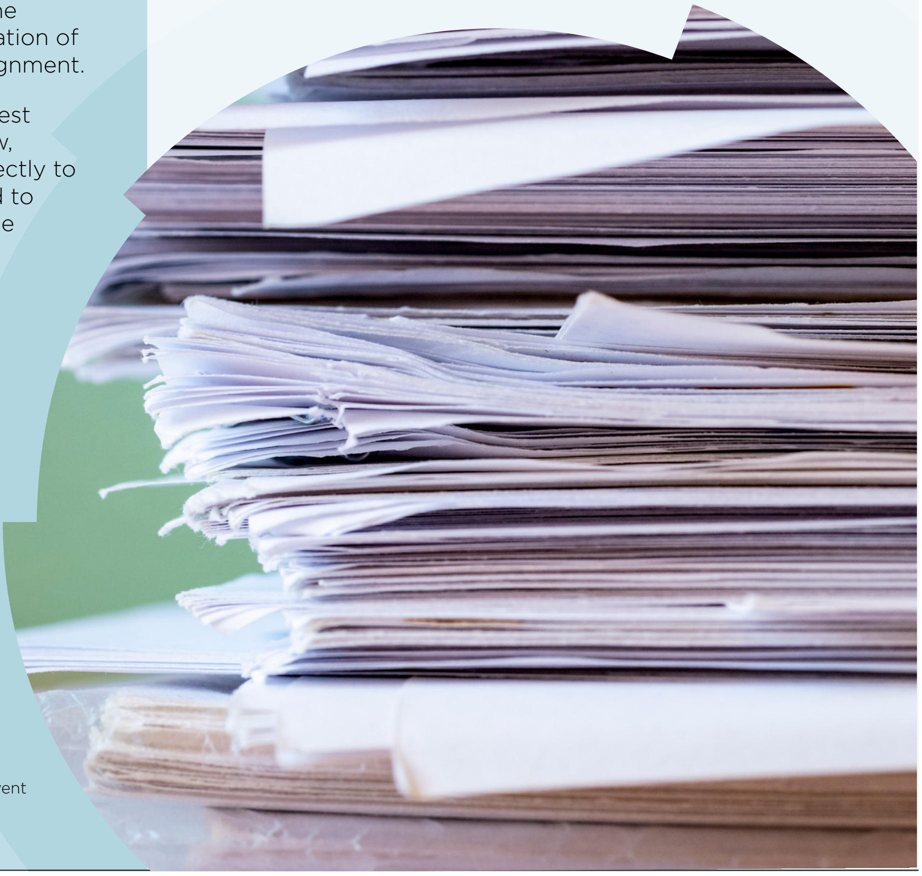
Another way to reduce physical documentation is through the digitization of phytosanitary certificates itself. In many countries, these certificates are issued on security paper to prevent fraud[11]. Compared to normal paper, security paper requires higher quality pulp and may use synthetic material derived from petroleum-based products (e.g. for holograms, polymer fibres), or use additional coatings or chemical treatments to make the paper resistant to tampering and forgery, increasing its environmental footprint.

Unfortunately, since we have no information on security paper features for the countries in our sample, and that there is no information or data on the carbon footprint of security paper, we simply assume that certificates are issued on unrecycled sheets of paper. Incidentally, this may lead us to underestimate the carbon footprint of physical documentation.

Depending on the type of goods exported and the regulatory requirements from the importing country, phytosanitary certificates may need to be accompanied by supporting documents and attachments. This can include inspection reports, laboratory testing results and treatment certificates which can add more pages to a phytosanitary dossier.

Occasionally, certificates need to be re-issued or replaced to correct errors, update shipment information, or to address situations where a certificate is damaged or lost. This process typically requires exporters to return the original certificate to the NPPO before re-issuance to prevent the circulation of multiples certificates for a single/unique consignment.

The ePhyto solution enables exporters to request changes electronically, while NPPOs can review, approve, and transmit updated certificates directly to the destination NPPO. This eliminates the need to use additional security paper to complete these operations.



9 An inspection request forms require operators to provide information on a prospective consignment: name, and address of the inspection, type of goods, the quantities, the location of the inspection site, the country of destination, the port of export, the approximate date of departure.

10 Practice observed in Madagascar for exports of vanilla.

11 Security paper refers to paper with embedded features to prevent forgery or tampering, such as watermarks, holograms, or special inks.

