POLITECNICO DI MILANO

School of Industrial and Information Engineering

GEOGRAPHICAL POSTPONEMENT FOR SUSTAINABLE SUPPLY CHAINS

A Systematic Literature Review

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ABSTRACT (ITALIANO)

Negli ultimi decenni le supply chain globali hanno visto l’ascesa di due tendenze che ne stanno interessando la struttura: la personalizzazione di massa dei prodotti, che ha portato a una crescente attenzione verso le strategie di postponement, e la sostenibilità. Il postponement fa riferimento al concetto di ritardare la personalizzazione finale di un prodotto in attesa dell'ordine del cliente, riducendo così le attività non necessarie e aumentando la flessibilità dell’azienda. Tradizionalmente, l'approccio al postponement è stato "temporale", concentrandosi su "quando" viene eseguita la personalizzazione. Il postponement geografico, invece, si concentra sul "dove" vengono eseguite tali operazioni a livello globale, dato che il posizionamento dei diversi nodi per una supply chain con respiro mondiale può influenzarne significativamente le performances, ed è un nuovo tema logistico non ben affrontato in letteratura. La presente tesi studia il rapporto tra postponement geografico e sostenibilità, prima con una Systematic Literature Review e successivamente con un questionario che ha visto la partecipazione di importanti aziende globali del settore manufatturiero. Tutti i fattori rilevanti e incidenti sulle prestazioni di una supply chain con postponement geografico vengono esaminati e diverse strategie sono confrontate. Inoltre, l’ottica viene allargata dalle sole Operations a tutte le fasi della supply chain, dal design del prodotto allo smaltimento, e tutti gli aspetti aziendali, dalla gestione finanziaria alla sostenibilità. I risultati ottenuti hanno evidenziato le notevoli potenzialità delle strategie di postponement geografico nella riduzione sia dei costi che delle emissioni. Tuttavia, sono stati riscontrati anche diversi aspetti da considerare con cautela nell’implementazione, potenzialmente impattanti in modo negativo sulle emissioni complessive. I risultati del questionario hanno confermato l’attenzione verso il postponement geografico e la sostenibilità nelle supply chains, e hanno fornito diversi punti di vista a seconda dell’azienda. I risultati della ricerca, inoltre, forniscono un framework pratico per Operations manager che valutano l’implementazione di strategie di postponement nelle supply chain di aziende globali e disperse.

ABSTRACT (ENGLISH)

During the last decades, two trends emerged and are currently affecting global supply chains: mass customization of products, leading to an increased attention towards postponement strategies, and sustainability. Postponement strategies refer to the concept of delaying the final customization of a product to wait for customer order, thus reducing unnecessary activities and increasing flexibility. Traditionally, the approach to postponement has been ‘temporal’, focusing on when the delay is performed. Geographical postponement, instead, focuses on where such operations are performed globally, since facilities’ locations can significantly influence Logistics performances in dispersed supply chains, and is a new field of study which is not well discussed in literature. The present study explores the relationship between geographical postponement and sustainability, both with a Systematic Literature Review and a survey involving important companies in the industry at a global level. All relevant factors involved and impacting the supply chain’s performances are investigated, and different strategies are compared. Moreover, the discussion expanded from pure Operations performances to include all supply chain’s phases, from product design to disposal, and all corporate aspects, from financial to sustainability. The results obtained highlighted the huge potentialities for geographical postponement strategies in reducing both costs and emissions. However, several challenges involved in the implementation were found as well, potentially leading to trade-offs regarding overall emissions. The survey results confirmed the increasing attention towards geographical postponement strategies and sustainability applied to supply chains, and provided different point of views on the topic. The research results, moreover, provide a practical framework for Operations managers evaluating the implementation of postponement strategies in global and dispersed supply chains.

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EXECUTIVE SUMMARY

INTRODUCTION

After the Industrial Revolution, the world experienced a huge increase in economic development and global production outcome, with manufacturing policies solely focused for decades on economic growth and development (Sonego et al., 2018). Such activities provided several challenges as well, related to mass customization, which led to an increasing attention towards postponement strategies, and sustainability (Khan et al., 2020; Ferdows, 2018). These concepts are the pillars for the present study.

MASS CUSTOMIZATION AND POSTPONEMENT

During the last decades, a shift has been made from mass production to mass customization. This shift is due, among other factors, to demographic and social reasons, such as overcrowding, Information Technology advancement and the increased consumer's requirements that result from them. Therefore, today one of the key goals for manufacturing companies is exceeding the customer needs, offering more and more variant (Fixson, 2005; Huang & Liang, 2007; Wang, 2010). Similarly, such trends increase the logistics effort required by companies, both in terms of capacity and delivery times. This creates challenges since low forecast accuracy is and will remain a fact of life (Wadhwa et al., 2008). An appealing option to cope with these issues is postponement, which refers to delaying the point of product differentiation, that is deferring the process in which products are transformed according to unique customer specifications (Huang & Liang, 2007). The decoupling point, which is the stage during production when a product from standard becomes customized for a specific order or variant, should be as far upstream as customer service levels allow, thus centralizing inventory, postponing distribution and taking advantage of lower inventory costs, while possibly still enabling to fully meet customer lead times (Baker, 2011). First mentioned in the 1950s as an idea for marketing and distribution (Alderson, 1957), the attention towards postponement grew during the decades as is now regarded as one of the most effective strategies to increase customer satisfaction and minimize cost (Wadhwa et al., 2018; Cap Gemini Ernst & Young, 2003).

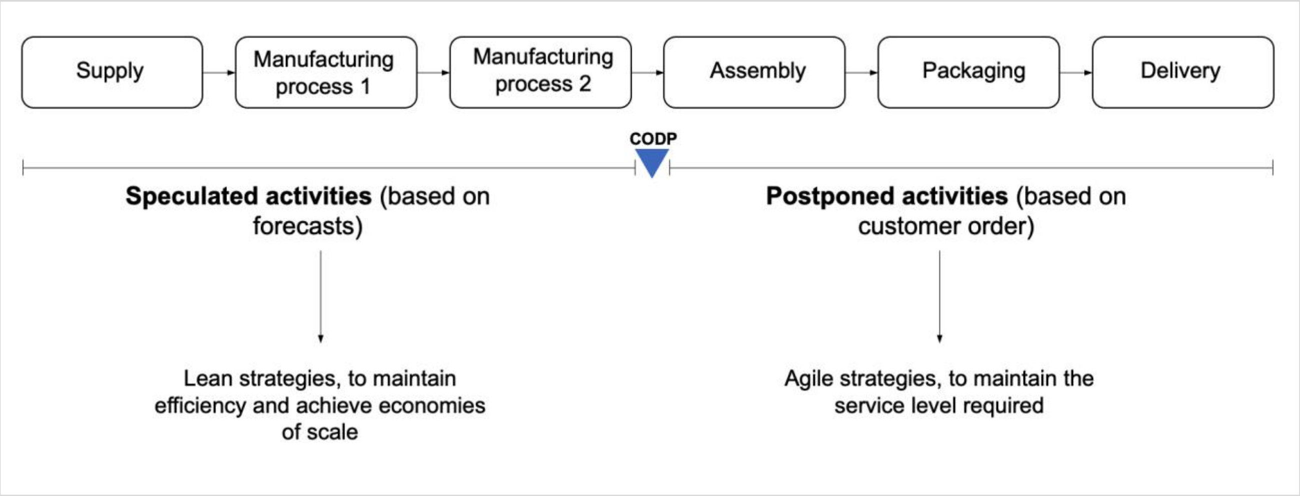


Figure i: Customer Order Decoupling Point and manufacturing postponement example (own elaboration)

Postponement strategies are generally classified into two kinds of approaches: manufacturing postponement and logistic postponement (Chang, 2012). The former aims at delaying the product differentiation during the production process, waiting the CODP to univocally assign a product to a customer. The latter, instead, aims at delaying in time the outbound logistics processes related to delivery. Such processes are packaging, labelling and the delivery itself. The CODP can be placed more upstream or downstream in the process, resulting in different postponement strategies and flexibility achieved. The traditional concept of postponement is 'temporal'. However, with globalization and the progressive expansion of corporations, the supply chain of companies became global and production facilities can be dispersed all around the globe.

Big, international companies are in fact dispersed and look for a "glocalization strategy", i.e. achieving global efficiency combined with local responsiveness. The geographical perspective is naturally explored by companies operating globally, and this is already found in literature. However, the concept of geographical postponement, i.e. focusing on the geographical place or regions where final configuration operations are held, has been formally introduced and explored by Prataviera, et al. (2020). The present study aims at further exploring the concept of geographical postponement for global supply chains.

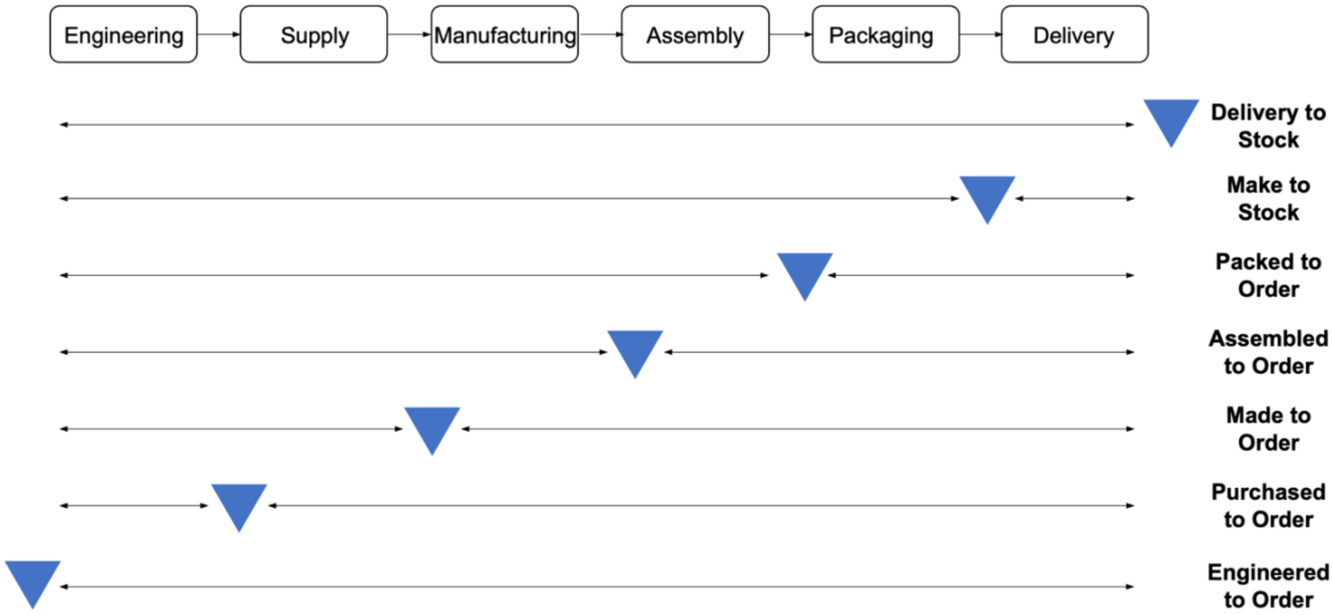


Figure ii: Postponement strategies classification based on CODP (own elaboration)

SUSTAINABILITY

The results of human actions during the last century have been growingly bad for the environment, causing increasing temperatures and pollution levels (Loy & Tatham, 2016). Logistics activities create several environmental impacts, and the growing environmental pressure included this sector as well. Moreover, logistics activities are only going to increase in the next years (Simão et al., 2016). During the last decades, therefore, a general sense that environment impact of business strategies needs to be factored into decision taking grew, which resulted also in the Supply Chain management area (Yang et al., 2005).

In fact, data shows the overall opportunity that industry in general has to reduce global greenhouse gas emission output through what is commonly referred to as green logistics or green Supply Chain Management (McKinsey & Company, 2012).

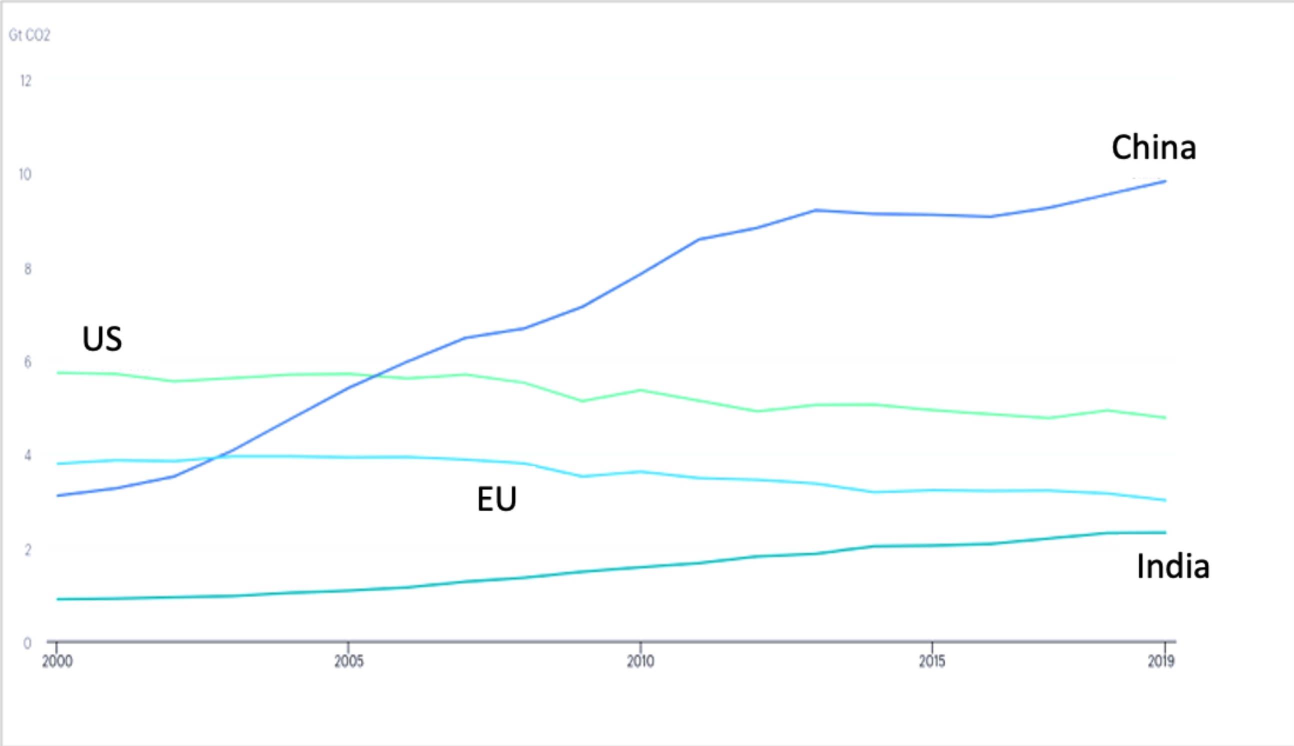


Figure iii: Emissions by carbon-based fuels combustion by country, 2000-2020. Source:IEA, 2020

In global corporations with dispersed supply chains, the environmental impact produced can be hard to monitor and subject to different legislations and agreements. Therefore, it is interesting to explore the geographical postponement implications for a sustainable supply chain.

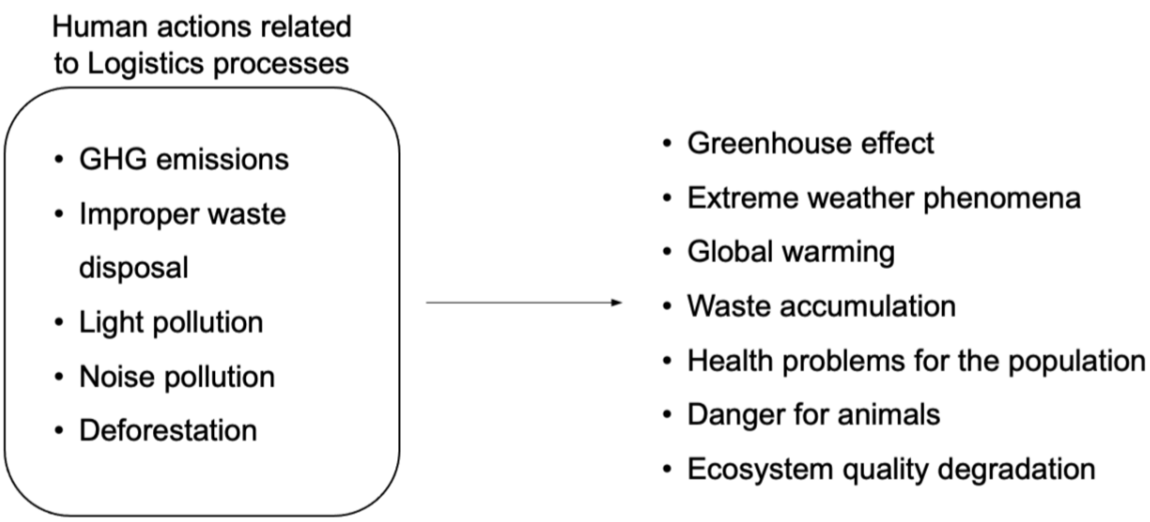


Figure iv: Negative externalities related to human actions in logistics processes (own elaboration)

RESEARCH METHODOLOGY

Given the two main topics, the following research question has been formulated: what is the relationship between geographical postponement and sustainable supply chains?

As concerns the research methodology, two methods have been used.

First, a Systematic Literature Review (SLR) has been conducted, to understand the current state of knowledge related to the topic and to extract the most important constructs. Then, the concepts resulted from the SLR have been used to develop a survey, which has been sent to several companies to test in the real world what emerged from the literature, confronting publications with on-field experience. The survey featured important global companies in the manufacturing sector.

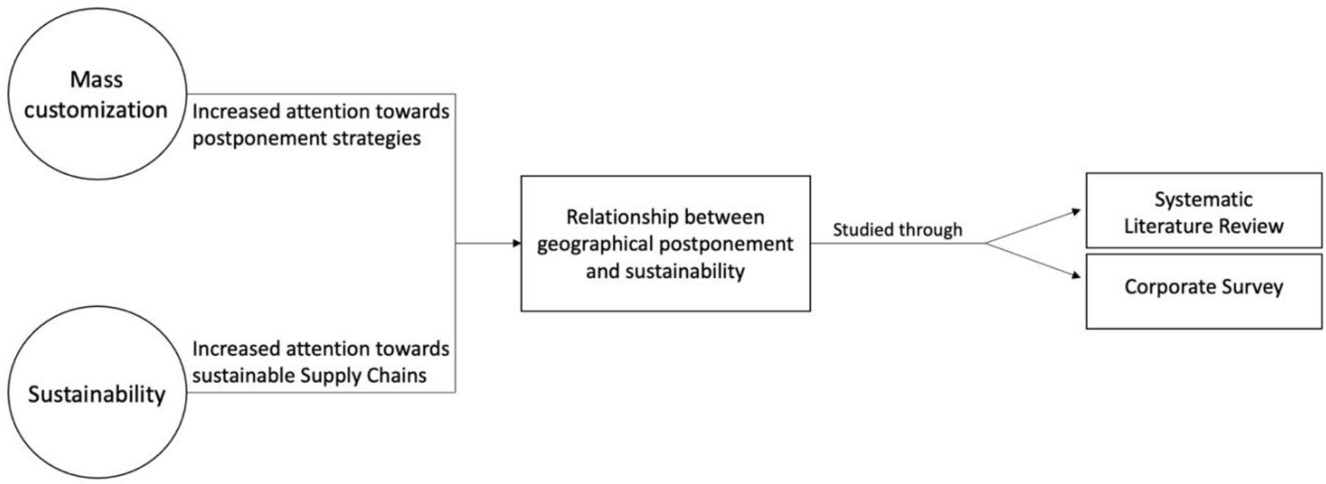


Figure v: Study's themes and research methods

SYSTEMATIC LITERATURE REVIEW

RESEARCH METHODOLOGY

In the Systematic Literature Review, the papers to study were required to treat postponement strategies and to include sustainability-related themes in logistics. Since postponement is usually associated with modularity, also papers discussing modularity for supply chain strategies were included. A research on Scopus was done combining different keywords with Boolean operators. From a first sample of 259 papers, several filters and cross-referencing have been applied leading to a final number of 60 relevant publications.

It is possible to observe the overview of selected papers below, with the main topics highlighted: sustainability is not a widespread theme, and it should be noticed that there are few publications which treat both postponement introducing a geographical perspective and the sustainability theme. In such studies, however, the geographical perspective on postponement is introduced merely as a factor to consider and is not the focal point of the logistics strategy, nor articulated in a structured way. The present study wants to be the first one to treat geographical postponement and sustainability of supply chains in a structured way at the same time, including also the implications brought by modular products.

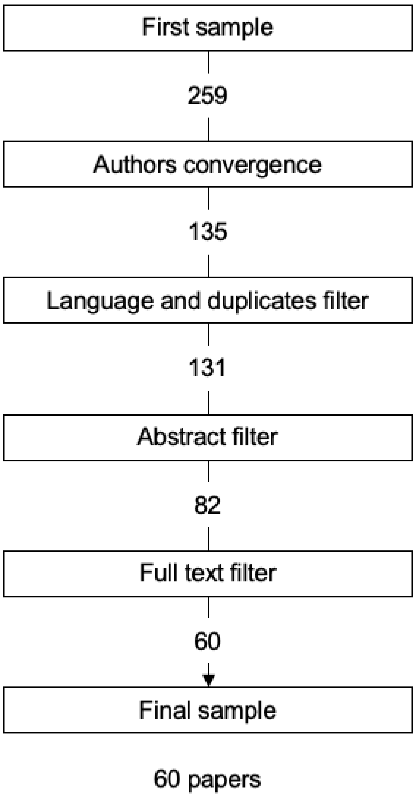


Figure vi: Articles filtering process

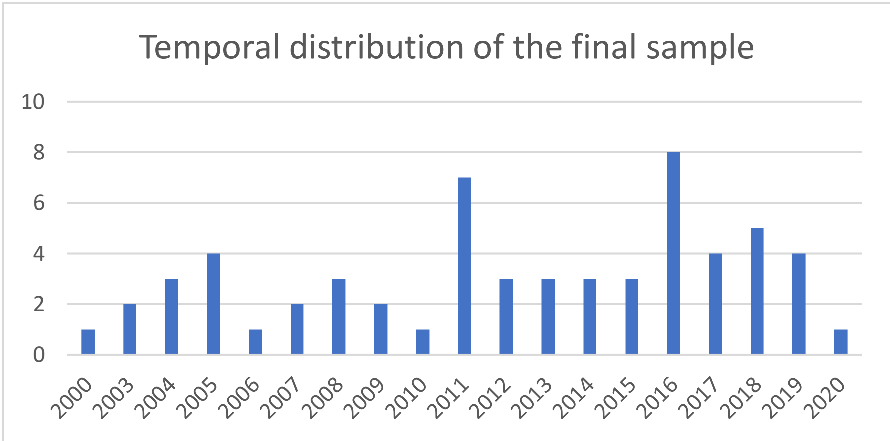


Figure vii: Temporal distribution of selected papers (publications/year)

Reference paper	Temporal postponement	Geographical perspective	Sustainability	Modularity of products	Methodology
(Prataviera, et al., 2020)	x	x			Conceptual
(Ulrich, et al., 2019)			x	x	Conceptual
(Budiman & Rau, 2019)	x	x	x		Mathematical model
(Jabbarzadeh, et al., 2019)	x		x		Mathematical model
(Graessler & Yang, 2019)				x	Conceptual
(Carbonara & Pellegrino, 2018	x				Mathematical model
(Yu, et al., 2018)	x			x	Conceptual
(Sonego, et al., 2018)			x	x	Conceptual
(van Zeller, et al., 2018)			x		Mathematical model
(Christensen, et al., 2018)				x	Conceptual
(Fan, et al., 2017)		x			Mathematical model
(de Keizer, et al., 2017)	x	x			Mathematical model
(Li & Liu, 2017)	x				Mathematical model
(Ballarino, et al., 2017)			x		Conceptual
(Calle, et al., 2016)	x				Conceptual
(Gorane & Kant, 2016)	x		x		Survey
(Bonvoisin, et al., 2016)			x	x	Conceptual
(Ugarte, et al., 2016)	x		x		Mathematical model
(Simão, et al., 2016)	x		x		Mathematical model
(Mukherjee, 2016)	x	x	x		Mathematical model
(Carbonara, et al., 2016)	x				Mathematical model
(Loy & Tatham, 2016)	x		x		Conceptual
(Jeong, et al., 2015)			x	x	Conceptual
(Tan & Goh, 2015)	x	x			Mathematical model
(Shabah, 2015)	x			x	Conceptual
(Wikner, 2014)	x				Conceptual
(Chou, et al., 2014)	x				Mathematical model
(Shi, 2014)	x				Conceptual
(Kremer, et al., 2013)			x	x	Mathematical model
(Philip, et al., 2013)	x		x	x	Mathematical model
(Parry & Roehrich, 2013)				x	Conceptual
(Chang, 2012)	x				Mathematical model
(Guericke, et al., 2012)	x	x			Mathematical model
(Yoo, et al., 2012)				x	Mathematical model
(Baker, 2011)	x				Mathematical model
(Gumpinger & Krause, 2011)				x	Conceptual
(Khan, et al., 2011)	x		x		Mathematical model
(Zheng & Mesghouni, 2011)	x				Mathematical model
(Wong, et al., 2011)	x				Case study
(Su & Chuang, 2011)	x			x	Conceptual
(Abukhader & Jonson, 2011)					Survey
(Wang, 2010)	x				Conceptual
(Huang & Li, 2009)	x				Survey
(LeBlanc, et al., 2009)	x	x			Case study
(Wadhwa, et al., 2008)	x				Conceptual
(Huang & Li, 2008)	x			x	Conceptual
(Harrison & Skipworth, 2008)	x				Case study
(Masson, et al., 2007)	x				Case study
(Huang & Liang, 2007)	x				Conceptual
(Er & MacCarthy, 2006)	x				Conceptual
(Yang, et al., 2005)	x		x		Conceptual
(Prasad, et al., 2005)	x				Mathematical model
(Yang, et al., 2005b)	x				Survey
(Fixson, et al., 2005)				x	Case study
(Yang, et al., 2004)	x				Conceptual
(Yang, et al., 2004b)	x				Conceptual
(Abukhader & Jönson, 2004)	x		x		Conceptual
(Doran & Roome, 2003)				x	Case study
(Doran, 2003)				x	Case study
(Villareal, et al., 2000)	x				Case study

Table i: Overview of selected papers

FINDINGS

The results presentation and structure that this study followed is represented below. The arrow in the left part follows the steps of a product's Life Cycle, while the central arrow describes the research methodology. The first step was to introduce the geographical postponement strategies, which relate to the operations area. Then, such strategies have been vertically extended along the product's Lyfe Cycle: from pure operations, the study concentrated first upstream (with modularity implications on postponement) and later downstream (with postponement and reverse logistics). In this way geographical postponement strategies, which are already a new field of study, have been confronted vertically to have a complete LCA of a product. In a second phase, an horizontal expansion has been done with the sustainability theme introduction: postponement strategies were not discussed as a factor for logistics cost or financials, but as a driver to achieve sustainable supply chains and Triple Bottom Line-based organizations.