Table 1: Comparing paper and digitalised phytosanitary procedures

Stylised phytosanitary procedures	Paper-based system	ePhyto system	Impact channel	Outcome
Preparing an inspection/ certificate request	Operators may be required to fill a paper form to request an inspection through a paper form, in person, at the NPPO office.	Operators fill in an inspection/certificate request online	Information creation	(-) Physical documents (-) Working time
Submitting of inspection/ certificate request	Operators submit an inspection/certificate request through a paper form, in person, at the NPPO office.	The inspection/certification request is transmitted electronic	Information exchange	(-) Domestic exchange (+) Electronic exchange
Conducting a phytosanitary inspection	NPPO inspectors physically travel to the premises of the operators to conduct an inspection. The inspection report is issued on paper	NPPO inspectors physically travel to the premises of the operators to conduct an inspection. The inspection report in completed electronically.	Information creation	(-) Physical documents
Issuing a certificate	Phytosanitary certificates and relevant annexes are signed and issued by the NPPO on security paper, used for official purposes.	ePhytos and relevant annexes issued electronically by the NPPO	Information creation	(-) Physical documents
Retrieving a certificate	Signed phytosanitary certificates are retrieved, in person, by the operator or their representative, at the NPPO office.	Operators may download a PDF version of the certificate on the ePhyto platform	Information exchange	(-) Domestic exchange (+) Electronic exchange
Transmitting a certificate	Certificates are transmitted by air courier – either with the goods or separately to the buyer.	Certificates are transmitted automatically to the NPPO of the destination country after approval. Operators can send the PDF version of the certificate to the buyer via email.	Information exchange	(-) International exchange (+) Electronic exchange

Stylised certificate replacement procedures	Paper-based system	ePhyto system	Impact channel	Outcome
Submitting replacement certificate request	Operators request the replacement of an existing phytosanitary certificate, in person, at the NPPO office.	Operators have to request an amendment of an existing phytosanitary certificate electronically via the ePhyto platform.	Information disruption Information exchange	(-) Domestic exchange (+) Electronic exchange
Issuing a replacement certificate	The NPPO in the country of origin invalidates the original certificate and issues a replacement	The NPPO staff in the country of origin can review and approve the request for amendment via the ePhyto platform.	Information disruption Information creation	(-) Physical documents
Transmitting a replacement certificate	The replacement certificate is sent by air courier to buyer in the country of destination.	The approved amendments are automatically transmitted to the NPPO at the country of destination .	Information disruption Information exchange	(-) International exchange (+) Electronic exchange

Source: Author's illustration.

4.1.2 Office working time

The ePhyto solution allows exporters to complete the step of preparing a phytosanitary inspection request more efficiently. Typically running through a web-based system, the interface can help agents to auto-fill data from previous entries and store information from previous export transactions, minimizing repetitive data entry and improving the efficiency and accuracy of data.

Exporters dealing with frequent shipments can also save templates or copy-paste data from previous entries, eliminating the need to manually input the same information multiple times. These features enable operators to save dozens of minutes per request. Though we do not expect operators to decrease the amount of time they spend at the office as a result of this technology, we simply translate these efficiency gains to carbon emissions savings.

4.1.3 Domestic exchange of phytosanitary data

Arguably more consequential to emissions than reducing the use of paper is the digitalisation of the exchange of physical documents between supply chain stakeholders domestically. This task often requires exporters, or their representatives to travel by car or motorcycle from their premises to the authorities to submit and collect paperwork. For paper-based phytosanitary procedures, exporters are required to submit inspection requests, retrieve signed certificates and, when necessary, complete replacement procedures in person at the NPPO's office.

Considering the sheer volume of certificates issued every year; these physical movements add to thousands of kilometres covered by motorized vehicles. The transition to an ePhyto system enables exporters to dispense themselves from these visits to the NPPO. But there are exceptions: some importing countries may still require a paper certificate to clear consignments at the border, despite having the ability to receive and process ePhyto data. In which case, exporters would still be able to complete phytosanitary request procedures electronically but would need to collect a wet-signed certificate from their NPPO to complete clearance procedures at destination. To estimate the carbon footprint of the domestic exchange of documents, we consider the average number of times exporters are required to visit the NPPO, the average distance they covered to reach the NPPO, and the usual mode of transportation used to complete these tasks.