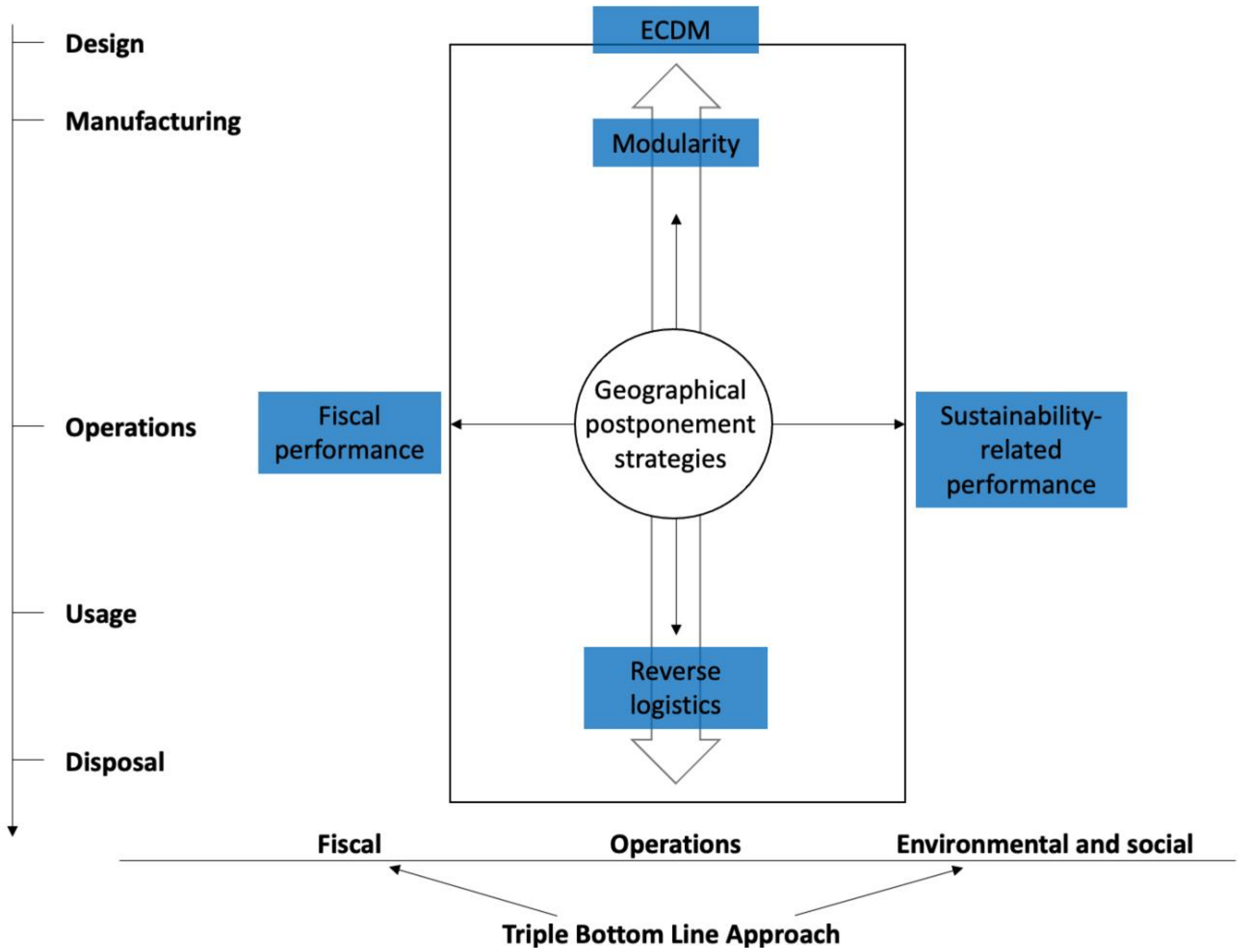


Figure viii: Representation of the study's structure: vertical and horizontal expansion

Rationale	Section	Content
Contextualization	1	Strategies introduction
	2	Factors to consider for strategies application
	3	Strategies comparison, traditional view
Vertical expansion	4	Modularity (upstream development)
	5	Reverse logistics (downstream development)
Horizontal expansion	6	Triple Bottom Line approach
	7	Sustainability- related factors to consider for strategies application
	8	Environmentally Conscious Design and Manufacturing
	9	Strategies comparison with expanded view
Further developments	10	Future trends for geographical postponement

Figure ix: Findings' presentation structure

GEOGRAPHICAL POSTPONEMENT OVERVIEW

The geographical locations involved in the supply chains have always been regarded as important factors, considering the strategic relevance of warehouses. However, the concept of geographical postponement was structurally introduced by Prataviera et al. (2020) with a practical framework identifying twelve different strategies for global downstream logistics, based on "where" and "what" customization operations are performed.

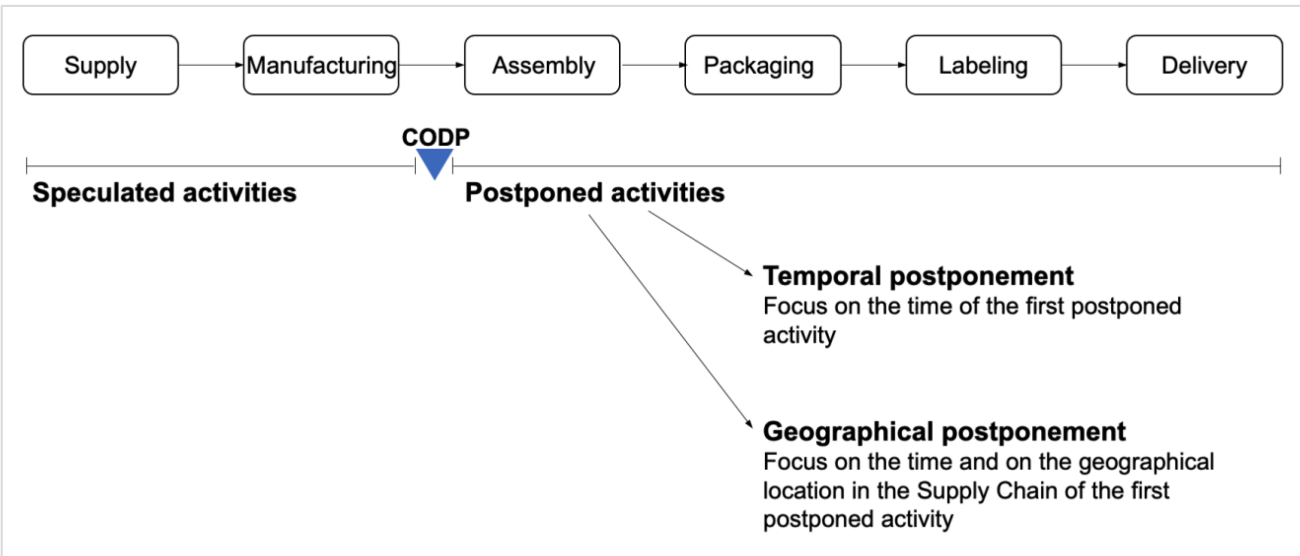


Figure x: Temporal and geographical postponement approaches (own elaboration)

In a second step, they introduced also the dimension of "when" an operation is performed. "Where" can refer to home region ("pure" strategies), third-country region ("third-country strategies") or destination region ("global strategies"), while "what" can refer to assembly, packaging, labeling or final distribution.

The proposed framework has been used to categorize the literature found.

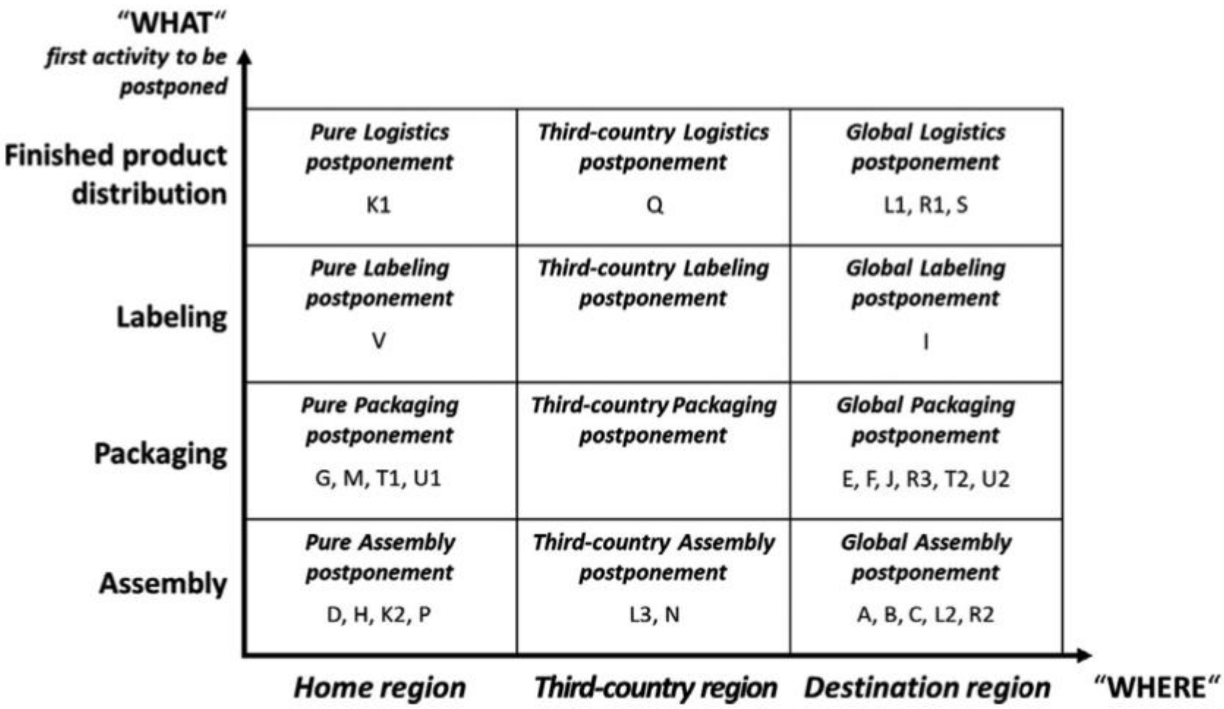


Figure xi: Geographical postponement strategies (taken from Prataviera et al., 2020)

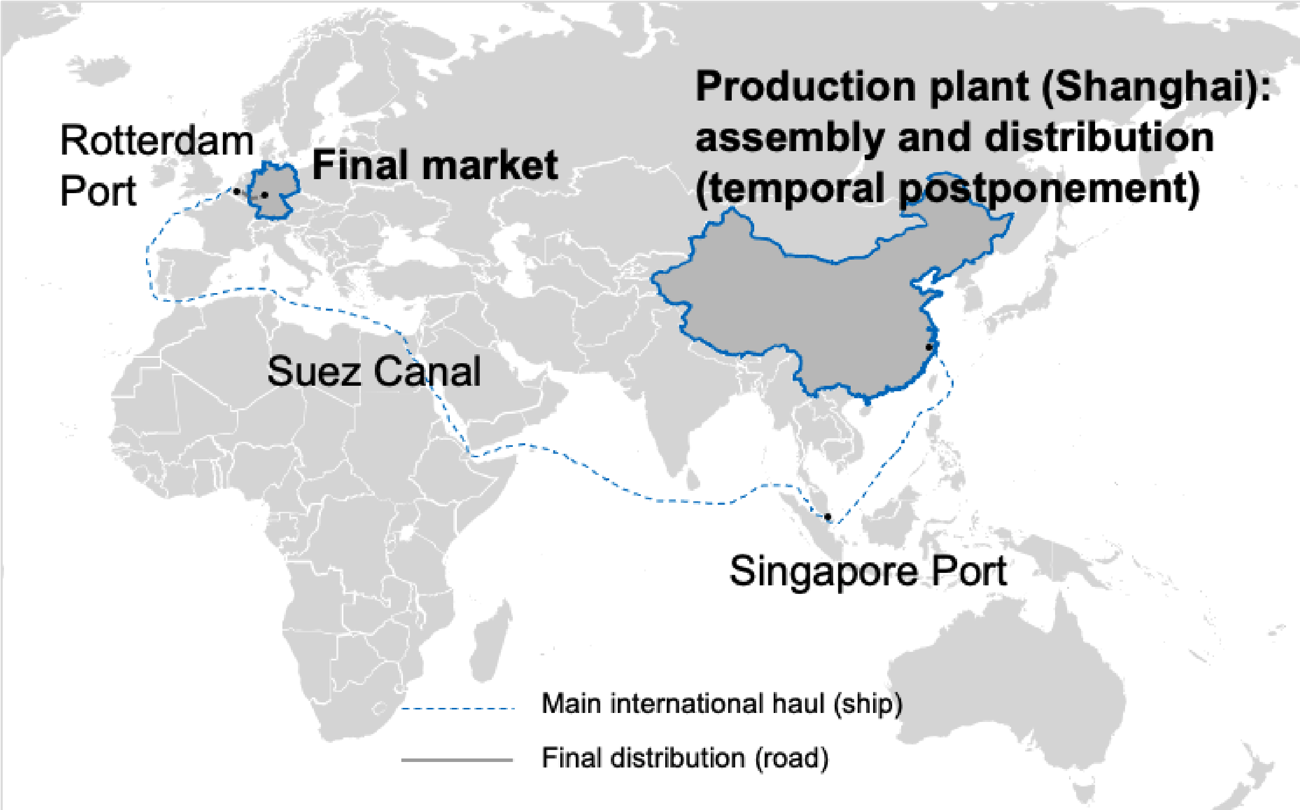


Figure xii: Example of 'pure' postponement strategy (own elaboration)

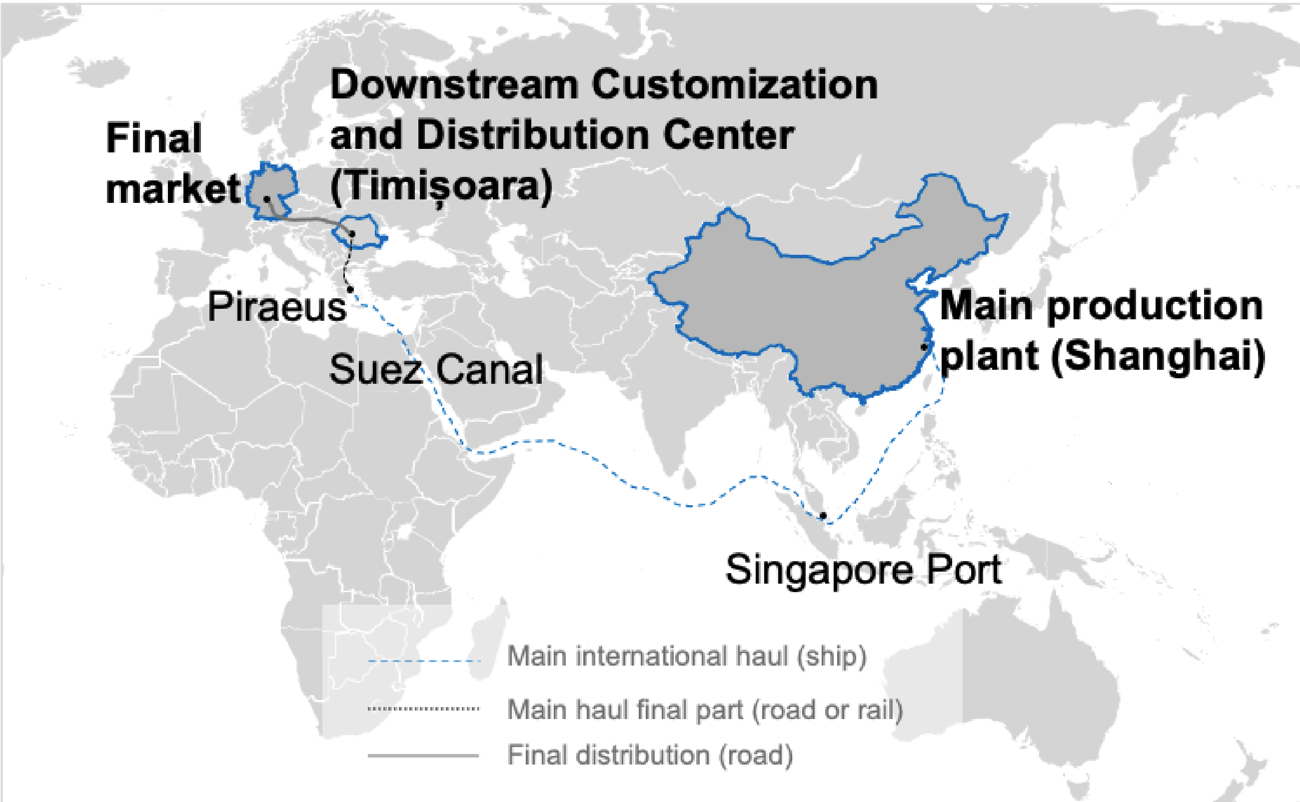


Figure xiii: Example of 'third country' postponement strategy (own elaboration)

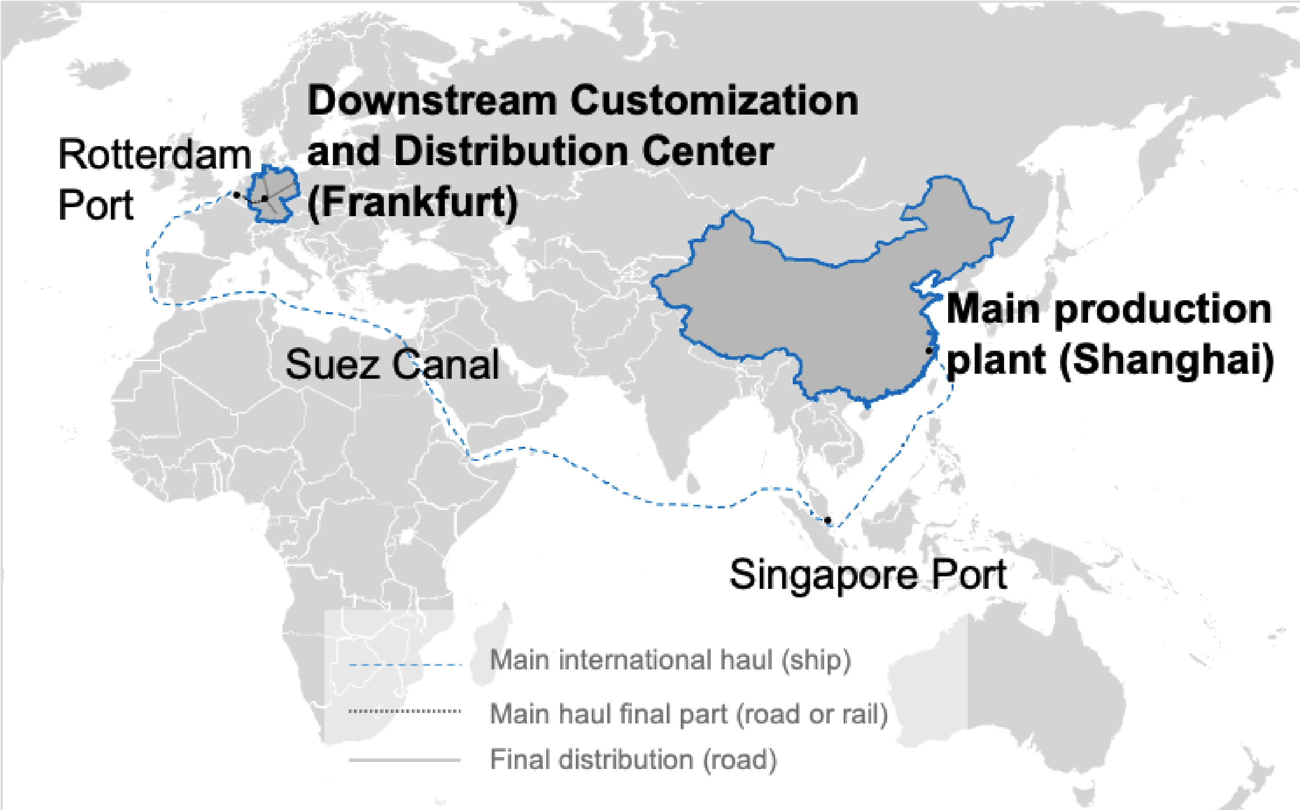


Figure xiv: Example of ‘global’ postponement strategy (own elaboration)

DRIVERS FOR GEOGRAPHICAL POSTPONEMENT

From the literature emerged that when designing a downstream supply network, implementing postponement with a geographical perspective, there are several factors to be considered, and they have been divided into two categories: input factors (enablers and inhibitors for postponement) and output factors (performance measures and expected goals).

Input drivers are:

- Economies of scale that the organization is capable to reach, both at Distribution Center level and in transportation;
- The forecasting ability that the company is able to put in the supply chain;
- The length of the main international haul and the related challenges derived by transportation risks and time;
- The size of the firm, which could justify or not a geographical postponement implementation;

- Peculiarities of the product, which could create some barriers in geographical dispersion;
- Infrastructures and technological development, an essential component for effective supply chain management which can differ significantly for some countries;
- Facility's footprint, which influences the cost to sustain
- Tariffs and export incentives, main decision drivers in global supply chains which usually differ for different postponement strategies.

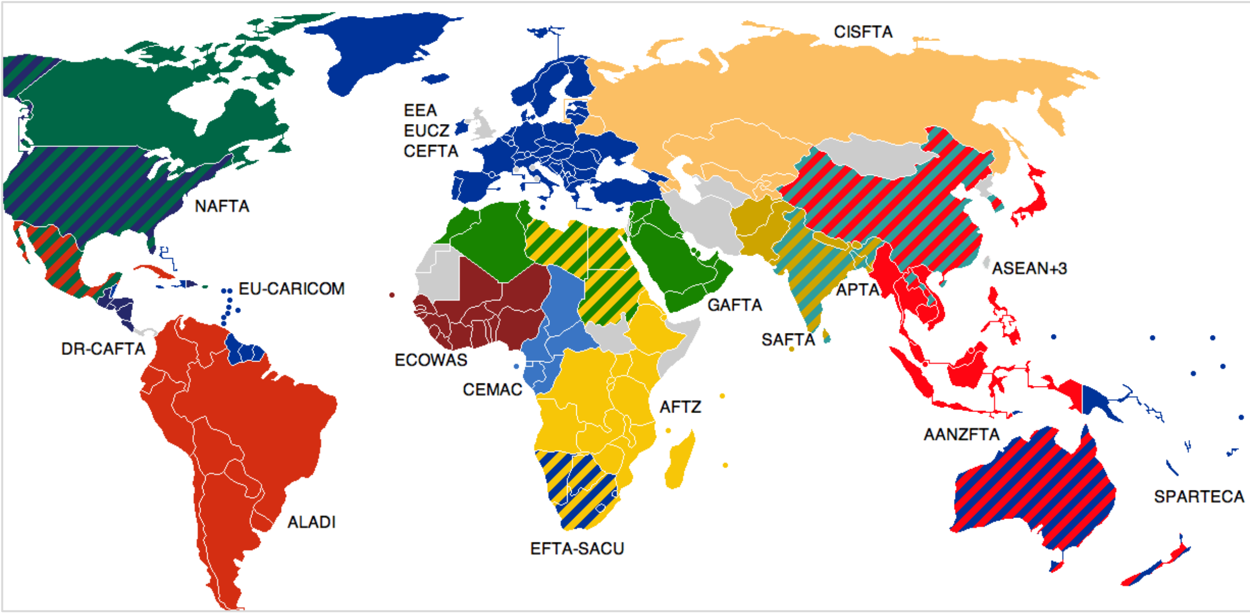


Figure xv: Free Trade Areas. Source: Wikimedia, 2009

Country	Average tariff rate (%, all products, 2018)
Brazil	7,95%
China	3,39%
EU	1,69%
India	4,88%
Japan	2,45%
Pakistan	9,45%
Singapore	0,24%
USA	1,59%

Table ii: Average 2018 tariffs in different countries. Source: World Bank

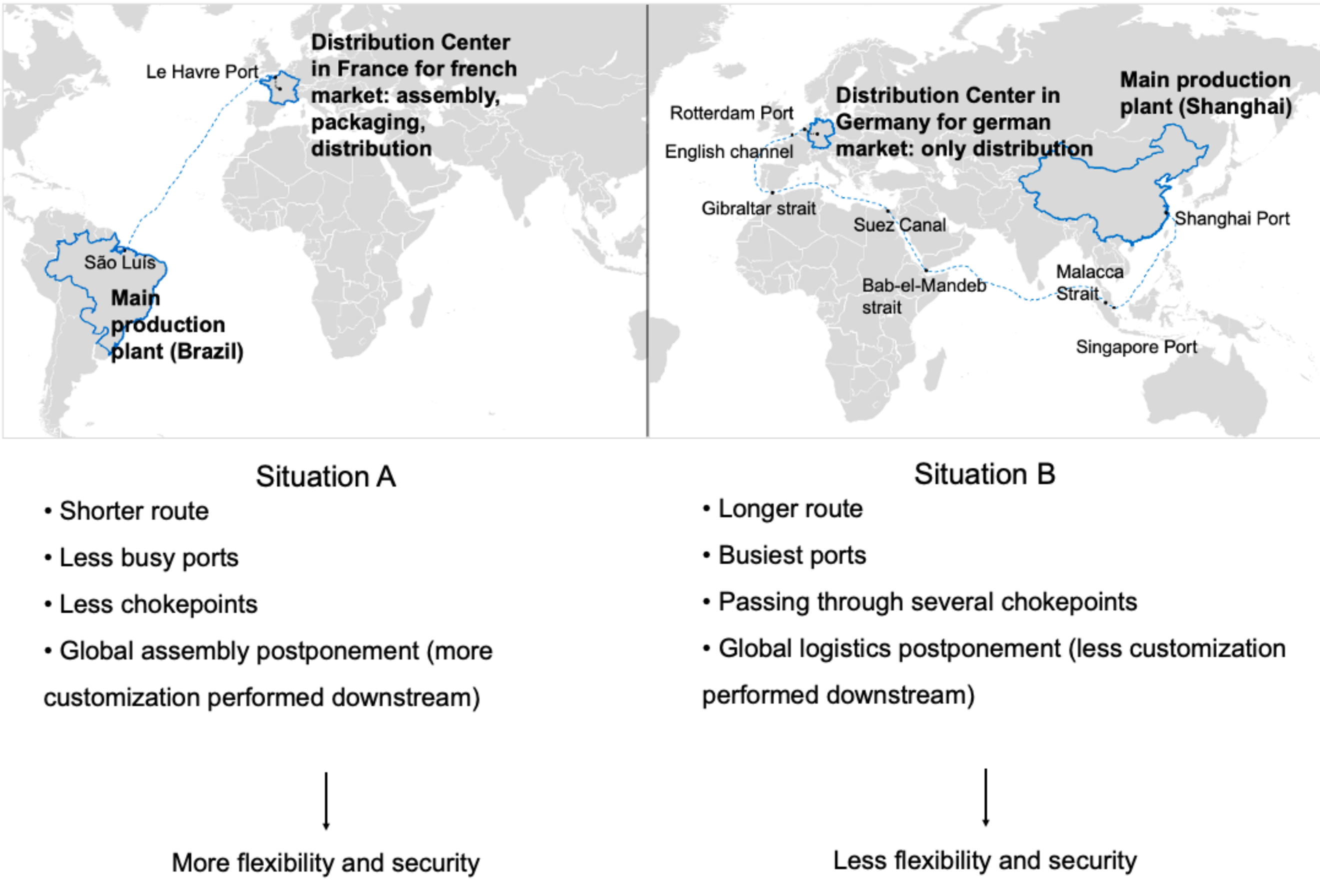


Figure xvi: Length of haul and related risk: a comparison between two Supply Chains serving the European market (own elaboration)