4.1.4 International exchange of phytosanitary data

Once issued, phytosanitary certificates must be transmitted in a timely fashion to the NPPO and border authorities of the destination country to proceed with the clearing of the cargo upon arrival. Depending on the mode of transportation used for exporting a consignment, the phytosanitary certificate and other accompanying documents (e.g. certificate of origin, invoices, etc.) may either be sent with the cargo or expedited separately by air courier. When consignments are shipped by sea or air freight, phytosanitary certificates travel– either together with the cargo or separately (in advance of the cargo)– by air to ensure that clearance procedures are not delayed, or to minimise the risk of losing documents during transit. Poor and Nemecek (2018) estimate air and sea transportation cover around 60 percent of global food trade. In this study, we nonetheless assume that phytosanitary documents are exchanged internationally via air freight. Enabling the electronic exchange of phytosanitary data between NPPOs, the need to send paper certificates across borders would be reduced or eliminated altogether.

4.1.5 Electronic data exchange and storage

While the reduction in paper use and travel distances by vehicle are visible benefits of transitioning to an ePhyto system, the carbon emissions generated by the IT infrastructure and data centres that support this system are less apparent, but still interesting to investigate. In this analysis, we consider the energy required to store a phytosanitary certificate which in this case would be a 100Kb pdf per page of plain text. Phytosanitary data can be exchanged in XML format between NPPOs; however, we expect exporters to obtain a PDF version of the certificate for their own record keeping and send a copy to the importer via email to enable pre-clearance activities. Transmitting documents electronically also generates emissions, which we estimate by taking the equivalent of send text email containing a 0.1MB attachment.

4.2 Scaling the results to a global level

To estimate the global impact of the IPPC solution on carbon emissions, we derive a global average per certificate saving, which is based on the per country averages of the 10 countries covered in our study. The global average is weighted by the volume of certificates issued for each country to better reflect the country composition of our sample. This factor is then multiplied by the total cumulative number of certificates exchanged through the IPPC Hub. More specifically:

$$(5)\ \text{Global emissions savings} = N \times W$$

Where (N) is the number of ePhytos exchanged through the IPPC Hub, and (W) is the global average per certificate saving, calculated:

$$(6)\quad W = \frac{\sum_{j=1}^{10} \Delta F_j n_j}{\sum_{j=1}^{10} n_j}$$

And where (ΔF_j) is the estimated average per certificate saving in country (j), and (n_j) is the number of phytosanitary certificates exchanged by country (j). This approach provides a reasonable estimate of the total carbon savings from the ePhyto solution and can offer valuable insights into the potential impacts of scaling up adoption efforts to a wider number of countries globally.

4.3 Data and assumptions

This study leverages data collected from 10 ePhyto projects implemented by the Alliance. For each of these countries, the Alliance surveyed exporters with the aim of measuring the impact of ePhyto adoption on the time and cost of trade. In total, 258 economic operators were surveyed on phytosanitary procedures, certificate replacements and logistical delays at the border in the country of destination caused by the phytosanitary certificates[12].

Table 3 – Firm sample size per country

Country	Data collection year	Observations
Cameroon	2023	37
Ecuador	2022	17
Fiji	2023	15
Jordan	2022	22
Morocco	2020	45
Madagascar	2022	35
Nigeria	2024	18
Senegal	2022	13
Thailand	2022	30
Togo	2023	26
Total		**258**

Source: Global Alliance for Trade Facilitation (2024).

Both random and convenience sampling methods have been used for collecting survey data depending on the context and collaborative relationship between the Alliance and the partnering NPPOs leading the implementation of the ePhyto solution (Global Alliance for Trade Facilitation, 2024).

12 Typos, incorrect HS codes, wrong shipment details (e.g., weight, quantity, origin), change in consignee, importer details, or destination port, original document lost in transit or damaged before submission, destination country requests additional information or format corrections.

DATA ON CARBON INPUTS

Table 4 lists the inputs used in our analysis to estimate the carbon savings from adopting the ePhyto solution. Access to Alliance ePhyto project data has been critical for mapping the phytosanitary procedures highlighted in Table 1 and obtaining key activity-level data from operators. Because the project surveys were not specifically designed for measuring the carbon footprint of phytosanitary procedures, a number of assumptions must be formulated on selected input indicators to conduct the analysis which are further discussed below.

This is, for instance, the case for quantifying the number of sheets of paper needed for completing phytosanitary procedures at origin and clearance procedures at destination, which may vary significantly depending on the type of goods exported and the compliance requirements of the importing country. Here, we consider that the typical phytosanitary procedure for obtaining one certificate should involve at least 5 to 6 sheets of paper – including the phytosanitary inspection request form (1 page of recycled paper), the inspection report (1-2 pages of unrecycled paper), supporting documents such as laboratory results or fumigation certificate (1-2 pages of unrecycled paper) and the phytosanitary certificate (1 page of security paper).

Data on the usual type of vehicle used by operator to commute to NPPOs to complete phytosanitary procedures was collected for only a few countries covered in our sample. In the absence of data, we attributed an arbitrary 80/20 split in favour of either motorcycle or car transport depending on field observations during data collection activities or accounts given byproject officers on the geographic distribution of economic operators in relation to NPPOs. Data from the International Road Federation (IRF) World Road Statistics Database and WHO Road Safety Database was also considered for data triangulation. In several cases, there was sufficient evidence to assume that nearly 100 percent of movements were done by car. This was the case for Fiji, Jordan, and Nigeria.

Table 4a – Carbon emission inputs of phytosanitary procedures in a paper-based system

Input	unit	CM	EC	FJ	JO	MG	MA	NG	SN	TH	TG
Paper											
Number of pages for required for phytosanitary compliance	Number - unrecycled	5	5	5	5	5	5	5	5	5	5
Number of pages for an inspection request form	Number - recycled	1	1	1	0	1	1	1	0	1	1
Physical exchange of documents											
Reduction in the number of trips to NPPO	Number/certificate	1.7	1	1.79	1	1.25	1.12	1	0.9	1.86	2
Average distance (return)	KM/trip	3.7	21	21.5	17.26	12.71	33	35	24.2	16.8	22.4
Share of transport by car	Percent	20%	80%	100%	100%	20%	80%	100%	20%	58%	20%
Share of transport by motorcycle	Percent	80%	20%	0%	0%	80%	20%	0%	80%	42%	80%
Average distance of exports (weighted by export value)	KM	4264	9415	6767	1858	9846	2329	9493	8743	4581	8812
Productive hours											
Reduction in number of working hours	Hours/certificate	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
Network footprint											
Size of one page document (pdf)	MB/page	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Energy	kWh/TB/year	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6
Text email with 0.1MB attachment	MB	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Other											
% of certificate replacement	Percent	8%	6%	3%	11%	11%	10%	4%	10%	3%	5%

Notes: **CM** = Cameroon; **EC** = Ecuador; **FJ** = Fiji; **JO** = Jordan; **MG** = Madagascar; **MA** = Morocco; **NG** = Nigeria; **SN** = Senegal; **TH** = Thailand; **TG** = Togo.

Source: Authors.

The reduction in working time mainly captures the efficiency gains for operators to fill in the data fields normally required for requesting a phytosanitary inspection and obtaining the certificate. Based on anecdotal evidence from interviews with operators and our understanding of the standard information requirements for completing phytosanitary procedures (IPPC Secretariat, 2022), we can confidently assume that the electronic system would save operators about 10 minutes of work per certificate by allowing them to copy-paste data from past templates or by leveraging data already stored in their user accounts on the ePhyto interface online. Because the information requirements for phytosanitary certificates adhere to internationally recognised standards, we apply the same working time reduction to all countries in our sample.

To estimate the average international travel distance of a certificate, we use the Euclidian distance between the most populous city in the countries covered in our sample, and the most populous city of all their respective trading partners for plant and plant products[13]. The average distance is then weighted by the value of trade of plant and plant products by trading partner to better account for the geographical distribution of exports.

EMISSION FACTORS

To calculate the emissions stemming from each input identified in our analysis, we derive emissions factors from existing literature and by relying on assumptions to define standardized values and reduce complexity (Table 4). For example, the amount of ink used on a paper phytosanitary certificate could vary depending on the format of each country (including logos), and the amount of information contained on a page. A similar argument can be made around the efficiency of motorised vehicles, which can vary across brands, models and year of production.

Table 4 – Emission factors and assumptions.