Output factors are:

- Reconfiguration cost, to re-structure the supply chain in the new configuration. This is one of the main initial cost and effort for managers to be considered;
- Cost of labor, still one of the main decision driver since opens up many opportunities for global manufacturing companies;
- Fiscal optimization, which has become a primary decision driver for operations managers and can be achieved with proper downstream warehouse location;
- Inventory cost, one of the most important outcome of effective postponement strategies;

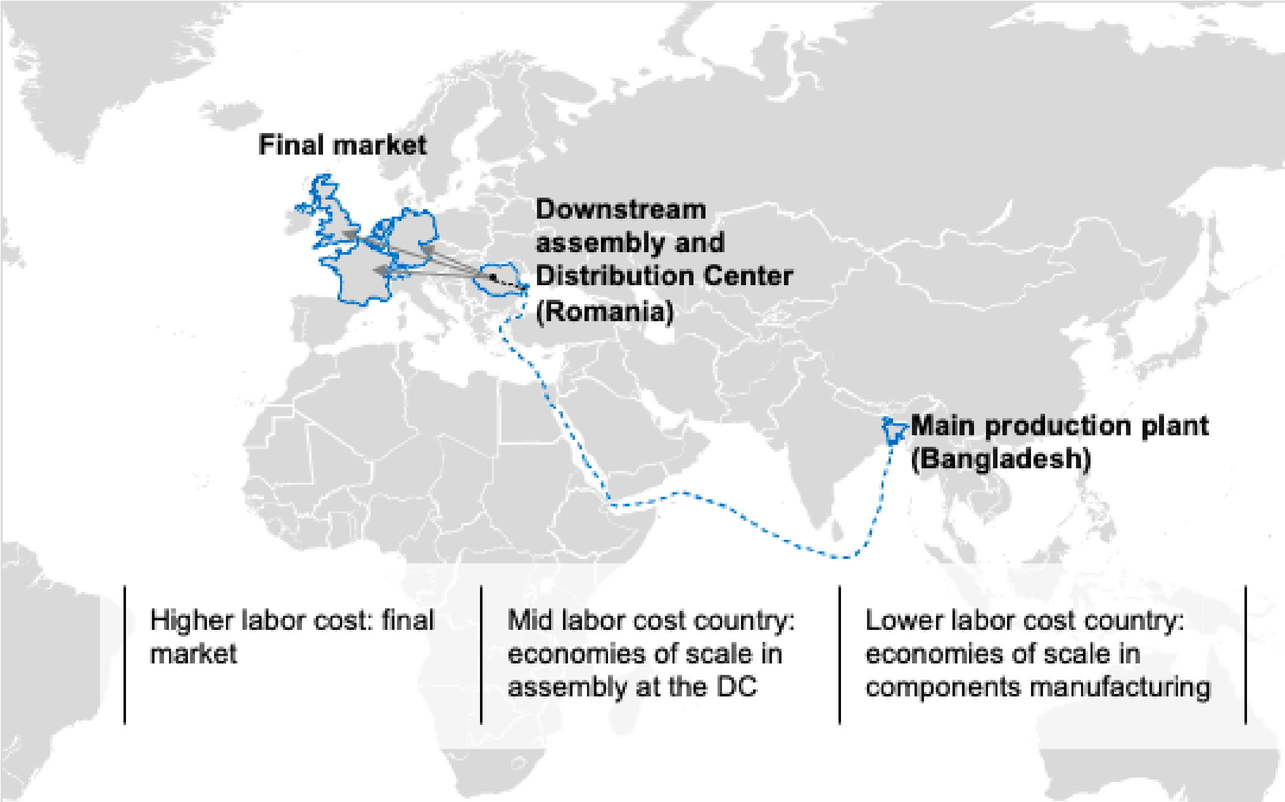


Figure xvii: example of ‘third-country assembly postponement’ strategy for labor cost optimization (own elaboration)

Country	Average corporate tax rate (2020)
Croatia	18%
China	25%
France	28%
Germany	30%
India	30%
Ireland	12.5%
Italy	24%
Romania	16%
Singapore	17%
Thailand	20%
USA	27%
Global average	23.79%

Table iii: Average corporate tax rates around the world. Source: KPMG, 2021

GEOGRAPHICAL POSTPONEMENT STRATEGIES ASSESSMENT WITH TRADITIONAL APPROACH

An efficient implementation of postponement strategies provide benefits in terms of costs and flexibility, and this is well studied in literature: recent studies confirm that the majority of implementations resulted in great success for customer satisfaction and costs.

Postponing customization activites geographically downstream was found to achieve a higher service level for the final customer compared to full speculation, for the same level of costs. Delaying assembly processes can enable a more bulk transportation, thus having better utilization of spaces and less transportation cost. Therefore, geographical postponement strategies can generally reduce the supply chain cost compared to traditional speculated strategies. Some real-case applications, in particular, confirmed the convenience of different geographical postponement strategies considering manufacturing costs, lead times, inventory cost and transportation costs. Postponement strategies were found to be relevant during the sourcing process as well, since buying and transporting raw materials could avoid having 'dead' stock during the long oceanic freights. Results showed, however, that in some cases of strong customization costs a speculation strategy could be preferred since the margins achieved are not outweighted. Moreover, modifications costs rise locating postponed operations closer to the customer in a global supply chain for three main reasons. First, supply chain redesign could require a strong initial investment. Second, a customized process is more expensive than a economy of scale-based one. Third, labour cost in the final destination region is often higher for companies with a global network. Therefore, each case would be better addressed if examined individually. Geographical postponement strategies were finally assessed considering the benefit provided in case of supply chain disruptions. Results showed that the flexibility provided enables to cope with disruption time and entity efficiently.

PRODUCT MODULARITY IMPLICATIONS FOR GEOGRAPHICAL POSTPONEMENT

Product modularity and postponement are closely related to each other. With modular products, it is possible to design the architecture efficiently so that any required combination can be conveniently assembled when needed. This matches with postponement perspective and goals, since modules can be configured later in the process and provide a wide range of product variants to be delivered to the market. This usually can be achieved only with standardization of components, which requires a fundamental redesign of them, as well as of functionalities and processes. However, redesign provides even many opportunities in manufacturing, since economies of scale, increased feasibility of change, increased variety, ease of design and testing, decreased lead-times, and easier diagnosis and maintenance can be achieved already at design stage, thus reducing total costs. Some examples are provided for this in the research, such as HP, Mercedes-Benz and Volkswagen. Standardization can be extensively applied to geographical postponement, and can contribute to the definition of a firm's organizational structure.

Modularity, however, is usually associated with an increase in weight and volume for three reasons: weight increase due to interfaces, over-sizing, and complex design interactions.

This could have an adverse impact on sustainability, since heavier products cause the need to have more trips, and higher emissions during transport. Developing a lightweight product would be clearly beneficial for sustainability but could be very complex and entail a long and iterative process.

REVERSE LOGISTICS IMPLICATIONS FOR GEOGRAPHICAL POSTPONEMENT

Overview

Reverse logistics refers to the backward flows of products to a point of recovery or proper disposal and is critical for the potential maximization of reused materials, thus decreasing the environmental impact. Reverse logistics practices are, in fact, still relatively low implemented in some countries and sectors.

	China	**India**	**EU**	**USA**
Currently in place	Banned or limited imports on packaging waste in 2017	Legislation favors recyclable substrates and formats	Packaging and waste directive	Important jurisdictions implementing bans on plastic bags
Recent moves or planned next steps	Proposal to ban single-use plastic bags by 2022	Pushing for increased number of awareness campaigns and collection points	Implementing a ban on selected single-use plastics	Introducing bills around reducing single-use packaging waste and increasing recycling

Figure xviii: Current state of regulations for packaging recycling (own elaboration)

Several types of reverse logistics channels are identified:

- In transit order cancellation
- Unacceptance by customer
- Packaging recovery for reuse
- Packaging recovery for recycling
- Warranties return
- Product recalls
- Unsold/expired goods from retailer
- EOL Value reclamation (recycling, reuse)

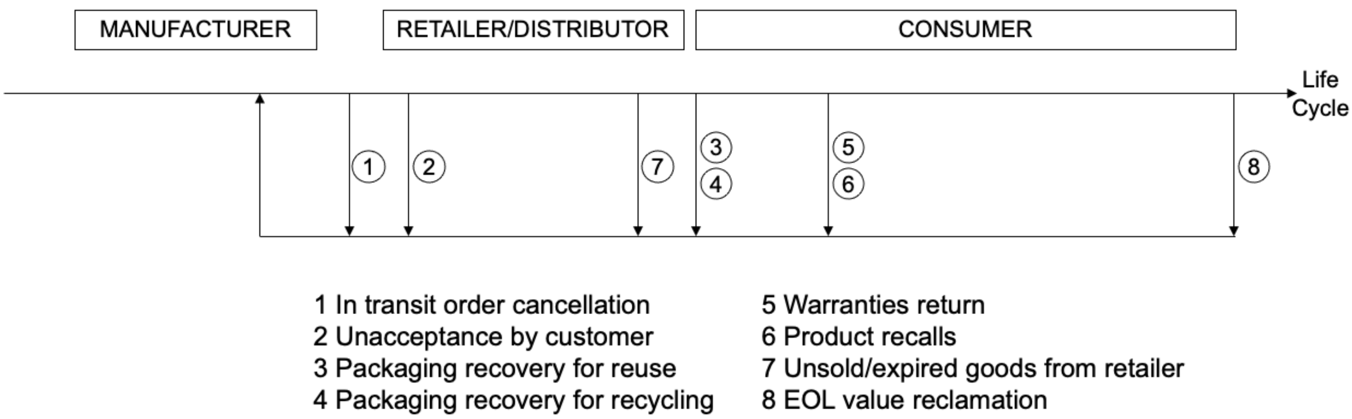


Figure xix: Different types of reverse logistics flows (own elaboration)

Moreover, several reasons could prevent companies to implement return management practices and were studied, such as lack of awareness, financial constraints and limited forecasting abilities of returned products.

Postponement for reverse logistics

Reverse logistics flows require a central location where to collect products. Therefore, a geographical postponement strategy could be integrated with reverse logistics to manage more efficiently the return of goods. In fact, a downstream Distribution Center with customization capabilities in the final market could be exploited as a return hub and product repair center.

For this discussion, reverse logistics flows are divided in ‘Before end-of-life return’ and ‘End-of-life return’.
‘Before end-of-life’ reverse flows can be of various types, and the following ones are taken into account:

- In transit order cancellation
- Unacceptance by customer
- Packaging recovery
- Warranties return
- Product recalls

All these flows can benefit from a geographical postponement strategy to have a more efficient disposal. Moreover, for ‘Packaging recovery’ a ‘Third country postponement’ strategy could be preferred if the collected materials are sold elsewhere. Using the warehouse for product recalls and maintenance should be done carefully, since repaired products could lead to bad perception by consumers.
‘End-of-life reverse flows include, usually, two types:

- Unsold/expired goods from retailer
- End of use by the consumer

In both cases, goods could be directed to disposal or be re-sold in a secondary market. In the first case, modularity plays a fundamental role enabling to better disassemble the product, sorting parts according to their most appropriate post-life treatment destination.
The process could be made internally or outsourced. Anyway, if the downstream DC is able to perform the disassembly it could be beneficial to locate it in a particular contry, if this provides some incentives for waste recycling. A company could have some agreements in a particular country and, in this case, could exploit a ‘third country postponement’. In the second case, where applicable, if the volumes are big enough they could justify a ‘Third Country postponement strategy’ in the secondary market.

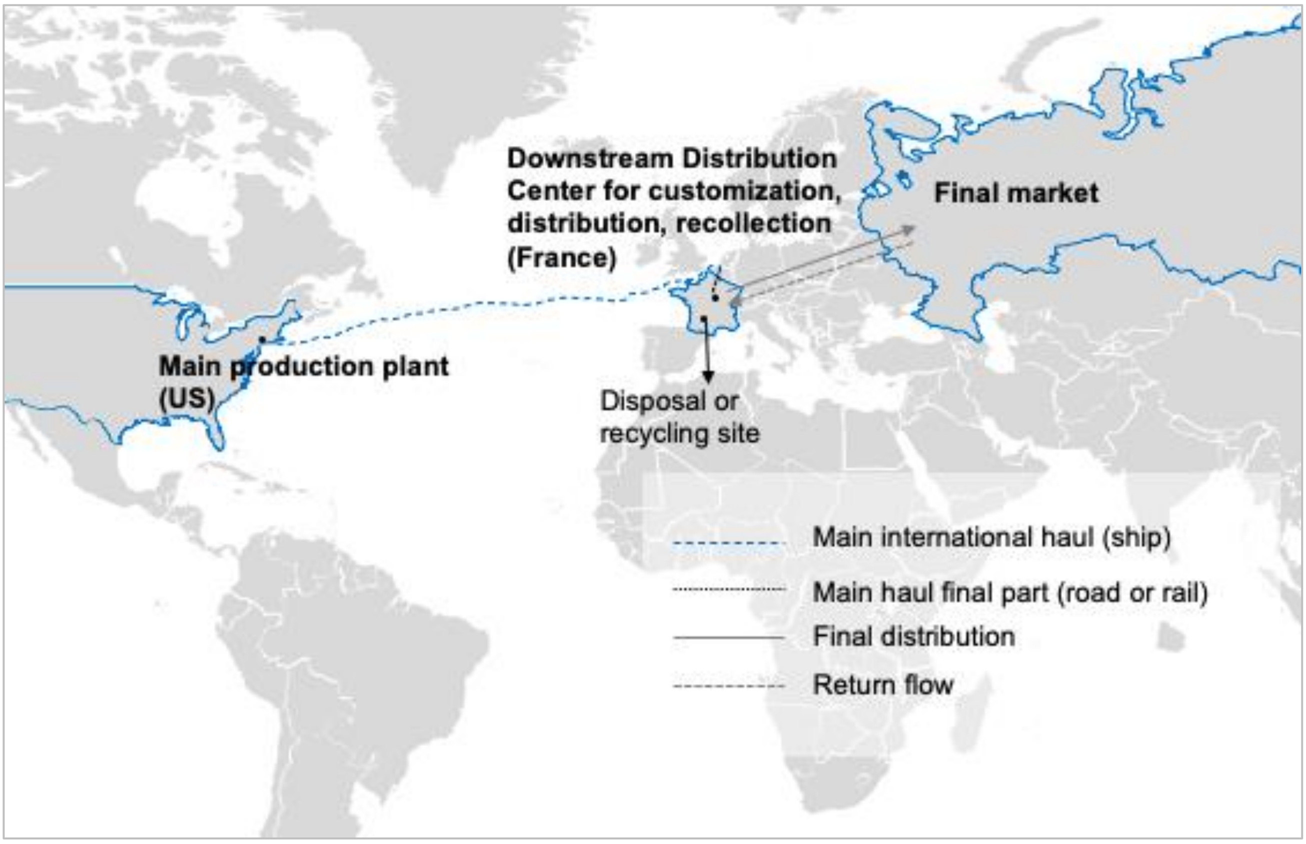


Figure xx: Third-country postponement strategy for EOL reverse logistics example (own elaboration)

REASONS TO INTRODUCE THE ENVIRONMENTAL PERSPECTIVE: THE TRIPLE BOTTOM LINE APPROACH

The growth of global supply chains has increased the amount of transportation and logistics worldwide, which account for a significant portion of overall emissions.

With an increase in the amount of activity, the overall level of emissions associated increase as well. Logistics activities, in fact, create several environmental impacts which are related to climate change, eco-system quality damage, and human health issues. The environmental deterioration caused by business activities has increased the awareness and pressure from various stakeholders in addressing the environmental issues, grounded in the 2015 Paris Agreement. Nowadays, it's becoming increasingly necessary for companies to factor environmental and social impacts of business strategies into decision taking, a concept known as 'Triple Bottom Line' approach.

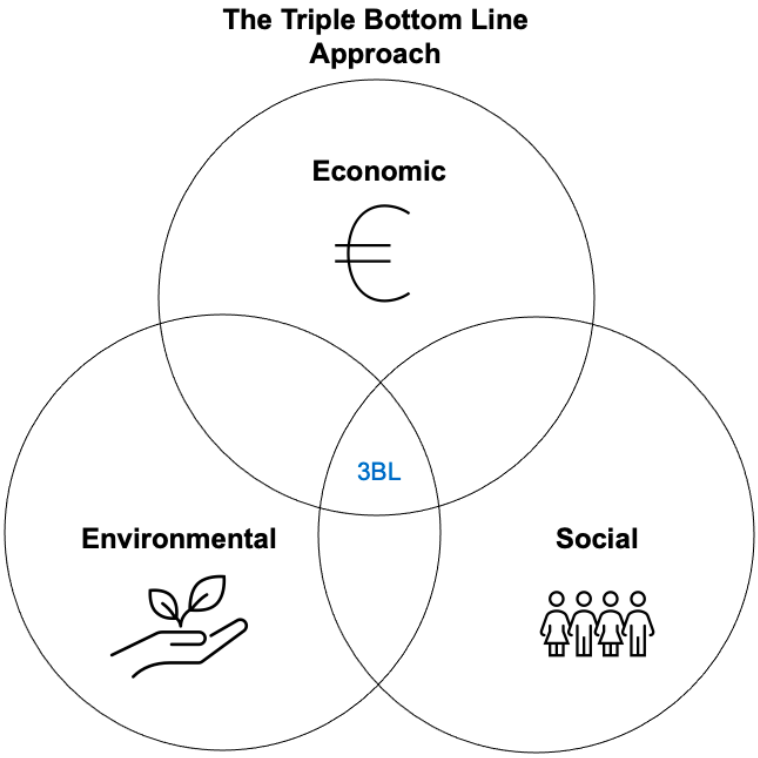


Figure xxi: The Triple Bottom Line approach (own elaboration)

This is extended in Logistics with the concepts of 'Green Supply Chain Management' first and, going a step further, 'Sustainable Supply Chain Management'. This study, however, focuses on GHG emissions and the social perspective will not be discussed. Industries have an incredible opportunity to reduce GHG emissions through green logistics, which anyway poses numerous challenges when confronted with reality, such as optimization in distances, lead time, fuel consumption, low GHG emission and cost.

SUSTAINABILITY-RELATED FACTORS

When designing a downstream supply network, implementing postponement with a geographical perspective under a sustainable approach, there are several factors related to sustainability which have to be considered. These are:

- Transportation and supply chain emissions, which generate huge environmental damage and must be carefully considered by companies pursuing sustainability. In particular, Scope 3 emissions from various stakeholders account for the largest part.

- Facility footprint, which is related to Scope 1 emissions and other outputs like light pollution and cementification of soil. Customization operations require usually more space in the downstream Distribution Center.
- Carbon cap, an effective regulation that many countries are adopting to control emissions which is relevant in the downstream Distribution Center location decision.
- Carbon tax, a price put on carbon in many regions which significantly differ for some countries and that must be carefully taken into account for global corporations.

Country	Carbon price ($/ton. eqCo2)	Carbon cap-and-trade implemented or scheduled	Carbon tax implemented or scheduled
Sweden	137	x	x
Norway	69	x	x
France	52	x	x
EU ETS market	50	x	
Canada	32	x	x
UK	24	x	x
California	18	x	
Shanghai*	6	x	

* China pilot test

Country	CPS (Carbon Pricing Score) at EUR60 benchmark
Norway	68%
France	55%
Italy	51%
UK	47%
Canada	34%
Japan	24%
US	22%
China	9%
Russia	7%
Indonesia	2%

Table iv (above): Carbon price in some major economies. Source: World Bank, 2021
Table v (below): Carbon Pricing Scores. Source: OECD, 2021

ECDM(ENVIRONMENTALLY CONSCIOUS DESIGN AND MANUFACTURING)

As said, postponement application is strongly related with modularity of products, which implies a substantial redesign of the product giving more engineering freedom and possibly leading to exploiting some opportunities for an eco-friendlier design. In fact, during the design stage most of the life cycle costs, as well as environmental impact, are determined. The life cycle of a product, more specifically, ranges from the initial specifications to the withdrawal from the market and the disposal during the EOL (End-of-life) Cycle. ECDM (Environmentally Conscious Design and Manufacturing) considers all these aspects during the design phase, falling under the concept of LCA (Lyfe Cycle Assessment). The key concept of sustainable design, to be actually implementable, is that it must be effectively green but balancing private interests of the company as well. For a postponement strategy, ECDM works on components and structure of the modular architecture of the product to increase the efficiency of all supply chain phases. Considering the usage phase, ECDM can create more sustainable products by extending the product's useful lifespan through upgrades, easier maintenance, and repairs that modular architecture enables. Moreover, in a geographical postponement strategy a downstream Distribution Center could be able to perform quick maintenance and upgrades. In this way, maintenance would require less travels thus reducing the carbon footprint. Considering logistics phases, ECDM can have huge impact since product characteristics and supply chain management are interdependent. A correct design can be beneficial for transports optimization, disposal phases and return management. For example, product shape can be modelled to optimize shipping or the architecture structured to ease disassemble, aiming to reduce the environmental output.

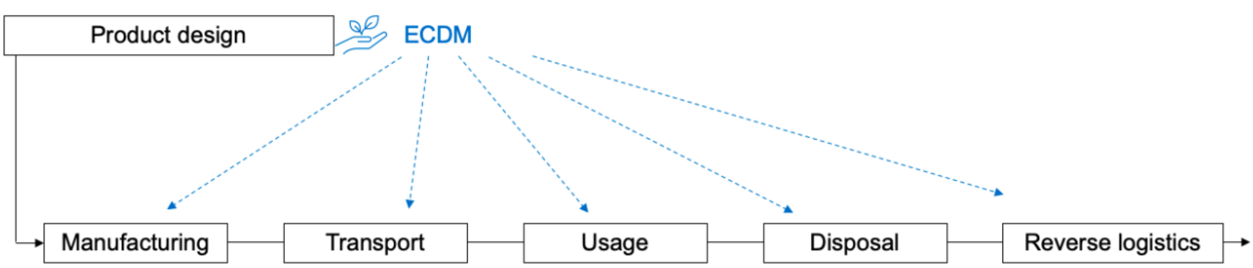


Figure xxii: Phases of product’s life cycle and ECDM (own elaboration)

GEOGRAPHICAL POSTPONEMENT STRATEGIES ASSESSMENT WITH TRADITIONAL AND ENVIRONMENTAL APPROACH

Postponement strategies usually lead to a trade-off in terms of emissions. The more the CODP is moved upstream the less unwanted processes are carried out, thus becoming more sustainable, but at the same time the system requires to be very fast involving more pollutant transportation phases. Moreover, some argue that a geographical postponement strategy can require more frequent transportations and over longer distances, since usually the path from the main plant to the final market is shorter than the path from the main plant to a secondary Distribution Center and then to the final market. Each case should be addressed individually and the two configuration factors, 'where' and 'what' to postpone can both influence the supply chain emissions. Given a country selected to host the customization operations, for example, some cases found that the best strategy for emissions minimization was logistics postponement, mainly given to best capacity utilization. Moreover, the more customization operations are done at the downstream Distribution Center, the more the facility would be big and energy consuming. Therefore, 'assembly postponement' performs worse than 'logistics postponement' in this regard. The literature found showed that geographical postponement strategies are usually beneficial in terms of overall emissions, in particular slightly increasing the fixed part but reducing significantly the variable one. Moreover, considering a particular country where to postpone, more speculated operations generally lead to more costs and emissions, but this could not be always guaranteed in the long term and is important to consider each case individually. A real case example, moreover, concluded that carbon cap and carbon tax can strongly increase corporate decisions and stimulate greener technologies.

Demand uncertainty affects strategies' performances as well: logistics postponement was found to have the worst performance, in terms of costs and emissions, against the increase in demand standard deviation, whereas assembly postponement was the best one. However, the greater the degree of the demand variability is the larger the benefits of applying a postponement strategy will be. The results also showed that at any given level of GHG emissions, geographical postponement strategies can provide cost savings. Similarly, the postponement strategy is useful in tackling the total greenhouse gas emissions irrespective of the amount of total costs. However, as said, usually total supply chain cost and GHG emissions have a tradeoff since greener solutions are more expensive.