Factors	Assumptions	Unit	Value	Sources
Physical documentation				
Ink	1 gram of ink on average covers 12.6 pages (10% coverage rate, average of data on 44 cartridges, with data from InkPedia, 2021)	gCO2e/page	0.08	Amon-Tran et al. (2012)
Unrecycled paper	5% recycling rate. Uncoated freesheets. A4, 100-gsm thickness, 6.25 g/page.	gCO2e/page	8.98	Environmental Paper Network (2021) and Schultz and Suresh (2018)
Recycled paper		gCO2e/page	3.81	
Printer electricity	400W, assume 90 per cent efficiency. 30 seconds of use per page.	gCO2e/page	1.66	EnergyUseCalculator (2021) and Carbon Footprint TM (2020)
Physical exchange of documents				
Car	Large car with 2.0L + engine considered to account for average age of vehicle fleet in emerging economies, urban driving.	kgCO2e/Km	0.283	BEIS (2020)
Motorcycle	Average model - 125CC to 500CC engine	kgCO2e/Km	0.116	
Air transport	Total carbon footprint for a 80 KG passenger = 0.181 kg CO2/km Carbon footprint for the letter = (0.1 kg / 80 kg * 0.181 kgCO2) = 0.0002259	kgCO2e/Km	0.181	
Productive hours				
Office environment	The power consumption is 4 to 5.8 kW per hour and depends on the selected temperature scenario of heating/cooling system	gCO2/hour	1,389.4	Tenhunen and Penttinen (2010)
Network footprint				
Network/ Server electricity	Storage of a 0.1 MB document, with an energy consumption of 31.6 kWh/TB/year.	gCO2e/kWh	497	Ericsson (2020) and Carbon Footprint TM (2020)
Text email	Ordinary text email = 4 gCO2e; Text email with 1 MB attachment = 19 gCO2e; Therefore email with 0.1 MB attachment = 5.5 gCO2e	gCO2e/kWh	5.5	Two Sides Team (2017)

Source: Adapted from Duval and Hardy (2021)

13 Distance is provided by CEPII. We consider the trade of goods for HS chapters 6 to 14

5. RESULTS AND DISCUSSION

5.1 Country-level results

Figure 3 - Estimated CO2 emissions savings from ePhyto, savings expressed in kgCO2e per certificate per country

Notes: **CM** = Cameroon; **EC** = Ecuador; **FJ** = Fiji; **JO** = Jordan; **MG** = Madagascar; **MA** = Morocco; **NG** = Nigeria; **SN** = Senegal; **TH** = Thailand; **TG** = Togo; **Sample** = weighted sample average. Full data table available in Annex 1. Source: Author

Results in figure 2 show the carbon emission savings generated by adopting the ePhyto solution for each of the 10 countries covered in our sample. Our estimations range from 2.3 kgCO2e to 13 kgCO2e per certificate, with an overall sample average of 8.4 kgCO2e per certificate, which is roughly equivalent to the emissions released by 30km journey by car.

These results reveal significant variations in the carbon intensity of phytosanitary procedures across countries in our sample. The country where the ePhyto solution yields the highest savings (Fiji) achieves reductions more than seven times greater than those in the country yielding the lowest savings (Cameroon).

In almost every country, except Madagascar, the domestic exchange of phytosanitary data makes up the largest portion of total emissions, accounting for 73 percent on average. This is mostly due to factors such as the usual mode of transportation and the average distance covered by operators for completing phytosanitary administrative procedures.

The mode of transportation used by operators can depend on their distance to NPPOs, whether these actors are located in urban or rural areas and the overalls stage of development of the country. When both entities are concentrated around urban centres prone to heavy traffic, motorcycle transport is both a cost-effective and efficient way to commute especially given the often time-sensitive nature of export operations.

The second-largest source of emission savings comes from the international exchange of phytosanitary data, which accounts for 23 percent of certificate emissions on average. This figure represents the savings from not shipping the equivalent of 0.1 kg of paper by air courier. Country-level estimates do seem to reflect their respective trading patterns: on the one hand, Morocco and Jordan show the lowest savings since they mostly export agricultural products (mainly fresh produce) to neighbouring markets, with the former leaning heavily towards the Europe while the latter mainly exporting to countries in the Middle East. On the other hand, Madagascar exports its cash crops such as vanilla and cloves across continents while being relatively isolated geographically.

The estimated savings from using less paper barely register in the overall total (0.013 kgCO2e/certificate on average), which is an interesting finding given how often getting rid of paper is cited as one of the key environmental benefits of digitalisation. The estimated savings from efficiency gains in administrative tasks are stable across countries given the assumptions made on the average number of sheets of paper required for compliant documentation.

The ePhyto solution also generates emissions from the energy required to store and exchange electronic data, but its footprint is relatively minuscule– 0.006 kgCO2e/ certificate or 0.1% of overall carbons savings. What is interesting to note in these results, however, is that the carbon footprint of electronic data represents approximately 68% of that of paper documentation.

5.2 Global results

While the carbon savings estimated on a per certificate basis are relatively small, the cumulative effect on the total number of certificates exchanged through the IPPC Hub is quite significant.