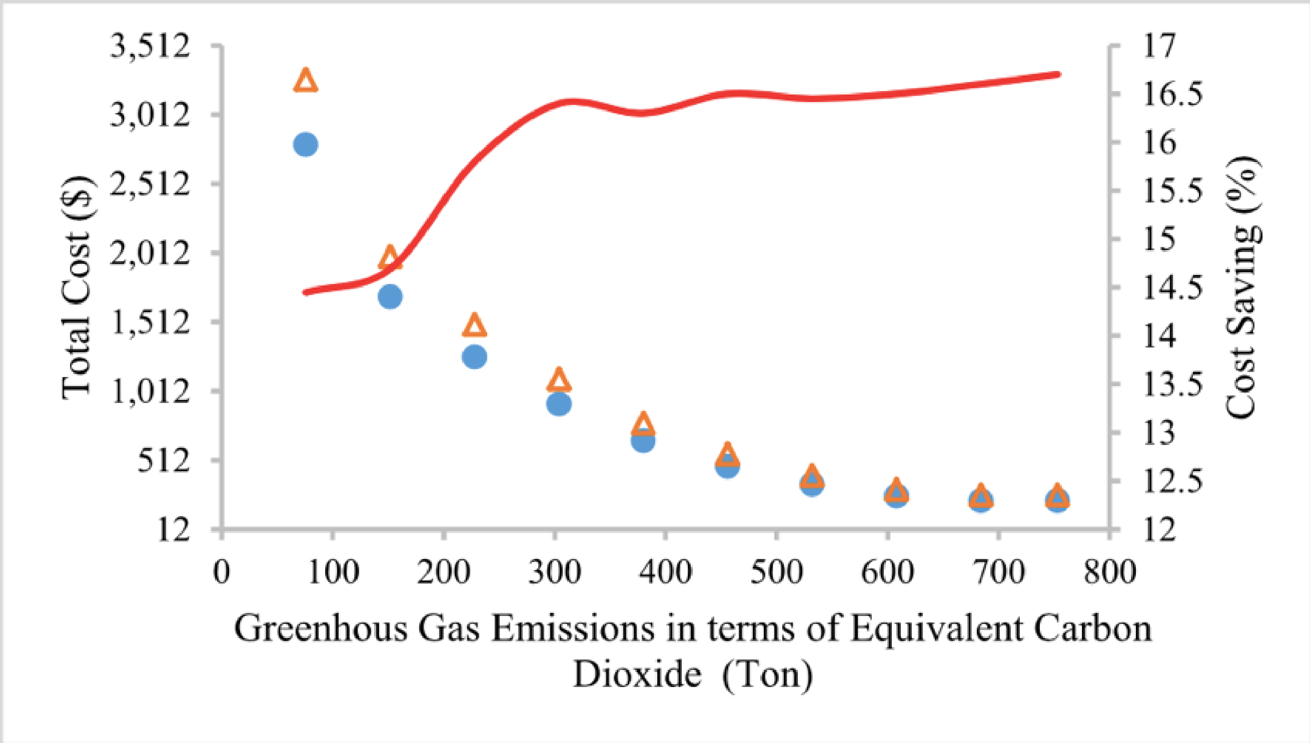


Figure xxiii: GHG emissions and total Supply Chain cost tradeoff (dotted line) (15% demand variability assumed). Source: Jabbarzadeh et al., 2019

Also, results showed that the reconfiguration and eventual new facility required strongly affect the environmental performances and can even offset the benefits in transportation in some cases. They also concluded that there are no solutions which improve the social implications without compromising too much both economical and environmental impact.Therefore, the best solutions lies in the tradeoff between the three aspects of the triple bottom line. To conclude, it should be stressed that the geographical location of the customization process influences the overall environmental impact as well, since transporting products in semi-finished form in bulk enables a better capacity utilization, while finished products and packaging require more space. Therefore, given a specific 'what' strategy, 'pure postponement' means that in general the products will be transported in a more finished form compared to the corresponding 'what' strategy in the third-country or destination region strategy, resulting in less utilization and more emissions per transport.

FUTURE TRENDS FOR SUSTAINABLE SUPPLY CHAINS WITH GEOGRAPHICAL POSTPONEMENT STRATEGIES

Some possibilities for future trends or improvements have been found in literature, which postponement strategy could benefit from.

Digitalization

One of the reasons of the relatively low implementation of postponement strategies over the past decades was the inadequacy in technology development, and global supply chains with geographical postponement strategies have the potential to further improve their performances and reduce emissions thanks to digitalization. Data sharing is a critical element which can boost or lower the performances of a geographical postponement strategy, enabling to have more reliable forecasts from the client and from suppliers.

For example, in a geographical postponement context with long international shipping new, faster data sharing enabled by IoT and 5G expansion can enable real-time data sharing, visualization of flows and ports congestion's optimization. The reduction in fuel consumption is twofold: by adjusting its navigation plan to minimize fuel consumption and by reducing anchorage time and maneuvering.

CPS (Cyber-Physical Systems) enable the synergy between computational and physical components and are expected to drive innovation and competition in future manufacturing and transportation. In this regard, the concept of VBTO refer to the idea of connecting customers via internet to the products already under production to find one that fits them, applying the concept of Floating Decoupling Point (FDP). Such practice can further reduce costs and material consumption. These concepts could eventually be integrated in a Cyber-Physical System, where a customer uses her smartphone to customize the product, see if it is available and eventually automatically place an order. Results found concluded that the more the supply chain is connected in an Internet-of-things (IoT) environment, the more this could be beneficial in terms of tracking better emissions and environmental performances as well.

E-commerce

E-commerce can be exploited by manufacturers applying geographical postponement, using the time lag between the moment when the customer places an order and the time she is willing to receive the product to perform customization operations. This could enable to stock basic components which are more environmentally friendly for the shipment thanks to the better utilization of space provided by bulk stocking. The time window is getting more and

more strict, but the huge volumes brought by e-commerce could lead to economies of scale in assembly thus justifying a postponement strategy.
On the other side, using the time window to perform customization means having the need to schedule faster last mile transportation, which are usually costly and more pollutant.

3D Printing

3D Printing could be used in Distribution Center to quickly perform final stage configuration after receiving the customer order, thus saving a significant quantity of material. Moreover, 3DP could be even used by final customers through home printers. The manufacturer could send a standard component and consumers could use their own purchased 3D printers to add the features they desire. From a manufacturer perspective applying a geographical postponement, this would mean sending only standard components directly to the final costumer, thus improving sustainability levels.

SURVEY

DESIGN PHASE

A survey was developed to further investigate the concepts of geographical postponement and sustainability found in the SLR. The survey questions are:

1. GOALS - When choosing a country where to perform some final stage configuration operations, one of the driving goals is operational cost minimization. For example, labor cost and transportation cost varies depending on the chosen country. How much would you consider the importance of operational cost minimization when choosing a country/region where to perform final stage configuration operations?
2. GOALS - When choosing a country where to perform some final stage configuration operations, one of the driving goals is fiscal cost minimization. The most relevant forms are: the possibility to exploit lower tariffs (duties) when shipping through that country and lower tax levels (third countries are often chosen for fiscal optimization). How much would you consider the importance of fiscal cost minimization when choosing a country/region where to perform final stage configuration operations?
3. GOALS - Some countries apply carbon taxes, a tax to pay for the CO2 produced. A particular country could be chosen for final stage configuration operations because it has lower carbon taxes in place. How much would you consider the importance of

minimizing tax-related costs (e.g. carbon taxes) in the country/region chosen for assessing final stage configuration operations?

4. FACTORS - Overall supply chain emissions come from different sources (transportation, facilities, suppliers...). The country/region where final stage configuration operations are done can change the overall level of emissions produced (for example, different transportations are used or new facilities are required). To improve the sustainability of your company, how important would you consider the overall amount of emissions produced by your supply chain, when choosing a country/region for final stage configuration operations?
5. FACTORS - The infrastructures of a country (roads, rails, ports) affect the performances and reliability of a supply chain, and different countries have different level of infrastructures. How important would you consider the level of infrastructures present in the country/region chosen for final stage configuration operations?
6. RECONFIGURABILITY - Moving some final stage configuration operations closer to the market is proved to provide cost benefits and lower lead times. However, it requires a strong initial effort and cost to re-configure the supply chain (for example building a new distribution center, moving some equipments there and train new people). This effort could vary depending on the chosen country. How important would you consider this initial 'reconfigurability' effort when deciding the country/region where to perform final stage configuration operations?
7. STRATEGY RELEVANCE - Given all precedent factors as a reference, in designing a supply chain aiming to delay some final stage configuration operations (assembly, packaging, labeling or distribution), how much importance would you give to the geographical perspective (the place or region where these configuration operations are held)?
8. COST BENEFIT - Given all precedent factors as a reference, how important do you think that performing final stage configuration operations (assembly, packaging, labeling or distribution) in a place geographically closer to the final market is, to reduce the overall cost?
9. SUSTAINABILITY BENEFIT - Given all precedent factors as a reference, how valuable do you think that performing final stage configuration operations (assembly, packaging, labeling or distribution) in a place geographically closer to the final market is, to reduce overall supply chain emissions?

10. FURTHER DEVELOPMENTS - Reverse logistics refers to the return flow of the product (or the packaging) after the use by the consumer, to be recycled or re-used, thus improving sustainability of the product's life cycle and potentially lowering company's costs. Having a distribution center, close to the destination market, where final stage configuration operations are performed could be exploited for reverse logistics flows. How much valuable and feasible do you think this solution could be, for a more sustainable supply chain?
11. FURTHER DEVELOPMENTS - How would you rate your company's effort to implement reverse logistics (refer to the description in the previous question)?
12. FURTHER DEVELOPMENTS - 3D Printing is considered a future solution for mass customization, where the final stage configuration operation is done directly by the final consumers at home with their printer. In a geographical postponement perspective, the manufacturer would send a standard component from the distribution center and consumers could use such method to add the features they desire. How important would you consider 3D printing, as a valid and feasible solution?
13. FURTHER DEVELOPMENTS - ECDM (Environmentally Conscious Design and Manufacturing) means considering the environmental impact of a product already at the design stage. In this way, it is possible to consider all the product's life cycle: production, transportation, usage and disposal, trying to design the product in such a way that optimizes the CO_2 emissions in all phases of the product's life. How would you rate the level of ECDM in your company (how importantly do you consider the environmental impact already at the design stage)?

DATA COLLECTION

For each question, the Likert scale (rate from 1 to 5) was used. After a pilot test to check comprehension, the survey was sent, and nine responses were collected. Such number does not enable to provide statistical validity of the results, which are however valuable considering the new field of study and the respondent companies.

Company ID	Founding year	Country (Global HQ)	Revenues range	Sector	Main product	Geographical reach
A	1969	France	> 250 mln	Aerospace	Commercial aircrafts	Worldwide
B	1933	Italy	50 mln - 250 mln	Manufacturing	Injection systems	Europe
C	1995	Italy	> 250 mln	Apparel	Shoes	Worldwide
D	1979	Italy	2 mln - 10 mln	Manufacturing	Mechanical equipments	Europe
E	1941	Liechtenstein	> 250 mln	Manufacturing	Mechanical equipments	Worldwide
F	1984	China	50 mln - 250 mln	Electronics	Computers	Worldwide
G1	1996	Switzerland	50 mln - 250 mln	Pharmaceutical	Drugs	Worldwide
G2	1996	Switzerland	50 mln - 250 mln	Pharmaceutical	Drugs	Worldwide
H	1915	Switzerland	50 mln - 250 mln	Pharmaceutical	Pharmaceutical packaging	Worldwide

Table vi: Respondent companies' overview

RESULTS

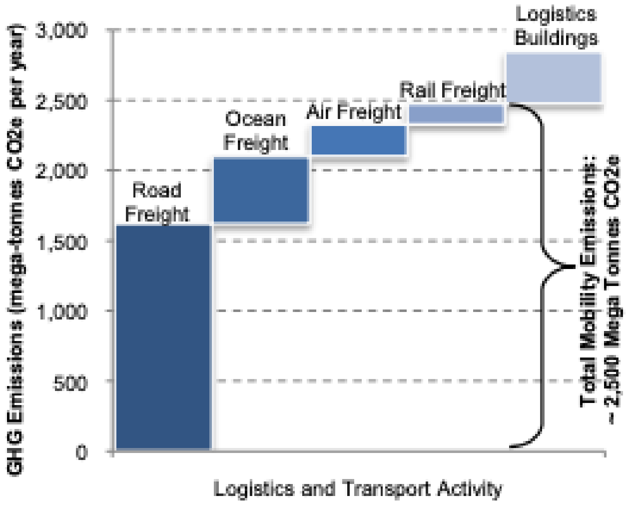
All the factors to consider where deemed as important with a degree of relevance that was different for some companies. In fact, the concern about some factors such as fiscal optimization, infrastructures, carbon tax or emissions could vary depending on the countries involved in the supply chain, corporate policies or size of the firm. For example, consumer oriented sectors with lots of dispersed facilities ranked fiscal optimization higher. The survey results highlighted a growing attention towards geographical postponement capabilities and opportunities, which is relevant considering the new field of study. Considering all factors, respondents recognized an high capability to improve both costs and emissions in geographical postponement. Sustainability is confirmed to be a relevant concern for firms as well, but some sectors and organizations, limited by corporate decisions or product's constraints, are slower in the implementation of radical changes for the sustainability of the overall Life Cycle. Reverse logistics, moreover, is a top concern but only mid-implemented. Finally, 3D Printing for downstream customization is just at a nascent stage and is not well known in corporate environments.

Company ID	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
A	3	2	3	3	3	3	3	3	3	3	3	2	4
B	4	4	4	4	5	4	3	5	4	5	4	3	4
C	4	4	4	3	4	4	4	3	2	4	4	1	n/a
D	3	2	3	5	5	4	3	5	5	5	2	5	1
E	4	3	1	3	3	3	4	4	4	4	4	1	4
F	5	5	1	5	5	5	5	5	5	5	3	1	5
G1	4	3	5	5	5	4	4	4	4	5	4	5	4
G2	4	3	5	5	5	4	4	4	4	5	4	5	4
H	4	4	3	5	3	5	4	5	5	3	1	2	1

Table vii: Survey results

DISCUSSION

The present study expanded the geographical postponement strategies framework proposed by Prataviera, et al. (2020) in two steps. First, a vertical expansion was presented, where strategies are not considered just in operations phase but considering the whole Life Cycle, from design (with modularity section) to reverse logistics. Then, an horizontal expansion was done from pure operations performances to fiscal and sustainable considerations, following the 'Triple Bottom Line' approach. To do this, all relevant factors to consider for an effective geographical postponement implementation were analyzed, both internally and externally driven. Such factors create a practical framework to follow when implementing geographical postponement. SLR's results showed that applying geographical postponement is the supply chain always leads to economic benefits from a pure profit optimization point of view. Instead, when the sustainability is introduced as a factor, each individual company case should be specifically addressed to give exact outcomes. This was found also in the survey, which highlighted also the different sensitivity towards sustainability of different firms. Geographical postponement could lead to a trade off in terms of emissions, with less international hauls but quicker and pollutant final deliveries. In particular, the more activities are performed downstream the more space can be optimized during international travel, but the more final delivery must become quick. This problem could be offset with a transition towards greener fleets, which is the trend of the present century. Road and shipping, the two transportation methods mostly involved in the study, account respectively for the first and second biggest amount of emissions in logistics.



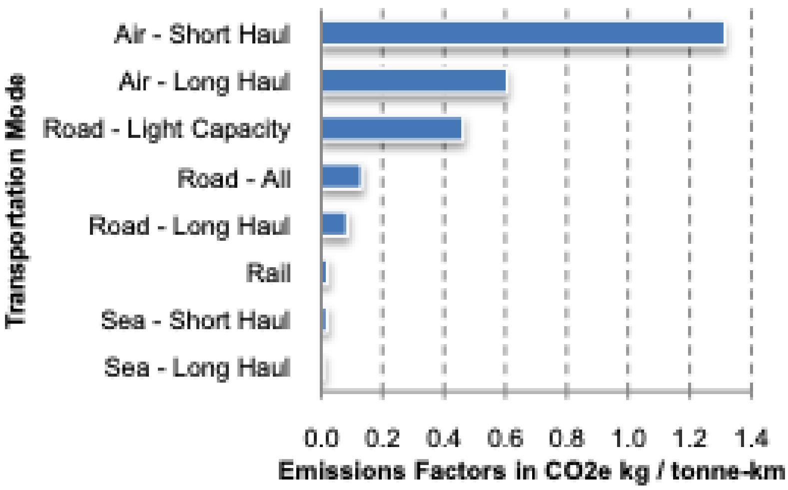


Figure xxiv (left): GHG emissions due to different logistics activities and transportation modes.
Figure xxv (right): Emissions efficiency for transportation mode.
Source: World Economic Forum, 2009.

Basing on the World Economic Forum (2009), supply chains with geographical postponement can significantly improve sustainability levels with greener transportation, both in the main haul and in final delivery, which could be achieved mainly in three ways. First, with clean vehicles: for shipping, a continuously growing sector, there is a lot of pressure for biofuels adoption and use of shorepower, as well as a lot of associations pursuing reduction in other forms of environmental damages such as biofouling or noise pollution to achieve sustainable trades, while for road transport there is strong concern for biofuels and electric transition. Today, electric vehicles are a feasible solution for last mile delivery but the are still barriers in the implementation for mid-range travels related to recharging times, autonomy and cost. The fast growth if e-commerce could further accelerate the transition towards greener road transports, even if home deliveries are already less pollutant than having all customers driving to the stores. Cleaner delivery could be also achieved with a more widespread use of intermodal transportation, which is seeing huge investments in the last years in the EU. Second, despeeding the supply chain and third, reducing the amounts of miles covered. From the results obtained, these two solutions do not seem feasible without compromising the service level, since consumer needs and geographical reaches are only going to increase. The only compromise would be to have new bigger ships, which would require several years and huge costs. Moreover, ships are today reaching a size limit set by some crucial world's Canals. Instead, a valuable alternative found in the study is the digitalization and cooperation between supply chain actors. With today's capabilities, a geographical postponement context can exploit faster data sharing to achieve better optimization of some parts of travels and reduce downtimes, for example with Port Call Optimization (PCO).

CONCLUSION

ACADEMIC CONTRIBUTION

The present study filled a literature gap regarding geographical postponement strategies, using the framework introduced by Prataviera, et al., (2020) and expanding it to have a broader view of related opportunities and implications. Following a SLR, all factors relevant to the implementation of geographical postponed supply chains have been presented, and their implications for logistics and overall corporate performances are given as a practical reference to consider. Such factors compose a new source of information for geographical postponement future studies. Then, the framework was used to compare different strategies not just from a traditional point of view, but with a Triple Bottom Line approach. All the results were practically assessed in a pilot survey which features some important manufacturing companies at a global level, and future trends for geographical postponement, potential basis for future research on this topic, are presented.

MANAGERIAL CONTRIBUTION

The present study provides a practical guideline to be consulted by Operations Manager when evaluating the possibility to introduce a geographical postponement strategy in their supply chains. With this work as a reference, they could understand and explore the different possibilities and challenges provided by different strategies, eventually including the sustainable aspect as well. They could first have an understanding of the factors to be considered, and apply them to their specific case. Then, they could compare some options and assess the different performances that would result from their decision. Again, this phase could include or not the sustainability aspect depending on the corporate policies.

RECOMMENDATIONS FOR FUTURE STUDIES

Finally, hints for future research can be recommended. All factors driving postponement decisions could be further studied and expanded both vertically, with deeper analysis and horizontally, with more factors. Electrification of transportations could be factored in when comparing the different geographical postponement strategies. Moreover, the survey presented was a pilot test for future studies and provides the basis for a more widespread and comprehensive analysis which could create statistical evidences. Global macrotrends, such as global warming opening up a new trade route through the Artic could be included. Finally, the future trends proposed were only introduced and provide a base for discussion.

INTRODUCTION

After the Industrial Revolution, the world experienced a huge increase in economic development and global production outcome. Manufacturing policies, however, have focused for decades solely on economic growth and development (Sonego, et al., 2018). Such activities created huge increase in development and opportunities, but provided several challenges as well. In the last decades in particular, two trends emerged in global markets, shaping competition between firms and strategic decisions: mass customization, leading to an increasing importance towards postponement strategies for manufacturers, and sustainability (Khan, et al., 2020; Ferdows, 2018). These concepts are the pillars for the present study. In the following introductory section, the two themes are explained and introduced.

MASS CUSTOMIZATION AND POSTPONEMENT

During the 20th century, manufacturers' focus has been solely on mass production, with manufacturing policies aiming at economic expansion and economic development (Sonego, et al., 2018). Eventually, large mass markets have been decomposed into smaller niche markets demanding higher levels of product variety. As a consequence, customization of mass produced products became one of the center attentions for many firms (Fixson, 2005), and a shift has been made from mass production during the last century to mass customization of the last decades (Huang & Liang, 2007). This shift is due, among other factors, to demographic and social reasons, since overcrowding and rise of middle class are boosting the consumption of products. The world is experiencing a huge growth in population and, according to some forecasts, the global middle class will grow by over 1.5 billion units by 2035, passing 5 billion people (Simão, et al., 2016). A huge increase in population results in more consumption of resources but also demand for product variety, fast deliveries and competitive pricing (Huang & Liang, 2007). Such results are, indeed, becoming even more important with the advent of Internet and information technology: they have helped increasing the consumers' requirements and the demand for more unique or niche products and, as a consequence, an increasing demand for customized products, which enterprises often struggle to satisfy (Li & Liu, 2017). Today, some observe that there has been a shift from

Mass Production to the so-called Mass Confusion issue, related to the extreme result offered and resulting in the burden of choice by the customers (Shabah, 2015). The phenomenon of Mass Confusions is fueled by the spread of e-commerce, which gives to customers infinite decision-power and stores visibility, with companies often struggling to face its complexity (Su & Chuang, 2011; Chang, 2012; Li & Liu, 2017). Therefore, today one of the key goals for manufacturing companies is exceeding the customer needs (Wang, 2010), offering more and more variants. Obviously, there is a significant difference between the two strategies from a manufacturing point of view. Mass Production was supported and made feasible by economies of scale. Instead, product customization could be counterproductive when economies of scale are not exploited. In the end, one, if not the main, goal driving production and logistics processes is still cost minimization (Establish, 2010).

The present study wants to focus on logistics processes, and strategies adopted to cope with the increasing product variation requirements, without forgetting the primary aim of cost optimization. As said, logistics processes and effort grow significantly with the huge increase in population and consumption that the world is experiencing today. Logistics processes, and related costs, grow exponentially with the advent of Internet, e-commerce and home deliveries as well. These relatively new concepts force companies to spend huge effort in logistics capabilities if they want to be reliable maintaining costs. In fact, online consumers require deliveries which are directly at home and very reliable, and in return are willing to wait some time from the purchase to the delivery, even if this time window is becoming more and more tiny and competitive. The great customization required produces some issues from a manufacturer point of view, both for production and for delivery options. A company with a perfect crystal ball would always manage to have the right parts and product inventory available at just the right time to satisfy total demand but, unfortunately, this is not how it works in modern and demanding supply chains. Low forecast accuracy is and will remain a fact of life (Wadhwa, et al., 2008). An appealing option to cope with these issues is postponement, which refers to delaying the point of product differentiation, that is deferring the process in which products are transformed according to unique customer specifications (Huang & Liang, 2007). This involves designing and developing standard or generic configurable products that can be customized quickly and inexpensively once actual consumer demand is known (Oracle Corporation and Cap Gemini Ernst & Young, 2003). The key in a postponement strategy is to have a common component in the supply chain for most of the push phase (product variant speculated) and move product differentiation as close to the pull phase (product variant indicated by the customer order) of supply chain as possible (Wadhwa, et al., 2008). The decoupling point, which is the stage during production when a product from standard becomes customized for a specific order or variant, should be as far upstream as customer service levels allow, thus centralizing inventory, postponing distribution and taking advantage of lower inventory costs, while possibly still enabling to fully meet customer lead times (Baker, 2011). In this way, a company implementing a postponement strategy can improve the service level and reduce the total cost (Chang, 2012). The concept of postponement was first mentioned in the 1950s (Alderson, 1957) as an idea for marketing and distribution, but the concern about such strategy grew only after several decades. Today, logistic strategies have been recognized among the seven best to cope with global challenges like product variability and logistic inefficiency (Wadhwa, et al., 2008). A study by Oracle Corporation and Cap Gemini Ernst & Young (2003) showed that over 75% of respondents implementing postponement derived significant benefits and considered their implementation a success, and 91% of respondents noted significant improvements in customer satisfaction and inventory costs. While it is proved to be a very effective strategy and is largely used at

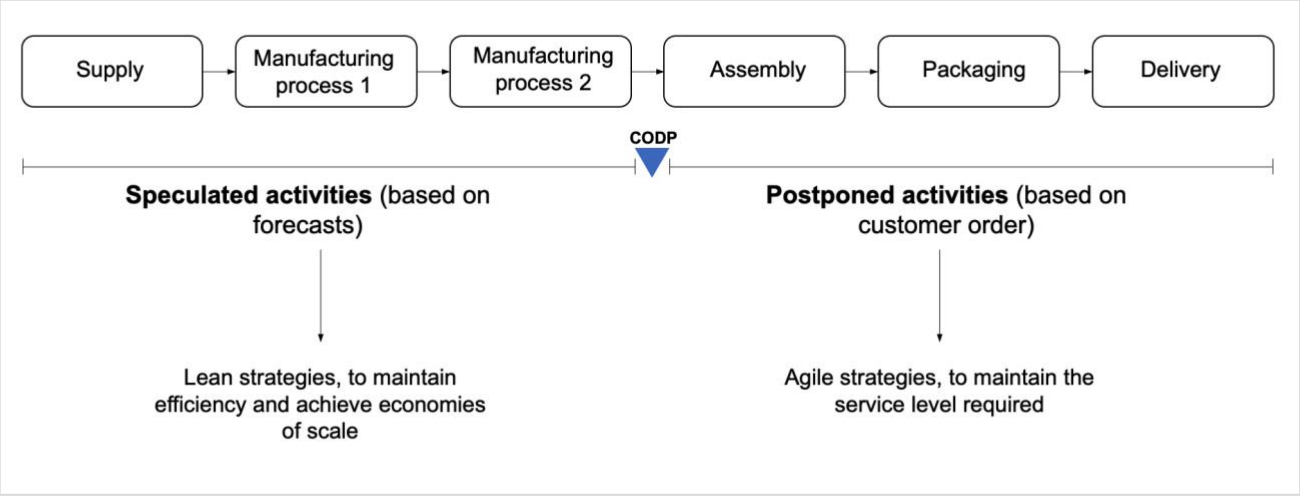


Figure 1: Customer Order Decoupling Point and manufacturing postponement example (own elaboration)

a global level, some players and some sectors still don't apply such strategy extensively. Wadhwa, et al. in 2008 pointed out as in the automotive sector, a very capital intensive one where the number of components is huge, the concept of postponement strategy was just at a nascent stage, while all the effort was put on Lean Production exemplified by TPS (Toyota Production System). Similarly, a study by Gorane & Kant (2016) showed that in a big, developing country such as India, postponement application is still below average compared to more eradicated strategies like Lean Production. Postponement strategies are generally classified into two kinds of approaches: manufacturing postponement and logistic postponement (Chang, 2012). The former aims at delaying the product differentiation during the production process, waiting the CODP to univocally assign a product to a customer. The latter, instead, aims at delaying in time the outbound logistics processes related to delivery. Such processes are packaging, labelling and the delivery itself. The CODP can be placed more upstream or downstream in the production and assembly process, based on the tolerances allowed by the company. Ideally, all companies would pursue BTO (Build to Order) or even ETO (Engineered to Order), to consume only what is needed and have no wastes, which represents the maximum level of postponement applied possible. Obviously, this would create a very long TTM (Time to Market). On the contrary, the lowest level of postponement applied is represented by MTS (Made to Stock), where all products are manufactured based on forecasts, or even DTS (Delivery to Stock) for some consumer goods sectors, where products are delivered to the retailers based on forecasts. While this strategy enables a better TTM and product availability, the potential downside is to have products unsold and huge stocks. Therefore, postponement is the umbrella term to refer to very different supply chain strategies depending on the activities postponed. Due to its characteristics, different strategies are used in different sectors. According to (Huang & Li, 2009), electronics and IT industries implement more engineering and logistics postponement, clothing manufacturers are the most aggressive in applying postponed packaging/labelling and the manufacturers in electric appliances focus more on final manufacturing and assembly postponement. However, firms in the same industry could focus on different postponement strategies due to specific product characteristics, cost characteristics or production characteristics.

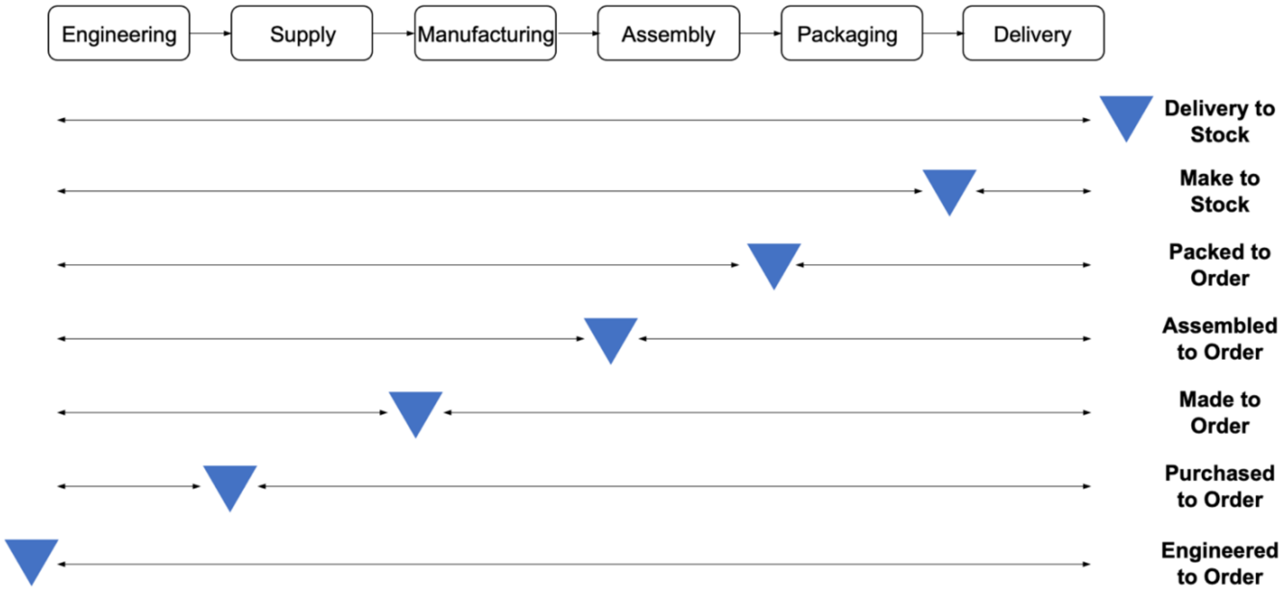


Figure 2: Temporal postponement strategies classification based on CODP (own elaboration)

The traditional concept of postponement is 'temporal': the delay, being it in manufacturing of logistics, is in time, and the final configuration operations are performed in the main production facility. With globalization and the progressive expansion of corporations, the supply chain of companies became global and production facilities can be dispersed all around the globe, with production facilities being in another continent compared to the final destination market. Since the 1980s, globalization has had a huge impact on production and markets, reflecting also on logistics operations (Chou, et al., 2014). A study by Interbrand showed that already in 2011, the 100 best global brands derived at least a third of their revenues from outside their home country (Interbrand, 2011). In fact, with global economic integration, production has been increasingly fragmented and has become a multinational activity (Dai, et al., 2021). Moreover, a global customer base required customization of mass-produced products, which made large players to fragment their market into smaller niches, introducing new products in shorter time intervals (Fixson, 2005), which could have contributed to increase the attention towards postponement strategies. This results in bigger stress in supply chain network planning and operations for companies. Big, international companies are in fact dispersed and look for a "glocalization strategy", i.e. achieving global efficiency combined with local responsiveness (Yang, et al., 2004). This is found also in (Huang & Liang, 2007), who conclude that, while global efficiency is a matter of concentration of upstream operations in large, economies of scale-based activities, local responsiveness can be achieved at downstream customization operations, making them more efficient and agile. Thus, the whole SC must become more competitive, and not just the production system (Gorane & Kant, 2016), which is the reason why postponement strategies can be particularly effective. Achieving only production efficiency lead companies to cost savings, but not investing enough in supply chain planning can become a burden for dispersed multinational companies delivering a wide range of products. In fact, as explored by Masson et al., (2007), chaos risk is one of the common risks large companies face nowadays, together with financial risk and market risk. Chaos risk is due to complexity in the supply chain and results in holding wrong or too much stock. Supply chain complexity is composed by a lot of factors such as the number of players involved, the delivery paths, the degree of customization and the variety of knowledge (Masson, et al., 2007).

When dealing with global supply chains, a company should focus on two things: configuration and coordination (Er & MacCarthy, 2006). Therefore, even the scope of postponement strategies expands to have a global perspective, since its operations affect multiple geographies. Postponement enables to treat uncertainty provided by forecasts and complex supply chains as an opportunity and not just problems (Yang, et al., 2004b). The geographical perspective is naturally explored by companies operating globally, and this is already found in literature. For example, having Distribution Centers close to the final market and customers has consolidated in the last years as beneficial for local responsiveness (Yang, et al., 2004; Ferdows, 1997; Yang & Burns, 2003).

However, the concept of geographical postponement, i.e. focusing on the geographical place or regions where final configuration operations are held, has been formally introduced and explored by (Prataviera, et al., 2020).

The present study aims at further exploring the concept of geographical postponement for global supply chains.

SUSTAINABILITY

Since the end of the industrial revolution, the world's global output due to production and logistics activities has been growingly bad for the environment, and some argue humans are on a slope towards self-destruction (Loy & Tatham, 2016).

The results of human actions resulted in continuously increased global temperature and pollution levels. The problem lies in multiple sources like waste materials and carbon fossil fuels which, when they are burned, produce greenhouse gases. These gases, such as carbon dioxide and methane, create global warming by heating the atmosphere. The

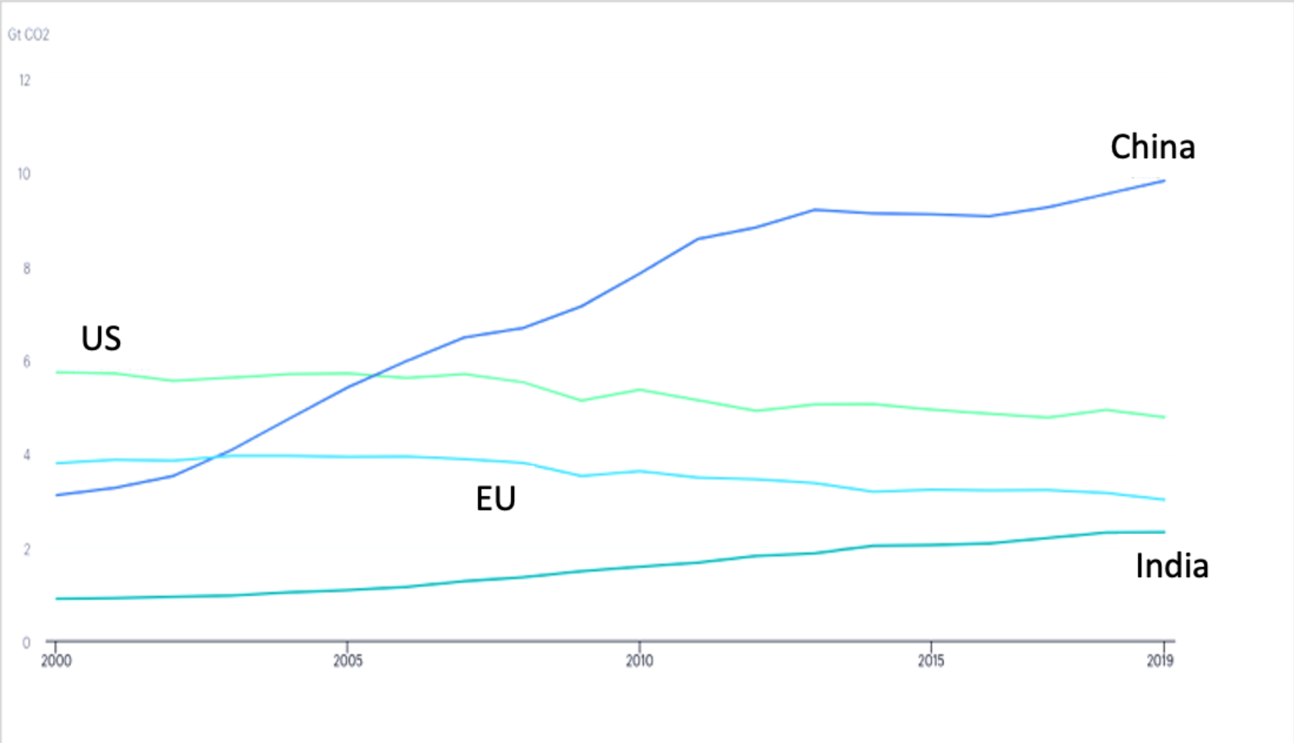


Figure 3: Emissions by carbon-based fuels combustion by country, 2000-2020. Source: IEA, 2020

resultant climate disruption causes extreme weather such as heat waves, flooding, blizzards, and droughts (the balance, 2020; Simão, et al., 2016). The growing environmental concerns, public pressure and environmental legislations have fueled a push toward sustainability in all industrial sectors, including logistics and supply chain activities (Simão, et al., 2016). Logistics activities in fact contribute to these issues and create several environmental impacts including increases in emissions related to climate change, eco-system quality, and human health (Ugarte, et al., 2016). Population, production and consumption activities are going to increase in the next decades, and so are logistics activities. These changes will have significant impacts on resource demand and environmental issues regarding supply chains (Simão, et al., 2016). According to (McKinsey & Company, 2012), companies have big and profitable opportunities to improve the resource usage efficiency, resulting in better environmental impact, throughout the supply chain. During the last decades, therefore, a general sense that environment impact of business strategies needs to be factored into decision taking grew (Yang, et al., 2005).

The sustainable development concept includes both environmental and social aspects and resulted for example in the Triple Bottom Line approach (TBL). TBL refers to the three 'E's that have to be factored in economic development: economy (economic growth), equity (social equity and inclusion), ecology (environmental protection) (Tseng, et al., 2018).

This resulted also in the Supply Chain Management area. If traditionally supply chain management dealt with material, money and men (3M), nowadays it has to be referred to as 3MeS, including also 'e' (environment) and 'S' (society, social inclusion), as suggested by (Mukherjee, 2016). The shift is not driven just by countries and institutions through regulations, but the opposite. Consumers are increasingly favoring environmentally friendly products thanks to the widespread of awareness about the issue and are for example increasingly sensitive to carbon emission information on products such as 'carbon labels' (He, et al., 2021). This was testified already by World Economic Forum (2009), according to which 67% of consumers in the UK were more likely to buy a low-carbon product.

Several forms of these environmental compliance came up: product certification and process certification. Product certification are carbon labels which are put on the product by firms and incentive the environmentally friendly consumer to buy their product. Process certification are certain standards which companies must obey to in order to do business in a particular sector. Just to give an example, ISO 14000 standard regulates the environmental management of business operations. The increased attention and concern regards sustainability along the whole life cycle of the product, including the design stage, transportation, usage, and disposal.

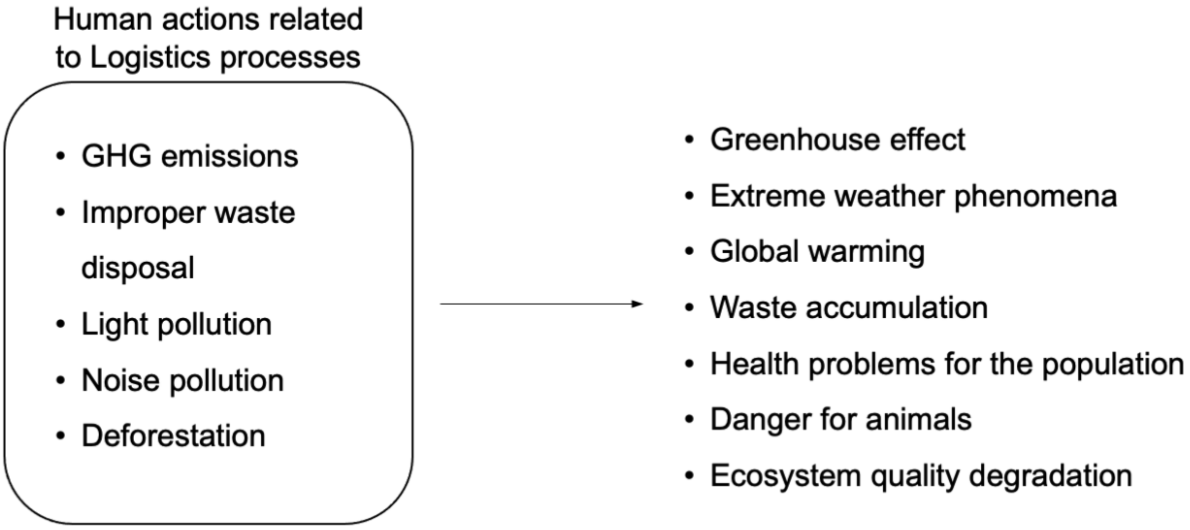


Figure 4: Negative externalities related to human actions in logistics processes (own elaboration)

In fact, reduction of GHG is not the only theme, since also waste management through reverse logistics can provide great benefits for the environment. When it comes to supply chain emissions, a large amount of them is related to transportation and logistics (Ugarte, et al., 2016). According to the World Economic Forum (2009) 5.5% of global CO2 output emissions are attributable to transportation and logistics, resulting in the staggering value of 2800 mega-tonnes each year. A more recent study by IEA (2020) instead concludes that more than 20% of world's global CO2 emissions area caused by transportation, and more than 70% of this is related to road transports.

Therefore, a key subject of study is GHG emissions caused by supply chains, both for the devastating effects they have and for the possibilities that logistics sector has to improve.

In fact, data from World Economic Forum (2009) shows the overall opportunity that industry in general has to reduce global greenhouse gas emission output through what is commonly referred to as green logistics or green supply chain management.

Green supply chain management is defined as “an integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the consumers as well as end-of-life management of the product after its useful life. This approach can reduce the ecological impact of industrial activity without sacrificing quality, cost, reliability, performance or energy use” (Simão, et al., 2016). In global corporations with dispersed supply chains, the environmental impact produced can be hard to monitor and subject to different legislations and agreements. Therefore, it is interesting to explore the geographical postponement implications for a sustainable supply chain, which is the second pillar of the present study.

RESEARCH METHODOLOGY OVERVIEW

Given the two main topics under investigation, this study explored if it is possible to study and compare postponement strategies under a geographical perspective in a structured way, and what are their relationship with sustainability.
Accordingly, the following research question has been formulated: what is the relationship between geographical postponement and sustainable supply chains?

As concerns the research methodology, two methods have been used.
First, a Systematic Literature Review (SLR) has been conducted, to understand the current state of knowledge related to the topic and to extract the most important constructs. Then, the concepts resulted from the SLR have been used to develop a survey, which has been sent to several companies to test in the real world what emerged from the literature, confronting publications with on-field experience.
The study is organized as follows: first, the SLR is presented, from the research process to the findings. Then, the survey design phase, data collection and results are proposed. Finally, the study ends with the author's discussion about the results obtained, their relevance and possible future research steps.

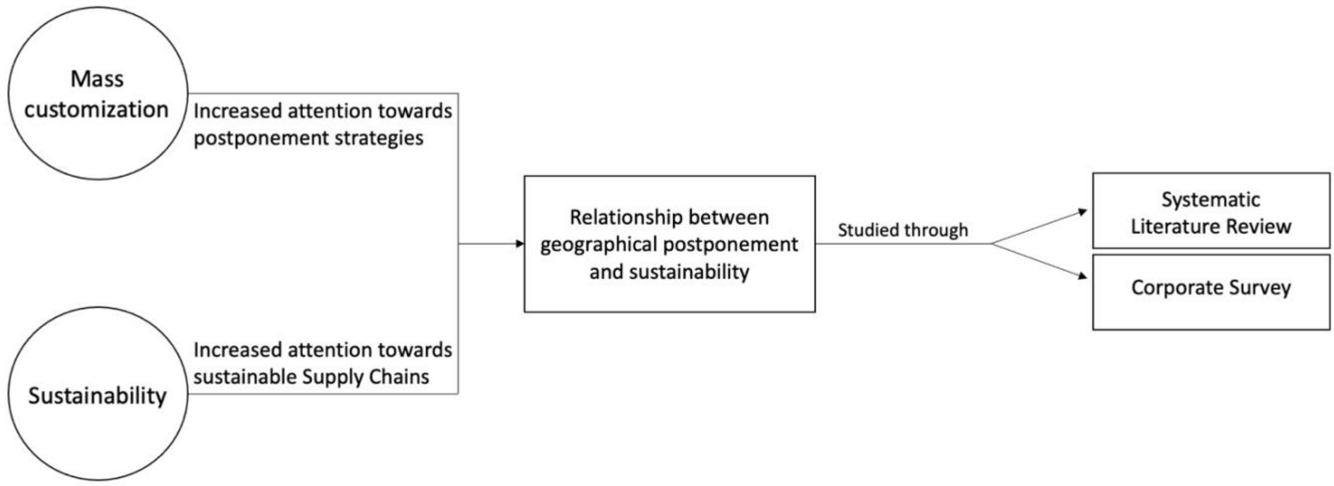


Figure 5: Study's themes and research methods

SYSTEMATIC LITERATURE REVIEW

RESEARCH METHODOLOGY

The conducted study followed a Systematic Literature Review method, as it is a key tool to manage all the knowledge under study and provide some future research areas (Tranfield, et al., 2003).

The Systematic Literature Review is a powerful tool to assess the existing knowledge about a particular topic as well as the gaps in research. SLRs differ from narrative reviews because they follow a scientific and transparent process, which is replicable and aims at minimizing bias (Tranfield, et al., 2003). SLRs became a standard in most recent years to transfer knowledge in a simple and structured format not only to researchers and academics, but also to practitioners, as a response to the increasing demand to have information in a rigorous way applicable in practice (Denyer & Tranfield, 2009; Craighead, et al., 2019).

The following framework has been used, as proposed by Tranfield et al. (2003) and Denyer & Tranfield (2009), later developed by Durach et al. (2017). The framework consists of six main steps:

1. Define the research question
2. Determine the required characteristics of primary studies
3. Retrieve a sample of potentially relevant literature
4. Select the pertinent literature
5. Synthesize the literature
6. Report the results

1 DEFINE THE RESEARCH QUESTIONS

The research question for the SLR follows the same approach of the overall study's goal, investigating if there is evidence in the academic literature of a way to study and compare postponement strategies under a geographical perspective with a structured framework. Consequently, the research question is the following: what is the relationship between geographical postponement and sustainability of supply chains?

2 DETERMINE THE REQUIRED CHARACTERISTICS OF PRIMARY STUDIES

The papers to study must have the following characteristics: first, they must treat postponement strategies, possibly with a geographical perspective. Second, they should include sustainability-related themes in logistics. Since it is a new and not well discussed theme, the research will not require to have papers treating both postponement under a geographical perspective and sustainability. Moreover, since postponement is usually associated with modularity, also papers discussing modularity for supply chain strategies will be included.

3 RETRIEVE A SAMPLE OF POTENTIALLY RELEVANT LITERATURE

In our case, once identified the research question, the first step was to identify the characteristics of the papers to look for. For this purpose, some pilot publications have been identified based on the required characteristics. Such publications have been carefully read to verify the alignment with the topic. Moreover, they helped to identify the first keywords, which were used to select other papers to expand and refine the keywords selection. It was decided to divide the keywords to use in three groups, each one referring to an area under study, to ensure selecting only literature dealing with the topic. The three groups are:

- Group A: area related to logistics, and Supply Chains in particular. For this purpose, keywords as “logistics”, “supply chain”, “distribution”, “global”, “strategy” have been chosen.
- Group B: area related to postponement specifically. For this purpose, keywords as “postponement” or “modularization” have been chosen.
- Group C: area related to sustainability. For this purpose, keywords as “sustainability”, “green”, “environment”, “emissions”, “carbon” have been chosen.

The online database Scopus was used to collect all relevant papers, since it is one of the most complete available online. This was to ensure no papers were missed. The keywords were combined with different Boolean operators (AND, OR), and applied considering the possibility to be found in other forms (“supply chai*” was used instead of simply “supply chain” for example). The importance was given to the presence of all three groups in the keyword combination, to ensure having papers on the postponement-sustainability relationship.

Keywords combination	# papers
postponement AND (sustainability OR green OR environment OR emissio* OR carbon) AND (logistics OR "supply chai*" OR distribution OR global)	3067
(postponement OR (geographic* AND differentiation)) AND (sustainability OR green OR environmen* OR emissio* OR carbon) AND (logistics OR (supply AND chai*) OR network OR distribution)	2454
(postponement OR (modular AND product*)) AND (sustainab* OR green OR environmen* OR emissio*) AND (logistics OR "supply chai*" OR distribution OR global OR strategy)	1323
postponement AND (logistic* OR (supply AND chai*) OR global OR downstream OR strateg* OR distribution)	1202
postponement AND (logistic* OR (supply AND chai*) OR global OR strateg* OR distribution)	1188
(postponement OR customization) AND (sustainability OR green OR environmen* OR emissio* OR carbon) AND (logistics OR (supply AND chai*) OR network OR distribution)	1184
(postponement OR modulari?ation) AND (sustainab* OR green OR environmen* OR emissio*) AND (logistics OR "supply chai*" OR distribution OR global OR strategy)	418
(postponement OR modulari?ation) AND (sustainab* OR green OR environmen* OR emissio*) AND (logistics OR "supply chai*" OR distribution OR global)	259
(postponement OR postponed) AND (sustainability OR green OR environment OR emissio*) AND (logistics OR (supply AND chai*) OR distribution OR global)	225
postponement AND (sustainability OR green OR environment OR emissio* OR efficien*) AND (logistics OR (supply AND chai*) OR distribution OR global OR international OR trade)	201
postponement AND (sustainab* OR green OR environmen* OR emissio*) AND (logistics OR "supply chai*" OR distribution OR global OR strategy)	179
postponement AND (sustainability OR green OR environment OR emissio* OR efficien*) AND (logistics OR (supply AND chai*) OR distribution OR global OR trade)	178
postponement AND (sustainab* OR green OR environmen* OR emissio*) AND (logistics OR "supply chai*" OR distribution OR global OR operations)	145
postponement AND (sustainab* OR green OR environmen* OR emissio*) AND (logistics OR "supply chai*" OR distribution OR global)	125
postponement AND logistics AND ((supply AND chai*) OR global OR sustainability OR distribution OR environment OR emissio*)	111
postponement AND (sustainab* OR green OR environment OR emissio*) AND (logistics OR (supply AND chai*) OR distribution OR global)	104
postponement AND (sustainab* OR green OR environment OR emissio*) AND (logistics OR "supply chai*" OR distribution OR global)	102
postponement AND (sustainability OR green OR environment OR emissio*) AND (logistics OR (supply AND chai*) OR distribution OR global)	96
postponement AND (sustainability OR green OR environment OR emissio*) AND (logistics OR (supply AND chai*))	62
postponement AND (sustainability OR green OR environment OR emissio*) AND (logistics OR (supply AND chai*)) AND (distribution OR global OR manufacturing OR tarif* OR dut*)	24
postponement AND sustainability AND (green OR environment OR emissio*) AND (logistics OR (supply AND chai*) OR distribution OR global)	4
postponement AND (sustainability OR green) AND (environment OR emissio* OR Co2 OR carbon) AND (logistics OR (supply AND chai*)) AND (distribution OR global OR manufacturing OR tarif* OR dut*)	4

Table 1: Keywords selection

4 SELECT THE PERTINENT LITERATURE

Several tests have been done before deciding the actual sample of papers to be kept. In total, 22 different combinations of keywords were analyzed, returning samples ranging from 3067 to 4 articles. The keywords “modulari?ation” and “strategy” added a lot of articles, but the latter returned components apparently not about postponement related to sustainability. For this reason, it was kept out. Modularity of product, instead, seems to be strongly related to postponement strategies. The selected combination of keywords, providing a good tradeoff between quantity and relevance of articles, is:

(postponement OR modulari?ation) AND (sustainab* OR green OR environmen* OR emissio*) AND (logistics OR "supply chai*" OR distribution OR global)

This search led to a sample of 259 relevant papers.

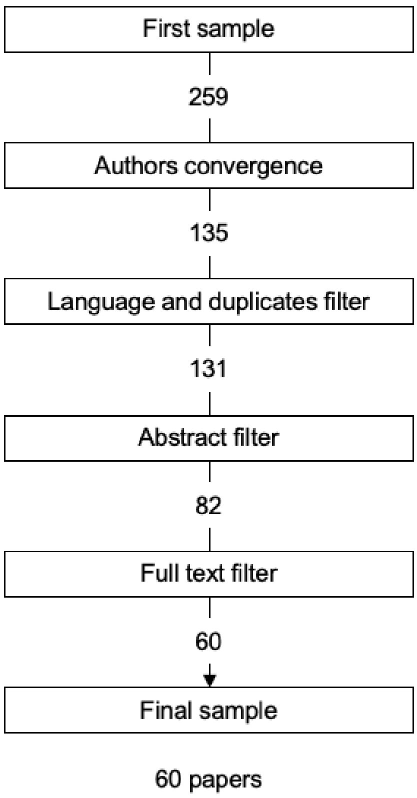


Figure 6: Articles filtering process

When conducting a SLR is a common practice to have all articles filtered by their titles by two or more authors. In this study, all titles of the sample were analyzed by the author and the co-supervisor of the thesis separately, to have a first convergence on the papers to be kept and the ones out of topic. This phase led to 135 articles remaining, therefore 48% of papers were discarded. The main reasons for this reduction of the sample size are related to the use of the keyword “environment” not in a sustainability-oriented way but just as a space, and of the keyword “postponement” not as a logistics strategy but as mere delaying in time of some decisions. Out of the 135 articles, it was decided to keep just the ones written in English, leading to sample of 131. All duplicates were eliminated with a search by title. At this point all abstracts were carefully read to get the main idea about the article, discarding the off-topic contributions and leading to a sample of 82 papers. Of these, 12 were not accessible nor found in any online platform. All the remaining articles were carefully read by the author, and cross-referencing was then applied. All chosen articles have been taken from important academic journals or international conferences, under the theme of Logistics, Operations or Supply Chain Management. Other 10 papers were eliminated because not on point or too broad, and two publications were added from cross-referencing, leading to a final sample composed by 60 relevant publications.