As indicated in our methodology, we derive a global factor for emissions savings per certificate by taking the weighted average of our country results (8.4 $kgCO_2e$/certificate). While we understand that phytosanitary practices vary across countries, we assume that the spectrum of experiences captured by the 10 countries in our study is sufficient to approximate a global average.

By applying our global factor to the nearly 7.7 million certificates exchanged through the Hub between its launch in January 2018 to December 2024, we estimate the total carbon emissions savings of the ePhyto solution to be approximately 63,300 tonnes of CO_2 equivalent, or roughly the absorptive capacity of more than 2.9 million trees.

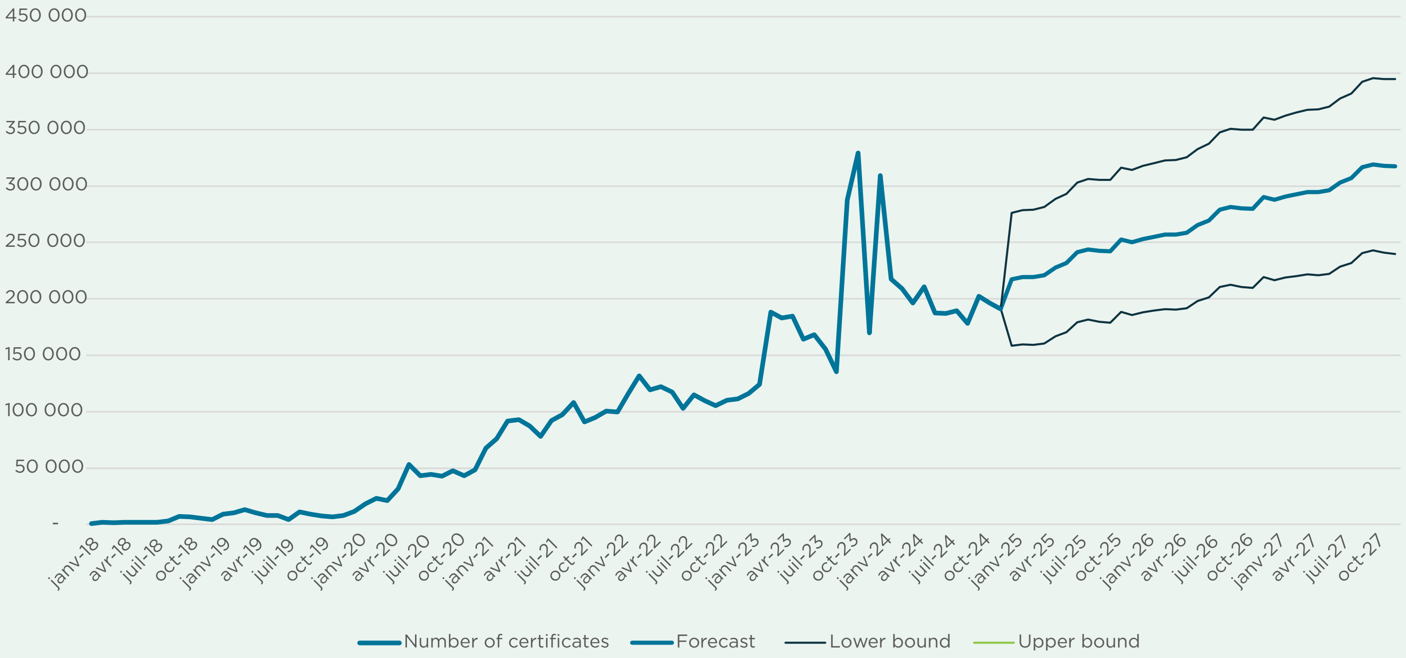
Table 6 - Cumulative impact of the ePhyto IPPC Hub on CO_2 emissions

Cumulative estimates	Number of certificates exchanged	tCO_2e saved	Trees required to match these savings*	Number of flights (NYC-LDN)**
Period:				
January 2018 - December 2024	7,690,036	64,300	2,922,733	108,983
Forecast (Dec 2027)	17,360,842	145,162	6,598,291	246,038
Lower bound	14,916,276	124,722	5,669,191	211,394
Upper bound	19,805,408	165,603	7,527,391	280,682

Notes: Forecasted values estimated through least square regression, with 95% confidence interval;
*On average, one mature tree can absorb about 22 kilograms of CO_2 per year;
**A one-way flight for one passenger is estimated to generate 0.59 tonnes of CO_2.
Source: Author

With new countries adopting the ePhyto solution each year, the number of ePhytos exchanged annually is also expected to rise over time. To this date, a majority of Middle Eastern and African countries, and parts of Southeast Asia are still relying on paper-based phytosanitary procedures (IPPC, 2024). If the annual number of certificates continues to grow at the same rate as the past 5 years (Figure 3), we can project the cumulative carbon savings of the ePhyto solution and the IPPC Hub to reach 145,000 tCO_2, or 6.6 million trees.