5 SYNTHESIZE THE LITERATURE: DESCRIPTIVE ANALYSIS OF THE IDENTIFIED PUBLICATIONS

TEMPORAL DISTRIBUTION

The temporal distribution trend of the selected papers is shown in Figure 7. The time span under investigation was not restricted. However, the first relevant paper retrieved to this study’s purpose was published in 2000, thereby showing that the relationship between postponement and sustainability is a relatively young research field. The selected articles were published between 2000 and 2020, with 32 publications (53%) between 2000 and 2013, and 22 (36%) only in the last five years, with a peak at 8 articles in 2016. The trend shows an increasing interest about this topic in the most recent years, and the peak could be related to a general increase in awareness about sustainability after the signing of the climate Paris Agreements in 2015. Moreover, this could be related to a broader attention towards the integration of sustainable practices in normal logistics and planning activities. Sustainability can present a strategic goal to achieve competitive advantage nowadays (Mukherjee, 2016), therefore companies are increasingly looking for new strategies and solutions to implement.

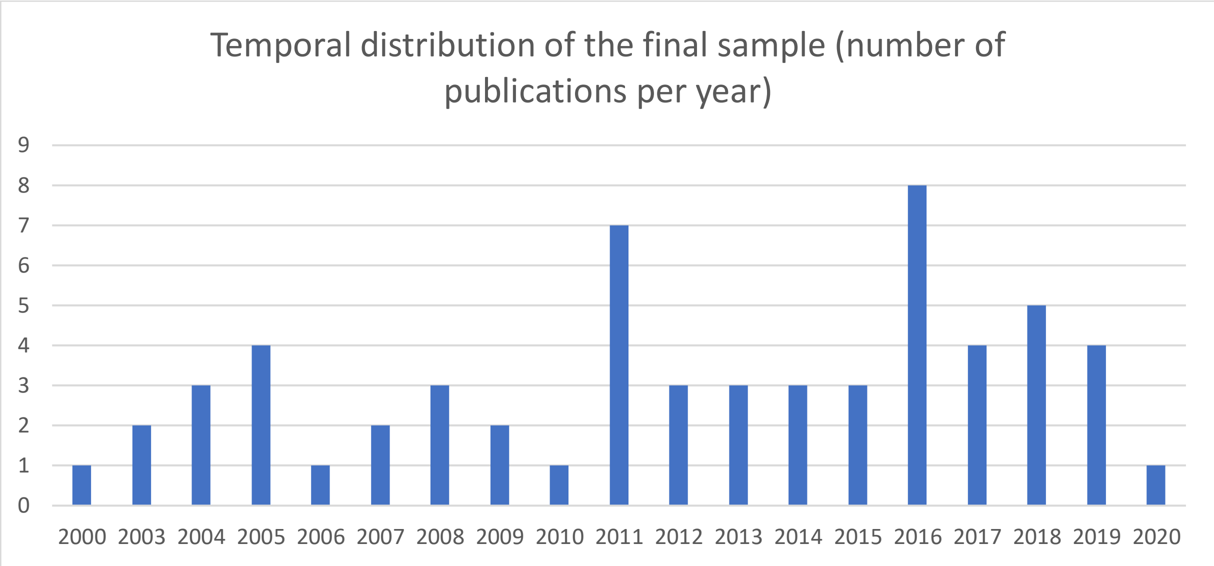


Figure 7: Temporal distribution of the final sample

PUBLICATION SOURCES

The 60 publications come from a huge variety of different journals and conferences. More in detail, the articles were published in 49 different sources and only a few, well-known journals, published more than one study. Of all articles, 44 came from scientific journals (73%) and 16 from conferences, congresses, or forums (27%). These journals focus on logistics, advanced manufacturing, operations, management sciences or supply chain management. As said, most journals and conferences have just one representative of the sample. The only sources with more than one publication are Computers and Industrial Engineering (2), IFIP Advances in Information and Communication Technology (3), International Journal of Operations and Production Management (2), International Journal of Production Economics (2), International Journal of Production Research (4), International Journal of Technology Management (2), Journal of Business Logistics (2), The International Journal of Logistics Management (2).

GEOGRAPHICAL DISTRIBUTION

Table 2 shows the country of publication of selected papers, to represent the geographical distribution of all studies. Where not available, the country of the author's institution has been selected. It is possible to notice that the total is larger than the sample size. This is

Country	# articles
United Kingdom	12
USA	8
Germany	7
Taiwan	7
China	6
Italy	4
Sweden	3
India	3
Netherlands	3
Denmark	2
France	2
Canada	2
Brazil	2
Pakistan	1
Mexico	1
Singapore	1
Korea	1
Singapore	1
Switzerland	1
New Zealand	1
Portugal	1
Chile	1
Australia	1
Spain	1
Iran	1
Saudi Arabia	1
Indonesia	1
Tot	75

Table 2: Geographical distribution of articles

due to the fact that fifteen publications are co-authored by researchers coming from different countries, in which case all nationalities are included.
Publications come from 27 different countries spread all over the world. Just 9 countries (30%) are present more than 2 times and together contributed to more than the 70% of all publications. The majority of publications came from developed countries (UK, USA, Germany, Italy) or regions where manufacturing or supply chain activities are particularly important (China, Taiwan, The Netherlands).

RESEARCH METHODOLOGIES

Publications were divided based on their research methodology and summarized in table 3. It was decided to categorize them in the following areas, using and expanding the definitions developed by Staudt et al. (2015).

- Conceptual paper: exploring a specific topic making conceptual distinctions, developing a framework or a theory, SLRs, no practical application, following the definition found in Bartolini et al. (2019) and Staudt et al. (2015). Such articles are great sources to contextualize a concept but do not provide empirical evidences or applications to support a rigorous analysis;
- Case study paper: investigating a particular topic and explore its usage in a real-life example. As proposed by Yin (2014), a case study research is an 'empirical inquiry that investigates a contemporary phenomenon in depth and within its real-world context'. Such research methodology is based on readability, credibility and concern with confirmability. Creating a good case study is a linear but iterative process, which is composed by the following steps: plan, design, preparation, data collection, analysis and reporting;
- Mathematical model paper: encompassing analytical studies with numerical examples, and developing mathematical models, heuristic methods, or optimization processes, following the definition found in Bartolini et al. (2019) and Staudt et al. (2015). Such methodologies provide empirical evidences and results of application, be them real-world based or simulated;

- Survey paper: development of a widespread study using a survey, summary, and analysis of responses. This is becoming one of the most used methods in scientific research since it enables to reach potentially a huge audience, and therefore validate statistically the results. Surveys requires strong effort in the preparation phase and in the pilot testing phase, to ensure that all questions are easily understandable and centered on the research topic (Bartolini, et al., 2019; Staudt, et al., 2015).

Conceptual examinations and discussions are present in 26 publications (43%), making it the most used tool. 22 researches developed and used an analytical model (mathematical, heuristic, optimization process etc), the 37%. 8 case studies and 4 surveys were also present.

Type of paper	# articles	%
Case study	8	13
Conceptual	26	43
Mathematical model	22	37
Survey	4	7

Table 3: Research methodologies

Reference paper	Temporal postponement	Geographical perspective	Sustainability	Modularity of products	Methodology
(Prataviera, et al., 2020)	x	x			Conceptual
(Ulrich, et al., 2019)			x	x	Conceptual
(Budiman & Rau, 2019)	x	x	x		Mathematical model
(Jabbarzadeh, et al., 2019)	x		x		Mathematical model
(Graessler & Yang, 2019)				x	Conceptual
(Carbonara & Pellegrino, 2018	x				Mathematical model
(Yu, et al., 2018)	x			x	Conceptual
(Sonego, et al., 2018)			x	x	Conceptual
(van Zeller, et al., 2018)			x		Mathematical model
(Christensen, et al., 2018)				x	Conceptual
(Fan, et al., 2017)		x			Mathematical model
(de Keizer, et al., 2017)	x	x			Mathematical model
(Li & Liu, 2017)	x				Mathematical model
(Ballarino, et al., 2017)			x		Conceptual
(Calle, et al., 2016)	x				Conceptual
(Gorane & Kant, 2016)	x		x		Survey
(Bonvoisin, et al., 2016)			x	x	Conceptual
(Ugarte, et al., 2016)	x		x		Mathematical model
(Simão, et al., 2016)	x		x		Mathematical model
(Mukherjee, 2016)	x	x	x		Mathematical model
(Carbonara, et al., 2016)	x				Mathematical model
(Loy & Tatham, 2016)	x		x		Conceptual
(Jeong, et al., 2015)			x	x	Conceptual
(Tan & Goh, 2015)	x	x			Mathematical model
(Shabah, 2015)	x			x	Conceptual
(Wikner, 2014)	x				Conceptual
(Chou, et al., 2014)	x				Mathematical model
(Shi, 2014)	x				Conceptual
(Kremer, et al., 2013)			x	x	Mathematical model
(Philip, et al., 2013)	x		x	x	Mathematical model
(Parry & Roehrich, 2013)				x	Conceptual
(Chang, 2012)	x				Mathematical model
(Guericke, et al., 2012)	x	x			Mathematical model
(Yoo, et al., 2012)				x	Mathematical model
(Baker, 2011)	x				Mathematical model
(Gumpinger & Krause, 2011)				x	Conceptual
(Khan, et al., 2011)	x		x		Mathematical model
(Zheng & Mesghouni, 2011)	x				Mathematical model
(Wong, et al., 2011)	x				Case study
(Su & Chuang, 2011)	x			x	Conceptual
(Abukhader & Jonson, 2011)					Survey
(Wang, 2010)	x				Conceptual
(Huang & Li, 2009)	x				Survey
(LeBlanc, et al., 2009)	x	x			Case study
(Wadhwa, et al., 2008)	x				Conceptual
(Huang & Li, 2008)	x			x	Conceptual
(Harrison & Skipworth, 2008)	x				Case study
(Masson, et al., 2007)	x				Case study
(Huang & Liang, 2007)	x				Conceptual
(Er & MacCarthy, 2006)	x				Conceptual
(Yang, et al., 2005)	x		x		Conceptual
(Prasad, et al., 2005)	x				Mathematical model
(Yang, et al., 2005b)	x				Survey
(Fixson, et al., 2005)				x	Case study
(Yang, et al., 2004)	x				Conceptual
(Yang, et al., 2004b)	x				Conceptual
(Abukhader & Jönson, 2004)	x		x		Conceptual
(Doran & Roome, 2003)				x	Case study
(Doran, 2003)				x	Case study
(Villareal, et al., 2000)	x				Case study

Table 4: Overview of selected papers

OVERVIEW OF SELECTED PAPERS

Table 4 shows the overview of selected papers, highlighting the main topics covered in the studies. It is possible to observe that sustainability is not a widespread theme, making it a relevant field of study. Moreover, it should be noticed that there are few publications which treat both postponement introducing a geographical perspective and the sustainability theme. In such studies, however, the geographical perspective on postponement is introduced merely as a factor, more or less relevant, to consider and is not the focal point of the logistics strategy, nor articulated in a structured and rigorous way. The present study wants to be the first one to treat geographical postponement and sustainability of supply chains in a structured way at the same time, including also the implications brought by modular products.

6 REPORT THE RESULTS

The SLR's results are deeply analyzed and proposed in a structured way in the 'Findings' section of the research.

FINDINGS

All publications have been divided into ten macro-themes and the following sections of the SLR are articulated as follows:

Rationale	Section	Content
Contextualization	1	Strategies introduction
	2	Factors to consider for strategies application
	3	Strategies comparison, traditional view
Vertical expansion	4	Modularity (upstream development)
	5	Reverse logistics (downstream development)
Horizontal expansion	6	Triple Bottom Line approach
	7	Sustainability- related factors to consider for strategies application
	8	Environmentally Conscious Design and Manufacturing
	9	Strategies comparison with expanded view
Further developments	10	Future trends for geographical postponement

Figure 8: Findings' presentation structure

In the first section, the geographical postponement concept is defined. Moreover, the framework developed by Prataviera et al. (2020), later adopted extensively in this study, is presented to discuss the main geographical postponement strategies.

In the second section, traditional factors enabling and impacting a geographical postponement strategy implementation are presented and examined.

In the third section, different geographical postponement strategies are compared from a traditional, profitability-based point of view.

In the fourth section, the implications between modular products and geographical postponement strategies are discussed. Modularity represents the development upstream for postponed supply chains.

In the fifth section, possible connections between geographical postponement strategies and reverse logistics are examined. Reverse logistics represents the development downstream for postponed supply chains.

In the sixth section, the sustainability theme is introduced and further discussed. Reasons and importance to introduce a sustainable point of view in the discussion for geographical postponement strategis are presented in details.

In the seventh section, sustainability-related factors enabling and impacting a geographical postponement strategy implementation are presented and examined.

In the eight section, the relationship between ECDM (Environmentally Conscious Design and Manufacturing) and geographical postponement is explored. ECDM represents the development both upstream and downstream for sustainable supply chains with postponement strategies, since it includes the whole life cycle of the product in its implementation.

In the ninth section, different geographical postponement strategies are compared including both economic and sustainable concern.

In the tenth section, future trends for geographical postponed supply chains are presented and discussed. In particular, the focus has been on the impact of digitalization in supply chains, 3D Printing and e-commerce.

GEOGRAPHICAL POSTPONEMENT OVERVIEW

The concept of geographical postponement was structured by Prataviera et al. (2020), introducing a practical and conceptual framework to deal with the spatial perspective of postponement strategy. However, the importance of the spatial perspective, i.e. of "where" the customization takes place, is not new to the literature. Van Hoek (1996) already discussed as placing some logistics operations geographically closer to customers could be beneficial for global, vertically integrated companies aiming to reach the "glocalisation" later developed by Yang et al. (2004). This concept is also reflected in the publications under study. Huang & Liang (2007) introduce the place where the customization takes place as a variable in their model. Yang et al. (2004) integrated the concept by Ferdows (1997) by which Distribution Centers geographically close to customers could be selected to better serve responsiveness-driven demand. The spatial perspective is already regarded as an important factor, even more in the last decades considering that the world is increasingly moving towards a phenomenon of borderless consumption, speed up also by new trends like the rise of e-commerce, and also towards 'borderless manufacturing' (Chou, et al., 2014). Competition, and modern-day competitive advantage, lies in supply chain networks more than between companies for large multinationals operating in dispersed geographies (Budiman & Rau, 2019). As explored by Ugarte et al. (2016), such companies spread their facilities across various regions to achieve better market segment coverage. In this environment, warehouses play a key, strategic, role and can be themselves sources for competitive advantage. They are a significant portion of logistics cost, up to 20% for the buildings and another 19% for the inventory within them (Baker, 2011). As stated by Tan & Goh (2015) the location of Distribution Centers, especially if in charge of performing final customization activities, is critical and can enable to better react to a shift in demand. This concept is taken also by Huang & Li (2009), who included the location of the warehouse as a determinant for postponement application in order to achieve faster processes under strong demand uncertainty. It's a normal business behavior to locate production and/or customization as close as possible to customers. For example, Gillette created a new European packaging and Distribution Center reconfiguring and assembling unpackaged razor blades to create over 1000 different variations for the European market, enabling to satisfy individual customer's needs (Yang, et al., 2005, Yang & Burns, 2003).

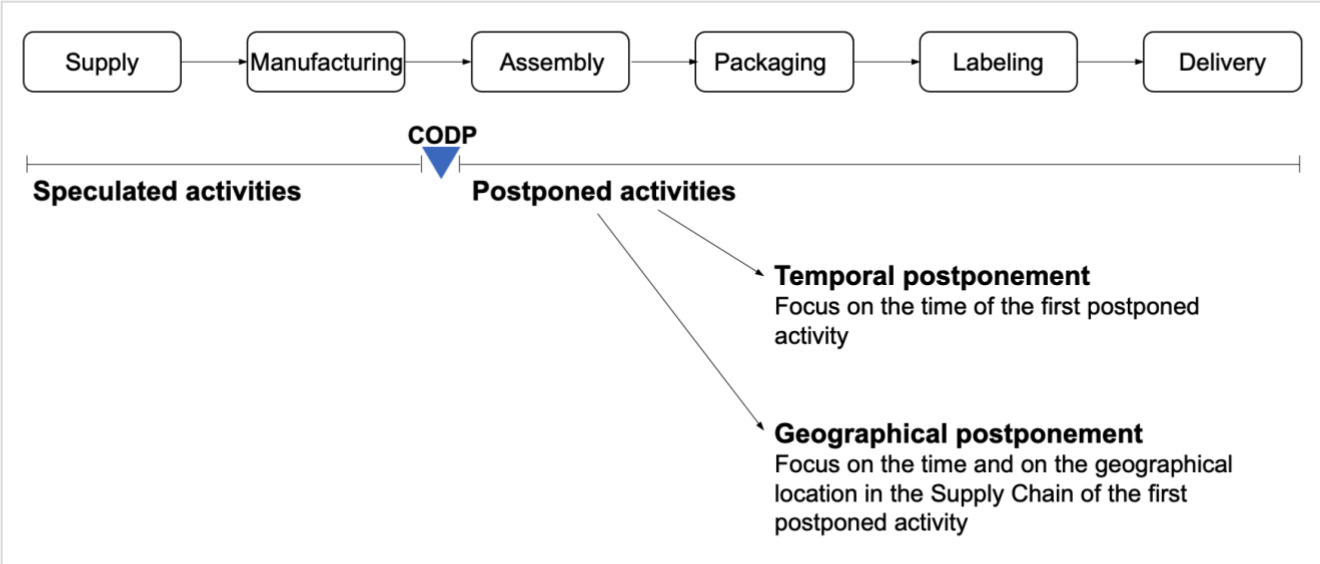


Figure 9: Temporal and geographical postponement approaches

Geography and physical distances are, and will continue to be, important for the manufacturing and distribution sector where physical objects need to be transported. This is even found at a higher level. Today, countries' market and distribution's competitions is played in the geopolitics field and world's giants know that they have to invest heavily on infrastructures and "bases" in foreign markets. China, the world's biggest exporter, is spending about 1.2 – 1.3 trillion dollars on the Belt and Road Initiative (Morgan Stanley, 2018), and strategically acquiring a lot of ports in importantly-located places such as Djibouti and Greece (The Diplomat, 2019).

GEOGRAPHICAL POSTPONEMENT STRATEGIES

The work by Prataviera et al. (2020), however, structured this location decision in a conceptual framework that can be used for managerial choices. It consists of a two-steps classification: in the first, they developed a two-axis framework and identified twelve different possible geographical postponement strategies for global downstream logistics, based on "where" and "what" customization operations are performed. In the second step, they introduced the dimension of "when" an operation is performed, meaning before or after the customer order, investigating each strategy individually.

In the first step, they identified 12 different possible postponement strategies for downstream supply chains, classifying them with a two-axis diagram.

The x-axis refers to "where" the customization operation takes place, while the y-axis refers to "what" operation is performed in each region.
For the x-axis (i.e. in which region the operation takes place) they identified three possibilities:

1. Home region: this is the region where the main production plant is. In fact, postponement can be performed in this region directly in the production facility (or another one inside the same region) and the finished product delivered downstream later, after receiving the customer order. The traditional 'temporal' postponement falls under this classification.

2. Third-country region: this is a region which is neither the main factory's one, neither the final customer's one. This decision could be really valuable for all companies looking for fiscal optimization as a source of advantage. The postponed customization operations would be, in this case, developed in a facility in the third-country, ready to be shipped to the final market's Distribution Center after receiving the customer order. This country could also serve as major Distribution Center for more final markets.

3. Destination region: this is the region where the final market is located. In this case products are delivered internationally in semi-finished form from the main production plant in the home country to the Distribution Center, where the customization operations take place. This strategy aims at achieving the higher responsiveness, locating inventories closer to the market.

The term 'region', in this study, can refer to single countries or bigger areas up to Free Trade Areas (FTA).
A FTA is "a grouping of countries within which tariffs and non-tariff trade barriers between the members are generally abolished but with no common trade policy toward non-members" (OECD, 2001). FTAS are, therefore, economic regions whose members have no tariffs between, but different tariffs with external countries. For example, USMCA Agreement between US, Mexico and Canada forms a FTA. The decision to not limit the term 'region' just to single countries has been made, following Prataviera et al. (2020), considering that taxes, duties, and TP (Transfer Pricings), common to all countries belonging to FTAs, are today a primary factor in the decision of location of facilities (Mukherjee, 2016; Yang, et al., 2004; Fernandes, et al., 2015).

As for the y-axis, they referred to all downstream operations that can be performed. The traditional concept of postponement just for assembling was expanded by Zinn & Bowersox (1988), including all operations up to the final distribution.
Therefore, they divided the “what” in the four categories:

1. Assembly
2. Packaging
3. Labeling
4. Final distribution

This first step led to 12 different geographical postponement strategies being identified (as in figure 10), crossing regions with operations. In the first step, the vertical axis (“what”) referred to the first activity to be postponed, while all previous operations are done in the home region.

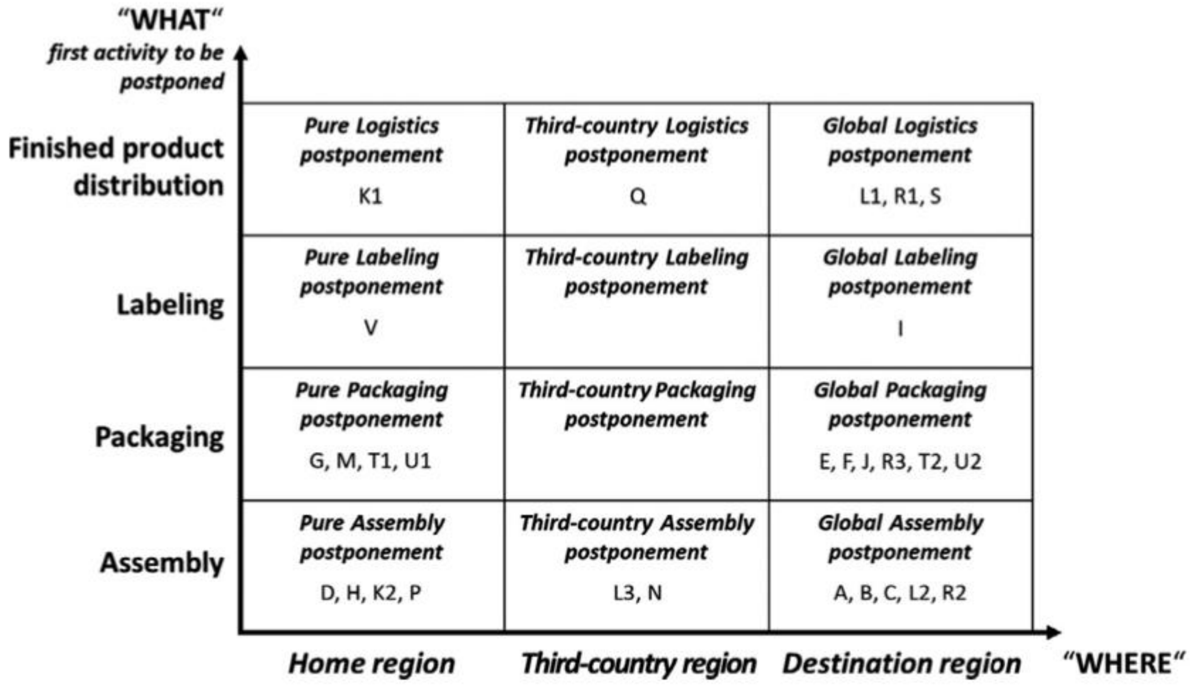


Figure 10: Geographical postponement strategies (taken from Prataviera et al., 2020)

The spatial perspective led the division in three main categories:

1. “Pure postponement” strategies: in this case customization operations take place in the home region, where the main production is located. This refers to the traditional concept of postponement, with all operations done in the same region (in the production facility, or in a DC within the same region), and therefore only temporal postponement can be done.

2. “Third-country postponement” strategies: products are shipped in semi-finished good form to a third-country, where the first postponed activity takes place.

3. “Global postponement” strategies: the semi-finished goods are delivered from the home country to the destination region, where the first postponed operation and eventually other manufacturing/assembly processes are carried out.

The following figures 11, 12 and 13 show the representation of an example of pure postponement, third-country postponement and global postponement strategies respectively, applied to an imaginary Supply Chain with main manufacturing facility in China aiming to serve the German market.

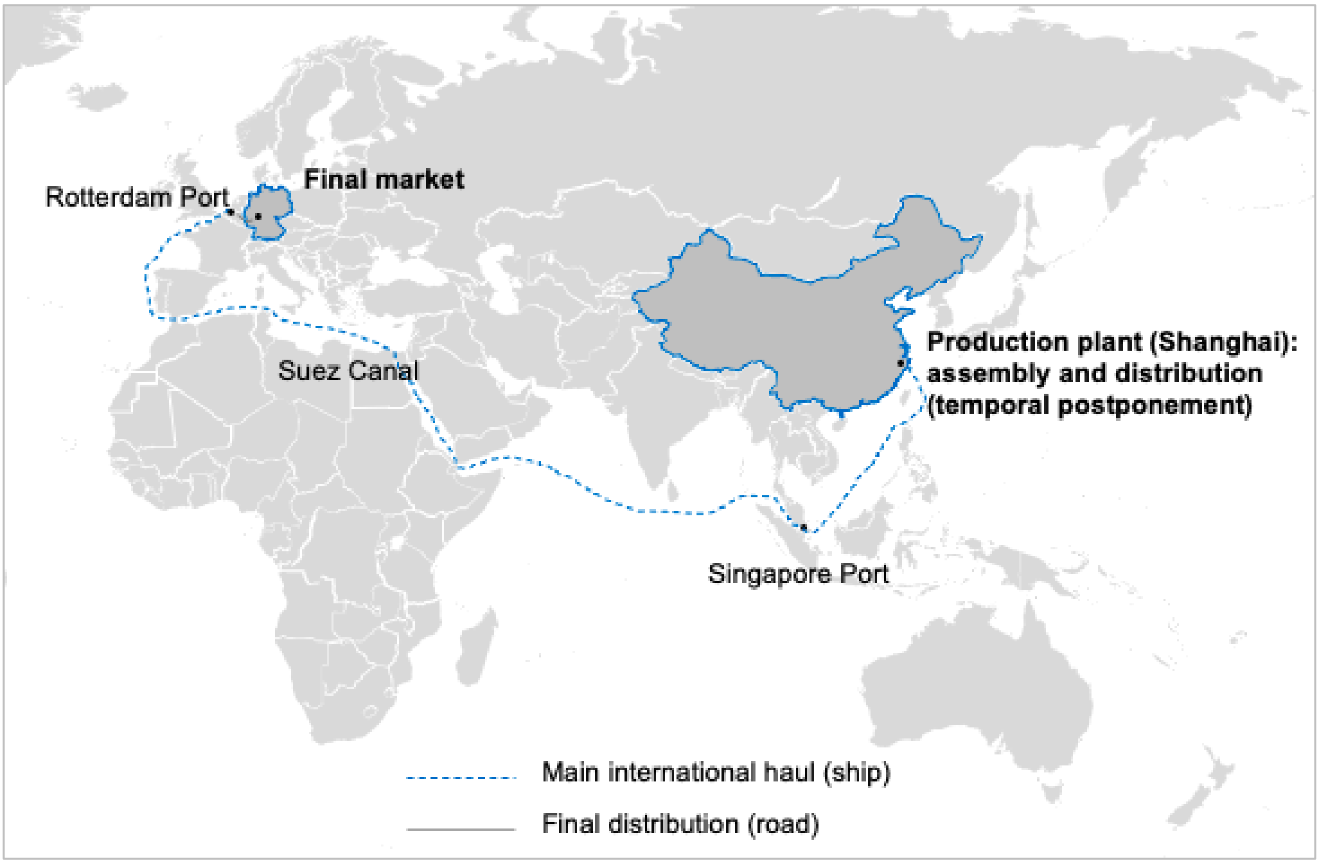


Figure 11: Pure postponement strategy example (own elaboration)

In the pure postponement strategy, all customization operations are performed in the main production plant in China, the home region. Therefore, this case constitutes a temporal postponement. From China, finished and packed products are directly shipped to the final market, which is Germany, through the main route connecting Asia and Europe via the Suez Canal. After a long international haul via ship, the product enters Europe and follows a final part of transport through road to reach the retailer or the final customer.

In the third-country postponement strategy, the supply chain has the same main production plant and final market, but exploits a downstream Distribution Center in Romania where customization operations take place. Products are, therefore, shipped from China to the Distribution Center in a less finished form. There, customization operations are performed ('what' operation is carried out is factored in and determines the actual geographical postponement strategy implemented), and the products are finally distributed to the final market.

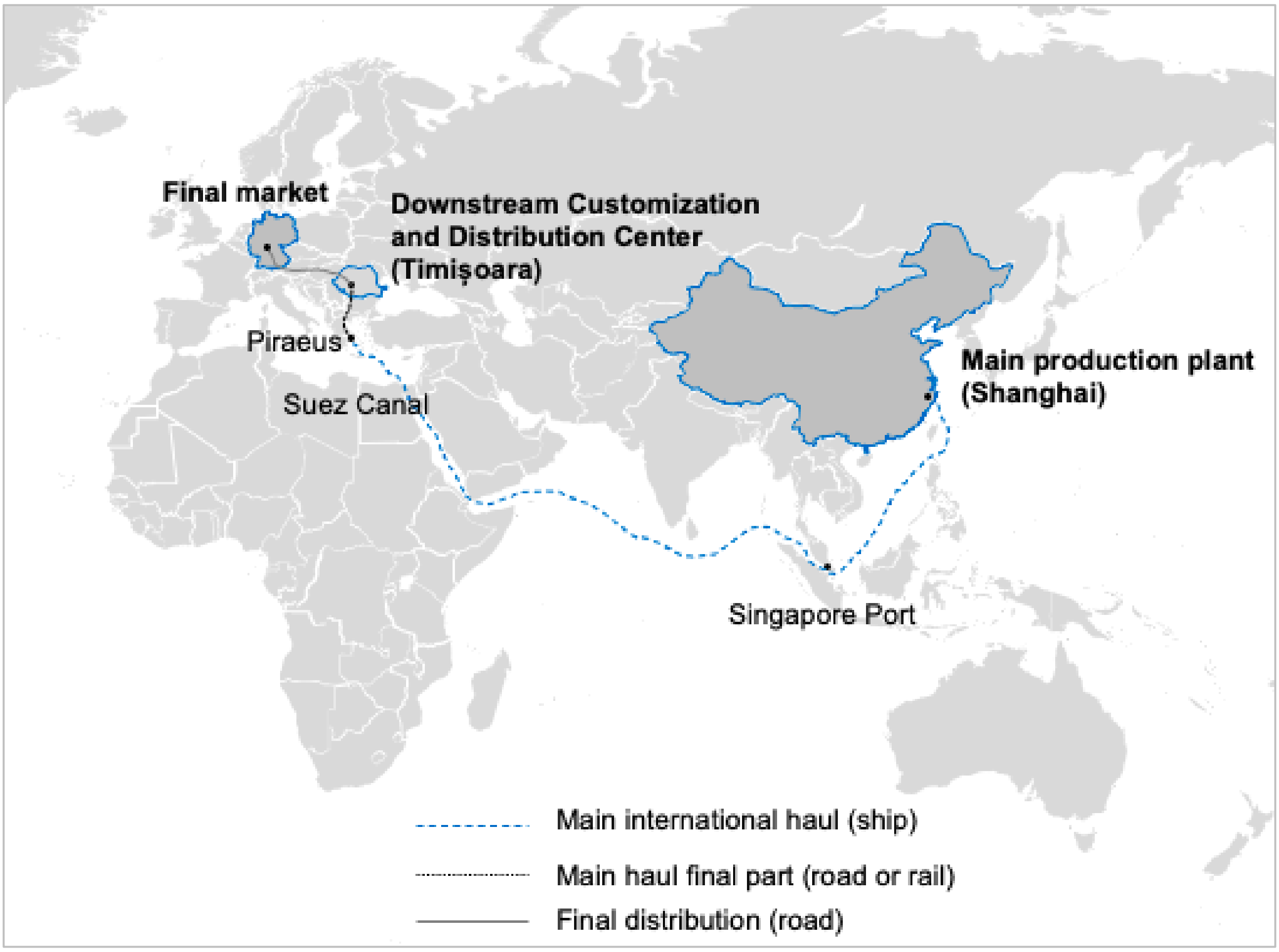


Figure 12: Third-country postponement strategy example (own elaboration)

In the global postponement strategy, the downstream Distribution Center performing customization operations is located in the final market, Germany. Therefore, products are shipped in a less finished form from China to Germany, where they undergo customization operations and are distributed to the customers.

In their study, Prataviera et al., (2020) verified the robustness of their framework applying it to 28 business cases taken from the literature, finding 10 out of 12 strategies applied to real cases. Therefore, the conceptual framework is valid and will be applied to classify some of the selected publications.

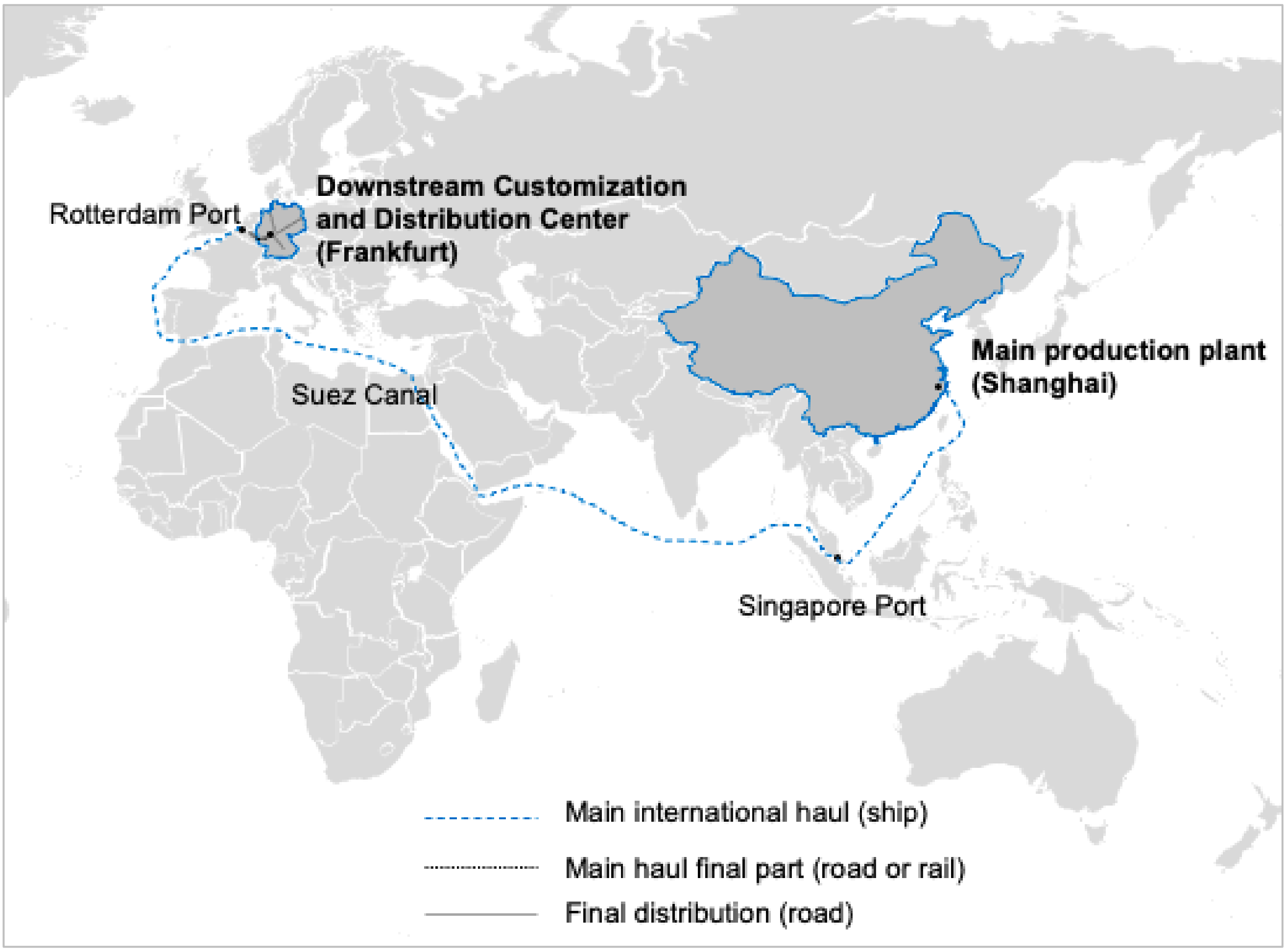


Figure 13: Global postponement strategy example (own elaboration)

In the second step, they highlighted the spatial perspective of each single downstream operation (manufacturing and distribution), expanding the framework studying each strategy separately, and introducing for this purpose a time perspective. Based on van Hoek (1997), they divided operations taking place before or after CODP (Customer Order Decoupling Point), which separates forecast-driven activities and demand-driven activities. In this way, the vertical axis refers to all downstream operations and doesn't points out just the first one to be postponed. Spatial and temporal dimensions are not necessarily connected, and therefore the same strategy can refer to different positions of the CODP.

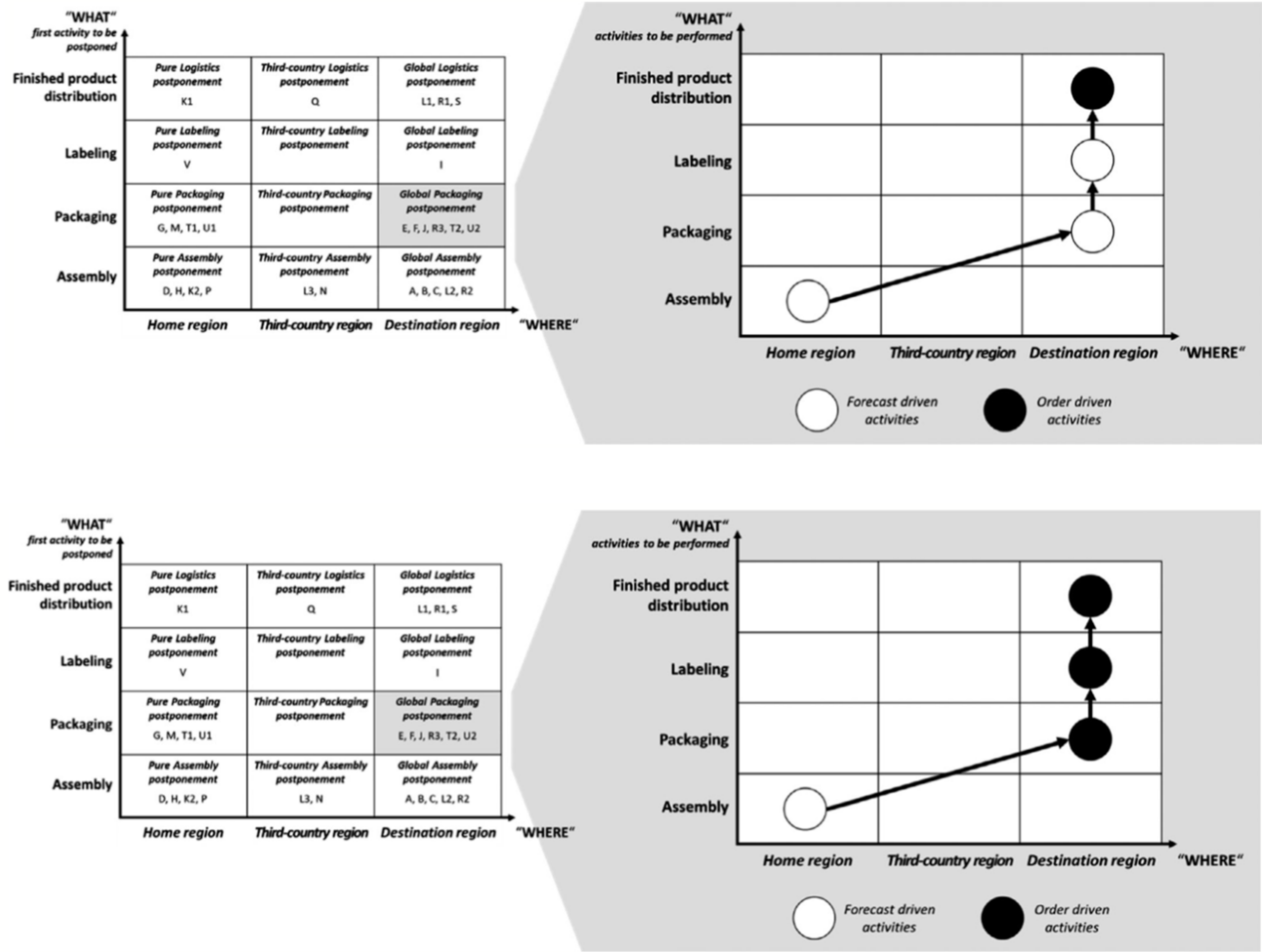


Figure 14: Different CODP positioning for the same geographical postponement strategy (taken from Prataviera et al., 2020)

As it's possible to see in figure 14, a specific strategy can differ in terms of CODP placing when introducing a temporal dimension. This is graphically highlighted with black and white circles, identifying activities performed after and before receiving customer order respectively. In the first example, based on Polaroid's real case, packaging is the first activity to be performed in the destination region as well as the first to be postponed. Assembled products are shipped from the home region to the destination region, where they are packed only after receiving the customer order and then labeled and distributed to the local market. In the second example, based on BT Health Care case study, the company ships assembled products from home (US) to destination (Europe) region as well, but once in European DC the products are packed and labeled based on forecasts, and distributed only after receiving customer order.

As said, even if the importance of the spatial perspective in postponement strategies is found in the literature, the study by Prataviera et al. (2020) introduced a new, reliable and replicable framework to assess and study different global downstream strategies when regarding supply chain management under postponement decisions.

For these reasons, the proposed framework will be used to categorize and collocate each relevant case study found in the literature. Moreover, to integrate the temporal perspective and the geographical one, the following approach will be utilized: all case studies addressing a traditional, temporal perspective on postponement (delay just in time of some operations), in which all operations from manufacturing to distribution are carried out in just one country (or FTA), will fall in the category of 'pure geographical postponement'.

Conceptually, temporal postponement is suitable also for 'global geographical postponement' classification in the cases where home region and destination region are the same. In fact, the country where the primary manufacturing takes places could be the final market as well. Since this study aims to focus on global supply chains, however, temporal postponement will be categorized as 'pure geographical postponemement.

DRIVERS FOR GEOGRAPHICAL POSTPONEMENT

In an ideal case, a company could produce exactly what is needed at the time it is needed. However, this is not the reality since forecasts errors will always remain (Wadhwa, et al., 2008). Postponement works as an effective tool to help dealing with uncertainty, lowering inventory costs while meeting customer lead times (Baker, 2011). From the literature emerged that when designing a downstream supply network, implementing postponement with a geographical perspective, there are several factors to be considered.

All factors to consider have been divided in two categories:

- Input factors: enablers and inhibitors for postponement;
- Output factors: performance measures and expected goals.

In the following section all factors, their sources and their implication for an effective implementation of a geographical postponement strategy are discussed.

INPUT DRIVERS: ENABLERS AND INHIBITORS FOR POSTPONEMENT

Input drivers are key factors to ponder before implementing a geographical postponement strategy since they directly affect a successful result. Those factors are enablers, requirements, regulations or inhibitors for postponement from the point of view of the company. Table 5 summarizes every factor and reference papers. Then, the following section discusses each one individually.

	Input factors	References
Internally driven	Economies of scale	(Wong, et al., 2011)
	Forecasting ability	(LeBlanc, et al., 2009) (Harrison & Skipworth, 2008) (Huang & Li, 2009) (Prasad, et al., 2005) (Yang, et al., 2005b)
	Length of haul	(Fan, et al., 2017) (Guericke, et al., 2012)
	Size of the firm	(Tan & Goh, 2015)
	Particularity of product	(de Keizer, et al., 2017)
Externally driven	Infrastructures and technological development	(Masson, et al., 2007) (Yang, et al., 2005b)
	Facility/soil costs	(Baker, 2011) (Ugarte, et al., 2016)
	Tariffs and Export incentives	(Fernandes, et al., 2015) (Mukherjee, 2016) (Yang, et al., 2004)

Table 5: Input factors: enablers and inhibitors for postponement (own elaboration)

ECONOMIES OF SCALE

Economies of scale have to be considered in two areas:

- Economies of scale at the Distribution Center level;
- Economies of scale in transportation.

At a Distribution Center level, when deciding if to geographically postpone downstream some of the customization operations, it has to be taken into account that concentrating processes in one or few facilities from a more dispersed existing configuration could lead to consistent economies of scale in logistics (Wong, et al., 2011).
Large multinational companies, especially, tend to be globally dispersed with various manufacturing plants producing a large portfolio of products. Often times such products are

all eventually distributed to the same market. If every plant has its own assembly, packaging, labelling and final delivery system this results in poor exploitation of economies of scale. Instead, having a Distribution Center with such customization operations capabilities directly in the final market, or closer to it, can enable to have just one or few facilities (Baker, 2011). In this way assembly, packaging, labelling or distribution operations could be scaled up and the company could achieve economic benefit from it.

It is to be taken into account, however, the fact that concentrating customization operations capabilities in one or few Distribution Centers would generally entail having a much bigger facility downstream, therefore requiring more investment.

Regarding transportation, for large companies with a global supply chain the distribution between the primary manufacturing plant and the final market often involves a long international haul, usually oceanic freight via cargo. When considering geographical postponement application, the benefit provided in transport efficiency should be taken into account. Not applying postponement, or postponing activities in the manufacturing plant's region (home postponement) require the international transportation of finished goods, which typically enable a poorer utilization of space (Son, et al, 2015). Instead, having some production processes held overseas enable to ship products in less finished forms, (un-packed or even components), which typically can be transported in bulk thus enabling a better capacity utilization. In this regard, the more activities are done overseas, the better it is. In fact, implementing an assembly postponement can require shipping just components, resulting in the best capacity utilization. In contrast, packaging or labelling postponement entails to ship products in a more finished form, thus requiring more space and poorer utilization (Yang, et al., 2004) The best configuration, for this purpose, would be obviously the limit-case to produce entirely overseas, shipping just raw materials in bulk from the supplier. However, this study focuses on the geographical postponement of some activities downstream in a global supply network.

In any case, capacity utilization during long international transports is surely a relevant factor to consider when pondering a postponement strategy with a geographical perspective.

FORECASTING ABILITY

The forecasts accuracy abilities of the firm are a critical factor to consider when evaluating a postponement decision, especially with a geographical perspective.

While it's true that postponement reliability and effectiveness increases as demand uncertainty increases (Huang & Li, 2009; Harrison & Skipworth, 2008), different forecasts accuracy abilities result in different postponement strategies application and entail the need to schedule production earlier or later. Suppose, as in most global supply chains, that for a company the delivery from primary manufacturing plant to Distribution Center involves a long international cargo transport. If the firm abilities, and the market, enable good forecasting capabilities, it would be possible to schedule earlier allowing cheaper ocean transport. Instead, waiting to schedule may require the use of expensive airfreight. In a domestic setting, the advantage could be rail vs. truck deliveries (LeBlanc, et al., 2009; Guericke, et al., 2012). The geographical location of the Distribution Center has also a strong connection with the service level and lead time wanted, which must be factored in with forecasting abilities. If the market is very uncertain or turbulent for example, a higher degree of customization should occur (Prasad, et al., 2005). Therefore, postponing customization processes geographically closer to the customers, possibly in the market region, would provide a significant benefit to the company facing strong demand uncertainty (Yang, et al., 2005b). For this reasons a company should consider forecasting abilities when deciding if to postpone activities in the home country (pure postponement) or geographically downstream.

LENGTH OF HAUL AND RELATED RISKS

When considering a geographical postponement strategy for a global firm, different locations for the downstream Distribution Center impact the length of the main haul required from the manufacturing plant for a particular product. Therefore, a company aiming at designing its global supply network should consider the length of the haul for two main reasons: impact on the forecasts accuracy and related risks.

First, as mentioned in the previous factor, length of the haul and forecasts ability are connected. Long lead times, such as overseas transportation typical of global manufacturing companies, can lead to a decreased validity of demand forecasts and can inhibit later adjustment of previously taken production and/or distribution decisions (Guericke, et al., 2012). While postponement directly aims at solving this issue, the degree to which this strategy can handle this problem still depends on the level of customization performed downstream after the oceanic transport. The more activities are performed upstream, the more decisions have been already taken when products are stored in cargo and are difficult to adjust. Hence, more safety stock would be required generally. Assembly postponement could be less affected by this issue, while a logistics postponement should require more accurate analysis. As explored by Wadhwa et al. (2008), having a facility able to receive semifinished goods and customize them after a long haul can significantly improve the overall flexibility provided by the supply chain. Therefore, a company designing its supply network should carefully consider also ‘what’ to postpone based on the length of the main haul: the more customization activities are performed after the main haul, the better it is in terms of responsiveness.

Secondly, longer haul means higher transportation risk. Some of the main sources of risk include delays, incidents and robbery. Approximately 70–80 % of vessel round trips experience transportation delays in at least one port. Delays are generally due to, above all, port congestion, restricted port access, maritime passages, and weather circumstances (Fan, et al., 2017). While it is out of the scope of this study to evaluate risks, those are all relevant factors to consider when designing a global supply chain with geographical postponement. In particular, being ships the main transportation mode in modern supply chains (Mediterranean Shipping Company, 2019), some efforts are being particularly devoted to port congestion minimization. For example, data sharing between different companies could be effective and some port-management methods have been proposed (see for example Loh & Thai, 2015).

Incidents and robberies are other potential risks, and a longer haul provides more possibilities of casualties. Incidents could mean the loss of numerous containers or, in worst cases, of the vessel. Incidents or issues could be provoked by any ship, potentially meaning long delays or even need to re-route for other vessels. These issues are particularly critical in trade ‘chokepoints’, such as very busy straits or channels, where the possibility and consequences of a casualty are even higher. The latest example, as recently as March, 2021, is provided by the Suez Canal incident. One of the biggest container ship in the world, part of Evergreen’s fleet, blocked all Canal’s pass after going sideways due to strong winds and required six days to be moved, causing incredible losses for global trades considering the strategic importance of the Egyptian canal.

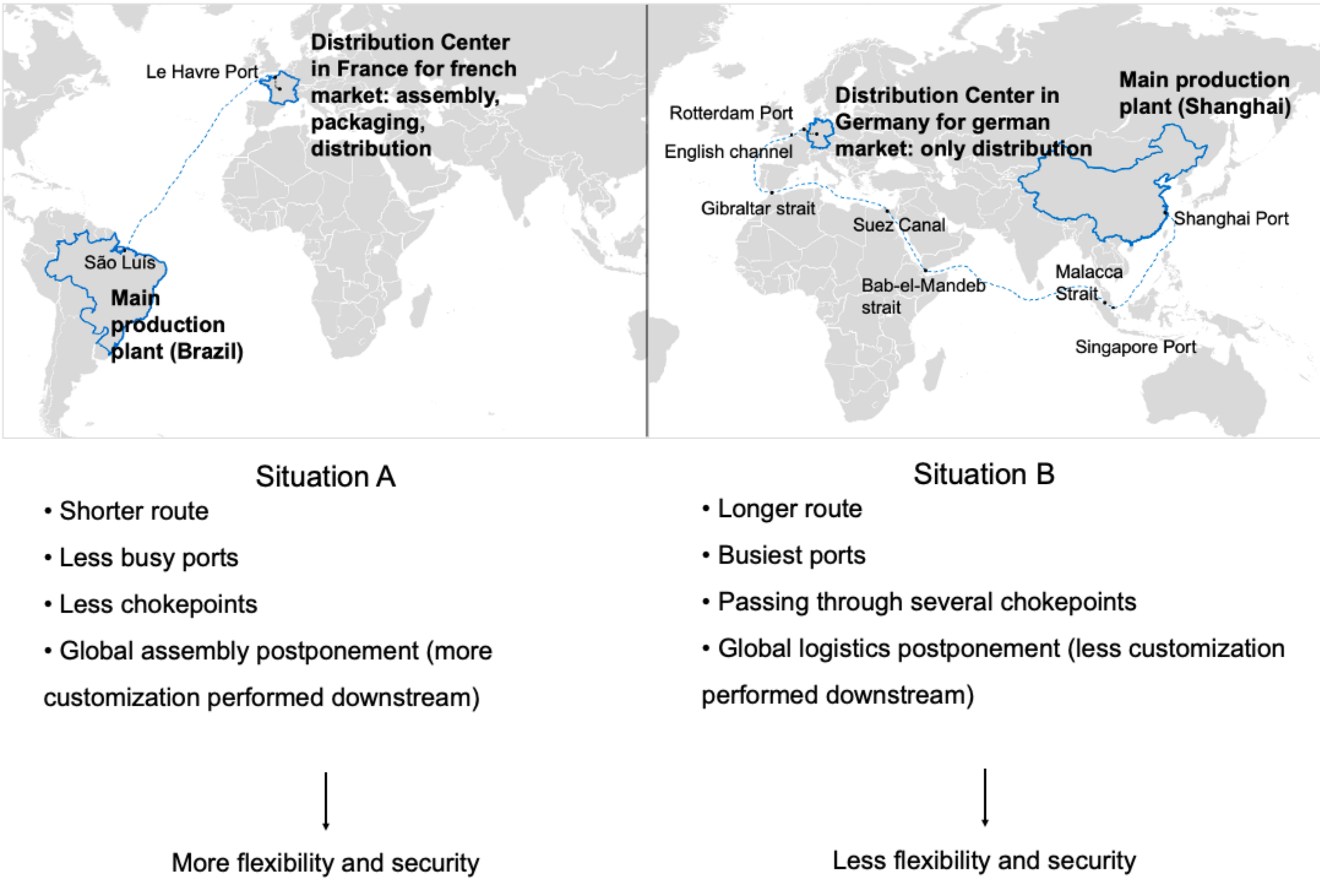


Figure 15: Length of haul and related risk: a comparison between two Supply Chains serving the European market (own elaboration)

SIZE OF THE FIRM

When pondering a postponement strategy decision, each firm should first evaluate if it is feasible for their structure and size. Larger companies have greater motivation and richer resources for postponement than small-and-medium companies (Huang & Li, 2009). In fact, some companies could simply be too small or too far upstream to implement postponement effectively, as suggested also by Tan & Goh (2015). The company should have enough products in its portfolio to justify a modularization and therefore a commonality of some components, since a modular product is the key to large-scale postponement (Wadhwa, et al., 2008). Then, it should have enough market to efficiently exploit the forecasting inaccuracy as an advantage (Yang, et al., 2004b). If lacking some structural components, the company could evaluate to focus on efficiency-based strategies such as Lean Production instead of more flexibility-based ones like postponement.