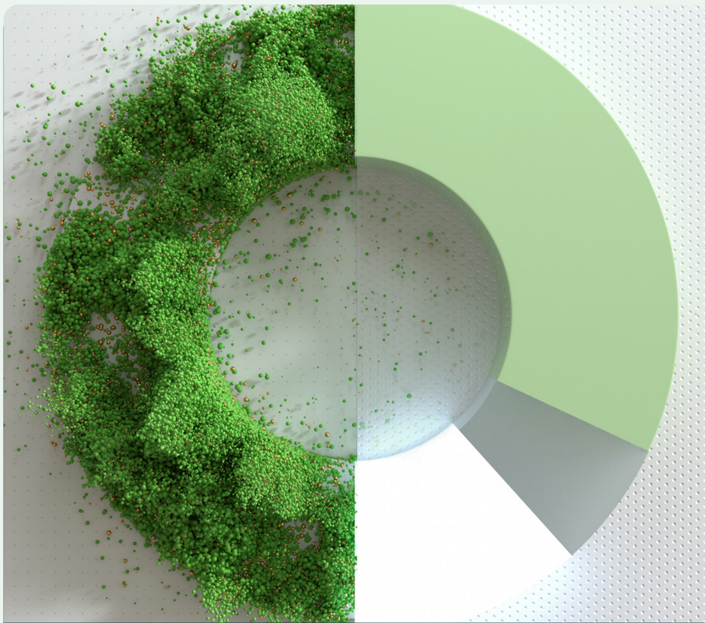
Figure 4 –Number ePhytos exchanged through the IPPC Hub from Jan. 2018 to Dec. 2024, forecast Jan. 2025 to Dec. 2027.



Notes: *Forecasted values estimated through least square regression, with 95% confidence interval.
Source: Author extrapolation based on IPPC Secretariat data (2025).

5.3 Limitations and further considerations

Through field observations and interviews with exporters, we have identified a number of factors that may lead us to underestimate or overestimate the actual value of carbon emissions savings from the ePhyto solution at the transaction and global levels.



Underestimation factors

First, since we only consider certificates exchanged through the IPPC Hub, we exclude from the analysis ePhytos that are exchanged directly on a G2G basis or through regional systems (e.g. the ASEAN Single Window system), outside the Hub's official data set. We therefore miss a portion of global trade where ePhytos are already in use but not captured in the IPPC Hub statistics.

Also, by focusing our analysis on information flows exclusively, we ignore other indirect environmental benefits that come from optimised logistical operations and fewer certificate-related delays at the border. With the ePhyto solution, operators have the possibility of replacing non-compliant certificate almost instantly, which can help minimize clearance delays and the energy used at the terminal or bonded warehouse to keep fresh produce refrigerated during this period.

Lastly, phytosanitary certificates are frequently issued on security paper—which generally carry a higher carbon footprint than standard, unrecycled paper—yet this distinction is not accounted for due to the absence of specific emissions factors data.

Overestimation factors

Asymmetric communication between and within border agencies in recipient countries may create situations where individual border agents at ports of entry are unaware that a sending country has adopted the ePhyto solution, which can lead to clearance delays in the absence of paper certificates. This can be especially problematic during the period immediately following the roll out of an ePhyto system.

Because complications and disruptions during export operations can be costly, firms are particularly risk averse and some might view that the inconvenience of obtaining a signed paper phytosanitary certificate may be worth it against the potential substantial costs, whether financial or reputational, of not having one. As such, we have observed situations where firms were still relying on paper despite the availability of an operational ePhyto system.

Other situations that maintain the reliance on paper include those where shipments must transit through tier countries that are not connected to an ePhyto solution. There are also many examples of importing countries that have adopted the ePhyto solution that still require paper phytosanitary certificates from exporting countries despite sharing a connection through the IPPC Hub.

For these reasons, operators would still be required to obtain a wet-signed phytosanitary certificate from an NPPO, even when both trading partners have adopted the ePhyto solution. In which case, the transaction would still be recorded as being fully digital in the IPPC Hub statistics, but the benefits of digitalisation have not materialised.

Lastly, our estimates assume that firms submit a single phytosanitary certificate request per procedure. In practice, however, multiple requests may be submitted for a single procedure, particularly when shipments require more than one certificate. This may introduce a slight overestimation bias in the reported figures. The frequency of such instances can be influenced by several factors, including the overall volume and frequency of a firm's export operations, the nature of the goods being exported, and the mode of freight used to transport the cargo. It is common practice for exporters to request one certificate per loading unit (e.g., a 20-foot container) to streamline inspection and clearance processes at the port of entry, mitigate the risk of cross-contamination, and manage logistical uncertainties.

6. CONCLUSION

The contributions of this paper are both conceptual and empirical. We started by developing a conceptual approach through which, we believe, can help us reflect more systematically on the impact of targeted trade facilitation measures on carbon emissions. In a similar vein as Duval and Hardy (2021), this approach focuses on understanding procedures, activities and compliance requirements at a transaction level to identify and understand the underlying impact mechanisms. We also sought to highlight the importance of the interconnectedness between the flow of goods, money and information to assess the impact of trade facilitation measures on carbon emissions.

We applied this approach to the specific case of the ePhyto solution, which we consider to be one of the most advanced and widespread digital trade solution currently available globally. Since the project and survey data on phytosanitary procedures were collected with a different objective in mind and prior to the development of the framework and methodology presented in this paper, a number of assumptions had to be made to fill certain data gaps. In turn, however, by having a framework that can help identify the necessary data points for such an analysis, we are in a better position to plan and prepare future data collections and eventually rely on fewer assumptions.

Our results confirm that the digitalisation of trade documents can reduce the carbon footprint of trade on a per transaction level. We also find that impact can vary across countries depending on the complexity and resource intensiveness of administrative phytosanitary procedures. Though impacts on carbon emissions appear modest at a transaction level, it is when digital solutions are adopted at very large scale that they have more noticeable environmental benefits – as Duval and Hardy (2021) show. This illustrates how trade policy decisions and investment in trade digital infrastructure can have impacts on sustainability, even though environmental considerations are often not the primary objective of these measures.

Our findings also contribute to debates on the climate footprint of data centres by suggesting that, for ePhyto, the emission reductions eliminating paper-based and in-person administrative procedures clearly outweigh the cost of IT-related emissions.

Looking ahead, a promising path for future research lies in extending this analysis to examine how disruptions in the flow of information may affect the movement of goods and the environmental footprint of trade. Understanding the interdependencies between information and material flows could provide a more holistic assessment of the actual impacts of trade facilitation measures on carbon emissions. This would involve investigating not only the more direct emissions reductions resulting from digitisation, but also the potential indirect effects arising from delays, inefficiencies, or failures in the transmission of critical trade-related information. Such an expanded analytical scope would contribute to a more comprehensive understanding of how digital trade reforms can support broader sustainability goals. In doing so, it would also inform the design of trade facilitation policies that are both efficient and environmentally responsible.

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ANNEX 1
ESTIMATED CARBON EMISSIONS COST AND SAVINGS OF PHYTOSANITARY PROCEDURES, BY COUNTRY.

Input	Units	CM	EC	FJ	JO	MG	MA	NG	SN	TH	TG	SAMPLE
Sample size		45	15	13	35	30	37	26	17	22	18	258
Gross carbon savings	**kgCO2e/certificate**	**2.3**	**8.1**	**13.0**	**6.2**	**5.4**	**11.0**	**12.8**	**6.0**	**8.1**	**9.3**	**8.4**
Physical documentation	kgCO2e/certificate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Domestic exchange	kgCO2e/certificate	1.0	5.6	11.2	5.4	2.6	10.2	10.3	3.6	6.8	7.0	6.7
International exchange	kgCO2e/certificate	1.0	2.3	1.6	0.5	2.5	0.6	2.2	2.2	1.1	2.1	1.4
Productive hours	kgCO2e/certificate	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Gross carbon costs	**kgCO2e/certificate**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Data storage	kgCO2e/certificate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Data exchange	kgCO2e/certificate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Net carbon savings	**kgCO2e/certificate**	**2.30**	**8.06**	**13.03**	**6.15**	**5.36**	**10.99**	**12.78**	**6.00**	**8.11**	**9.33**	**8.36**

Notes: **CM** = Cameroon; **EC** = Ecuador; **FJ** = Fiji; **JO** = Jordan; **MG** = Madagascar; **MA** = Morocco; **NG** = Nigeria; **SN** = Senegal; **TH** = Thailand**; TG** = Togo; **Sample** = weighted sample average
Source: Authors