PECULIARITY OF THE PRODUCT

Eventual peculiarities of the product and/or of the sector should be taken into account when implementing a geographical postponement strategy for global supply chains, where two processing stages can be separated by weeks or months of traveling. For example, products could be perishable or very fragile, and manufacturing processes can increase or decrease the decay rate of the product (de Keizer, et al., 2017). When processes increase decay rate, in particular, a firm could think of implementing more postponement and shifting customization operations further downstream, to delay processes as late as possible. Considering the decay rate and time of a product, the probability that product deplete during transport from a hub to a customer, can be used to determine which customers can be served from that hub. Some products are perishable and require to be transported in refrigerated areas, which entail more costs and more resource usage, turning into more overall emissions. In this regard, for such types of products costly hauls would be minimized as much as possible. de Keizer et al. (2017) concluded that the segments in the supply chain where decay is high should be managed responsively, and segments in the supply chain where decay is low should be managed efficiently.

INFRASTRUCTURES AND TECHNOLOGICAL DEVELOPMENT

Every year more than 11 billion tonnes of goods are moved from the shipping sector alone (The Conversation , 2020), and global supply chains require more than ever to be fast and reliable. All this would not be possible without infrastructures, which are an important factor companies consider when entering a new market, opening a new facility or pondering a new transportation route. Countries with more advanced and reliable infrastructures are more attractive for companies whose supply chain require a huge amount of transportation or fast lead times. Fast and efficient logistics delivery service, in the end, improve customers' satisfaction and perception (He, et al., 2021). Infrastructures include roads, ports, airports, inland terminals development and technological level inside them. For example, China is nowadays very competitive on the world's manufacturing map because of the incredible advancement in place in its infrastructures network (Masson, et al., 2007). In fact, China's government invested hugely in infrastructures during the last decades and is continuing to do so. Just to give a number, local government is expected to invest 1.2 -1.3 trillion $ in the Belt and Road Initiative (Morgan Stanley, 2018), developing its infrastructures to connect with the rest of the world. Locally, China has the most busy and advanced ports in the world, where automation and data-sharing enable to be extremely effective. Especially in developing countries, a particular market could be attractive from a pure economic point of view, but logistically hard or unfeasible due to a poor infrastructure system locally. Some argues that one of the reasons of the relatively low implementation of postponement strategies over the past decades was the inadequacy in technology development, particularly, in transportation, manufacturing, and information technology (Yang, et al., 2005b).

In fact, the technological development along the whole value chain is a critical factor to consider for a firm operating worldwide. Manufacturing technology is related to advancement of production and assembly processes, which are relevant factors but out of the scope of this study. Instead, information technology and particularly data sharing are a critical element which can boost or lower the performances of a postponement strategy, or help reduce losses when a disruption occurs, as studied by (Fan, et al., 2017). With data sharing it is possible to have more reliable forecasts from the client and from suppliers, and integrate them to control the whole supply chain network more reliably.

FACILITY FOOTPRINT

The cost of the soil is a relevant factor to be considered when pondering to build a Distribution Center for customization processes geographically downstream. In fact, usually product postponement requires additional space at the Distribution Center to both perform the customization and/or store final products (Ugarte, et al., 2016). This entails having a bigger facility, with more footprint, which can result in a significant initial investment to build it. If for logistics postponement this could be negligible, for packaging, labelling or assembly postponement this could require more attention. The more activities are performed in the facility, the more space would be required. For example, an assembly postponement strategy would require space for assembly, packaging and labelling lines, as well as more common spaces due to the increase in labor force. Therefore, this could be a relevant cost factor to consider. Especially considering that soil cost is higher in developed countries like Europe and US which is the target market for a lot of companies, as for this study. Besides the pure initial soil cost derived by a bigger footprint, higher facilities would entail having more fixed resource consumption such as electricity for lighting or cooling.

TARIFFS AND EXPORT INCENTIVES

In some countries, taxes and tariffs incurred for finished products are higher than for semifinished ones. Therefore, global companies can benefit from maintaining their inventories in bulk in the cheaper and/or pre-customised form and delaying expensive operations and point of product differentiation in another geographical area (Yang, et al., 2004).

Country	**Average tariff rate (%, all products, 2018)**
Brazil	7,95%
China	3,39%
EU	1,69%
India	4,88%
Japan	2,45%
Pakistan	9,45%
Singapore	0,24%
USA	1,59%

Table 6: Average 2018 tariffs in different countries. Source:World Bank

Companies could also exploit FTA (Free Trade Areas), entering an economic region from a less expensive country from a tariff's point of view. It is important for this purpose to distinguish between FTA and CU (Custom Unions). As previously explained, a FTA is an economic region whose members have no tariffs between them, but different tariffs with external countries. Therefore, a manufacturing company aiming to serve a specific country of a FTA could enter the economic region from the country with lower tariffs and then reach the final market, thus optimizing the duties cost. This is a well-known issue and was tried to solve with the 'rule of origin'.

Europe solved this problem precisely becoming a CU (and later even a single market). Customs unions are 'arrangements among countries in which the parties do two things: first, agree to allow free trade on products within the customs union, and second, agree to a common external tariff (CET) with respect to imports from the rest of the world (OECD, 2001). A CU, therefore, has common tariffs not only between its members, but each country has the same tariffs with respect to the rest of the world. In this way, for a foreign

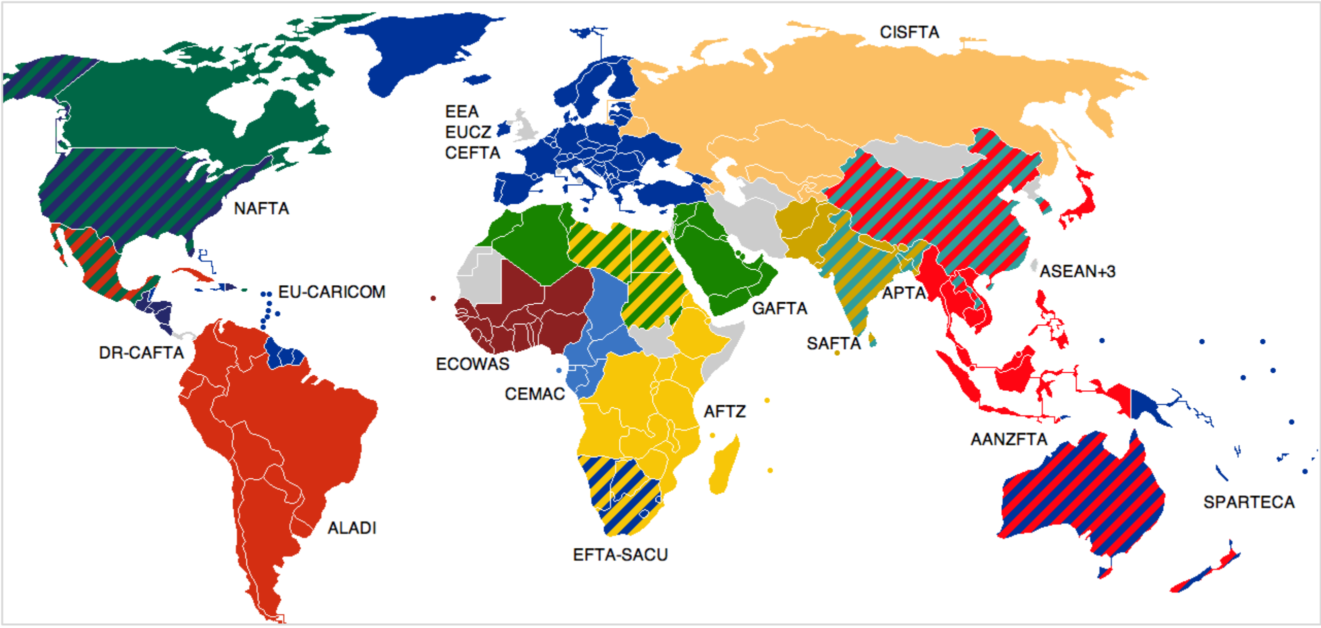


Figure 16: Free Trade Areas. Source: WikiMedia, 2009

firm entering the market from each of the members is exactly the same by a duties minimization perspective.

As a result, when deciding to postpone activities in typical markets like Europe and US, if for tax minimization the decision of the country could be relevant, for tariff duties optimization it is the same. However, as said, the CU common tariffs are generally lower if products are entering in sub-assemblies form compared to finished products to be just distributed. This is because if assembly is required, it means the company will perform operations in the CU's countries therefore bringing jobs and occupation. Thus, governments impose higher duties if no occupation is brought but just competition.

Therefore, for duties minimization it could be considered to geographically shift downstream the customization process, to the destination market or a third country.

OUTPUT FACTORS: PERFORMANCE MEASURES AND EXPECTED GOALS

Output factors (cost based)	References
Reconfiguration cost	(Gorane & Kant, 2016) (Carbonara & Pellegrino, 2018) (Tan & Goh, 2015)
Cost of labour	(Wong, et al., 2011) (Fan, et al., 2017) (Mukherjee, 2016) (Tan & Goh, 2015)
Fiscal optimization	(Prataviera, et al., 2020) (Fernandes, et al., 2015)
Inventory cost	(de Keizer, et al., 2017)

Table 7: Output factors: performance measures and expected goals (own elaboration)

RECONFIGURATION COST

Even if the supply chain structure can be a source of competitive advantage, a lot of companies still ponder their logistics decisions based on pure cost minimization, before looking at more strategic or peculiar aspects (Establish, 2010).

Postponement often requires a fundamental redesign and restructuring of present manufacturing processes which have been used for decades, as suggested by Gorane & Kant (2016). This could involve buying new packaging, labelling or assembly lines to be placed at the downstream Distribution Center for customization. Or, it could involve moving the present equipment from the primary manufacturing facility where the customization was previously done to the new location. In any case installation, retooling and retesting would also be required (Tan & Goh, 2015). This could entail an international equipment move and a very huge logistics effort just to set postponement, especially for firms shifting the customization processes downstream to avoid a long haul (ex from a 'home postponement strategy' to a 'global postponement'). Therefore, it requires a strong initial effort and investment, and its implementation can be challenging (Gorane & Kant, 2016). As suggested by Tan & Goh (2015) this seems to be one of the main reasons why postponement is not widespread. This is found also in a study by Oracle Corporation and Cap Gemini Ernst & Young (2003), reported in figure 17.

The initial effort required could lead to two situations: first, it could prevent the management to perform this relocation and second, it could even make postponement strategy cost ineffective.

For the first one, it's in the hand of logistics managers to properly convince their management of the effectiveness of the strategy, supported by data.

For the second, it can depend a lot on the sector, but in general payback time is low.

Wadhwa et al. (2008) addressed this problem in a case study regarding an automotive company producing trucks, which is a cost intensive sector. They included in the initial investment the cost of the new equipments, installation, trial, evaluation, re-engineering of processes, modification to ERP and training, and found a payback time of postponement investment of less than one year, making it a win-win strategy. In particular, postponing activities led to 9.2% more economic benefits compared to the initial costs.

For new companies, designing their logistics network from scratch, reconfiguration cost is not present since shifting equipment is not required. However, this firms would typically be small in size and could be prevented from adopting postponement since the beginning. As suggested by Tan & Goh (2015), postponement strategy is best suitable for big companies, which can rely on bigger market shares and exploit economies of scale.

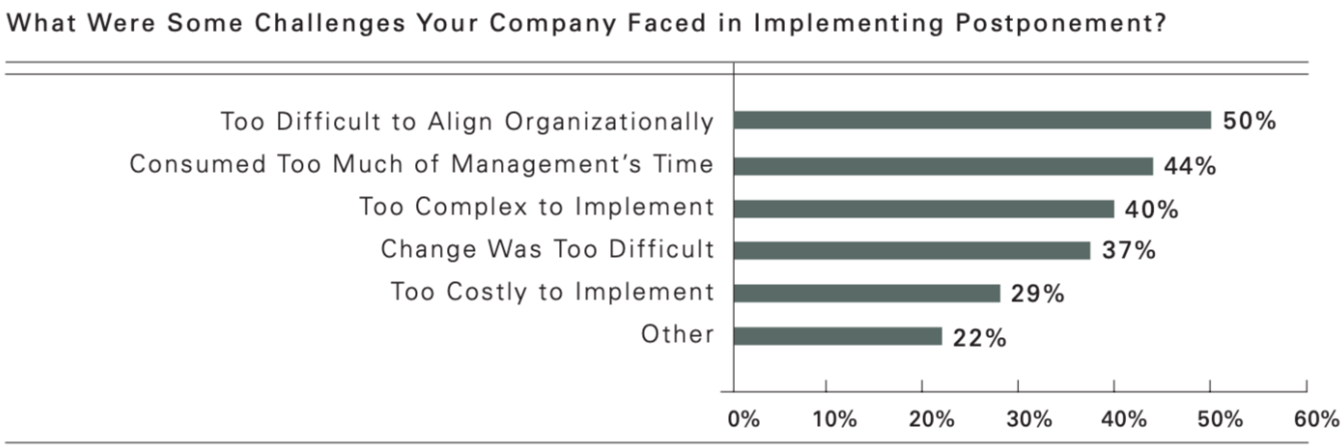


Figure 17: Reconfiguration effort as main effort for postponement implementation. Source: Cap Gemini Ernst&Young, 2003

COST OF LABOUR

Manufacturing companies have been pursuing low labour costs for decades, resulting in the 'delocalization' phenomenon of last decades to cheaper countries. Due to price competition, primary plants are placed by many companies in low-cost countries and manufacturing cost is one of the main factors considered (Mukherjee, 2016). In particular, China emerged as the global manufacturing center, or 'world's factory', for this very reason (Tan & Goh, 2015). As recently as 2008, relative wages in China are still 4% of those in North America (Ceglowski & Golub, 2012).

However, during last years China saw a constant growth and rise its standard of living. Unit manufacturing cost, as a result, are growing and increased from 22% in 2003 to 33% in 2009 compared to the United States (Ceglowski & Golub, 2012). Consequently, a progressive shift out of China for pure labor cost minimization reasons is currently undergoing. This is not surprising and falls under the concept of 'middle income trap', which refers to the concept that a under-developed country can rely on very low wages and weak currency, therefore being very attractive for delocalization of foreign firms and exports but, when the country experience constant growth, appreciation of its currency and higher standards of living, it becomes less attractive. This is what China is experiencing, where middle class passed from 39.1 million people (3.1 percent of the population) in 2000 to roughly 707 million (50.8 percent of the population) in 2018 (source: World Bank).

Nowadays, China is seeing a progressive shift out of the country by manufacturing companies towards cheaper places like Thailand, Vietnman, Cambodia or India. For example, companies such as Panasonic Corp, Foxconn, Samsung Electronics, and a few U.S. fashion companies, have been moving from China to cheaper manufacturing areas, such as Vietnam and India (Fan, et al., 2017). Tan & Goh (2015) provided a case study of a Singapore-based company postoponing final customization in China, whose purpose was twofold: exploiting lower wages and better serve its main market, which was China.

This is not just related to China, which is just the major example since destination of most of the overseas manufacturing over last decades (Tan & Goh, 2015). Middle class is rising in all continents, even if unevenly at different paces in different regions of the world. For each case, it will be referred to the standard threshold of 10$ income per day. From 2001 to 2011, Eastern Europe saw an increase in middle income population by 39 million. South America and Mexico saw an increase of 63 million.

A slower growth happened in India, where although the poverty rate fell from 35% in 2001 to 20% in 2011, the share of the Indian population that could be considered middle income increased from 1% to just 3%. Africa saw a similar path: poverty rates declined drastically from 2001 to 2011, but the shift has been primarily from poor to low-income status, and a 1% growth of the middle-income population (Kochhar, 2015). Final customers are in more developed countries like Western Europe and USA, where standards of living are high as well as wages. Applying postponement geographically, thus implementing customization processes in the final market, would mean having a manufacturing cost way higher and historically this was not cost effective. However, in contrast to the countries mentioned above, wages and labor cost in developed countries like Europe and the US are progressively decreasing due to an increase in productivity (Fan, et al., 2017).

Therefore, postponement activities with a geographical perspective could be a factor enabling the 'reshoring' of companies, as suggested by Tan & Goh (2015).

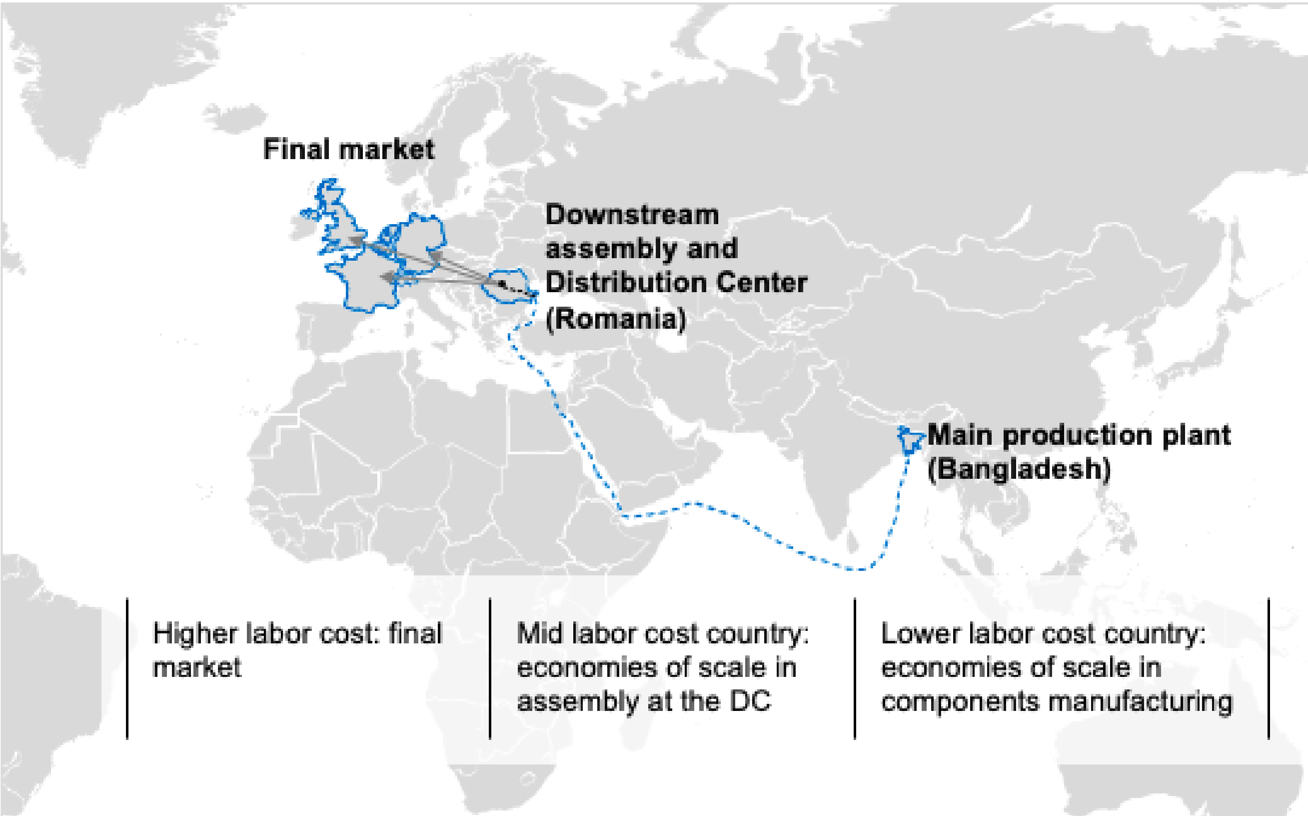


Figure 18: example of 'third-country assembly postponement' strategy for labor cost optimization (own elaboration)

When deciding the location of the customization processes, it should be taken into accout that the low wages in developing countries could be a factor less relevant and potentially offset by other elements like the increased flexibility brought by having customization closer to the customer. Fan, et al. (2017) pointed out as it may become attractive to relocate assembly centers from low cost countries closer to the area of overseas marlet, in such a way to postpone some SC activities. This would affect not only labour cost but also transportation, since the longest international haul would be done with subassemblies or raw materials, thus enabling a more efficient and cheaper transportation. Exploiting lower wages could however still be possible using a third-country based Distribution Center with customization processe in place (third country postponement). To achieve a good balance between labor cost and flexibility, a company serving the European market could have the primary manufacturing in South East Asia, assembly process in Eastern Europe from which to distribute to the final market, as in figure 18 above,, thus exploiting a 'third-country assembly postponement' strategy to optimize labor cost.

FISCAL OPTIMIZATION

The structures of global manufacturing firms are designed by both logisticians and tax lawyers (Henkow & Norrman, 2011). While logistics managers try to optimize the flow of goods and reduce transportation, their solutions must be checked with the reality of legal and fiscal issues of the firm and of specific countries involved. These solutions, in fact, could sometimes be cost-ineffective or even impossible when fiscal costs are included (Henkow & Norrman, 2011). Therefore, some companies design their distribution network based on fiscal optimization, besides pure logistics efficiency, trying to minimize the global tax burden (Prataviera, et al., 2020; Henkow & Norrman, 2011). Different tax rates are for these reasons a relevant factor to ponder when designing a global network structure.

In recent years, states and governments are trying to attract foreign firms by offering lower taxes and even incentives. In 2014, US state of Nevada made Tesla built its first Gigafactory locally by offering a 1.3 billion$ tax incentives over 20 years, the biggest of its history, in its plan of becoming a manufacturing destination (Lecher, 2016). The decision is based on the fact that the automotive firm is expected to bring up to 22,700 total jobs in the state. This is not the only 'gamble' made by Nevada government: in 2012 it provided a 89 million$ incentive to Apple and in 2015 a 335 million$ one to Faraday Future (Lecher, 2016). Consultancy firms are also offering new products to enable their clients to join fiscal optimization and supply chain performance, such as “tax aligned supply chain” by Deloitte or “tax efficient supply chain management” by KPMG. With this aim, a company redesigning its network could consider shifting customization activities to a third country, in between of the main production country and the final market. In this way it could both get closer to the customer and exploit some sort of fiscal optimization. Considering building a facility in single markets like Europe or USA, the choice of the country can vary depending on the tax level of each state within the single market. Therefore, this could be a primary driver for firms, and this phenomenon has been observed especially during last years. Manufacturing giants such as Stellantis and Tesla located their European HQ in the Netherlands, which is known for having light taxation and by some is even regarded as a tax heaven (van Dijk, et al., 2006).

Country	Average corporate tax rate (2020)
Croatia	18%
China	25%
France	28%
Germany	30%
India	30%
Ireland	12.5%
Italy	24%
Romania	16%
Singapore	17%
Thailand	20%
USA	27%
Global average	23.79%

Table 8: Average corporate tax rates around the world. Source: KPMG, 2021

Another fiscal factor to consider is transfer pricing. Transfer prices (TP) are the price that one division of a company charges another division of the same company for a product or service transferred between the two divisions (Fernandes, et al., 2015). Since TP are subject to the country where the transaction takes place, a company aiming at tax minimization should consider carefully the location of major facilities such as manufacturing plant and Distribution Center.

INVENTORY COST

The benefits of postponement regarding stock levels optimization have been largely discussed in literature for traditional postponement approaches, and it reflects in the same way when a geographical perspective is considered. Inventory minimization is one of the primary reasons for postponing activities and the hub location problem is, at the end, a stock location one (de Keizer, et al., 2017). The key to postponement is to have the common component for as long as possible along the supply chain (Wadhwa, et al., 2008). Therefore, all variations in demand for each different type of product can be smoothed by centralizing stock and lower inventory level cost, as explained by Baker (2011). In this way inventory can be held at the generic level and there will be fewer stock-keeping variants, resulting in less total inventory (Huang & Li, 2008). When implementing a geographical postponement strategy, companies carefully ponder what will be the result in terms of inventory level at all nodes of the supply chain, considering cycle stock, safety stock and possible 'obsolete stock'.

GEOGRAPHICAL POSTPONEMENT STRATEGIES ASSESSMENT WITH TRADITIONAL APPROACH

The geographical postponement framework developed by Prataviera et al. (2020) has been used to collocate every case study in the literature in one specific strategy, where applicable. All publications treating the postponement with a classical, temporal perspective (all customization operations performed within one country, where production and customers are) have been addressed as 'pure postponement' strategy, since the main focus of the study is to explore where the first customization activity takes place compared to the main production plant. Therefore, the 'pure' one is the strategy that better suits this situation. An efficient implementation of postponement strategies provide benefits in terms of costs and flexibility, and this is well studied in literature. Wadhwa et al. (2008) presented a study by Oracle Corporation and Cap Gemini Ernst & Young: over 75% of respondents derived significant benefits from the implementation of postponement and considered their implementation a success, and 91% of respondents noted significant improvements in customer satisfaction and inventory costs. Chang (2012) addressed the benefits of postponing packaging or labeling activities directly in the retailer's site. Even if the study doesn't provide informations on where retailers are located compared to the main production, it provides two conclusions: first, applying postponement will result in a higher service level for the final customer compared to full speculation, for the same level of costs. Second, the postponement benefits could not outweight the margins in case of strong customization costs at the retailer's site. In this case, a speculation strategy is preferred. Moreover, modifications costs rise locating postponed operations closer to the customer in a global supply chain for three main reasons. First, because of the redesign and change in equipment which could require a strong initial investment (Wong, et al., 2011; Gorane & Kant, 2016; Tan & Goh, 2015). Second, because a customized process is more expensive than a economy of scale-based one (Wang, 2010). Third, labour cost in the final destination region is usually higher for companies with a global production and distribution network. The study by (Guericke, et al., 2012) investigated the savings brought by postponing some activities closer to the customer region. They applied a mathematical model to a real-case company in the apparel industry with main factories in Asia (India or China, not specified) and customization in a Distribution Center in Europe to serve the local market. Since the first activity to be postponed is the dyeing of the garment, this is an example of global assembly postponement. Their study concluded that is convenient, especially with strong demand uncertainty, to re-sequence activities in order to perform the final dyeing based on customer orders. Their study explored different possible strategies and found that postponing customization activities closer to the customer is effective even in case of long hauls. However, the study didn't take into consideration taxes/export incentives, nor environmental costs. Tan & Goh (2015) studied which configuration would be optimal for a Singapore-based electronics company aiming to adopt a 'global assembly postponement' strategy, since the firm wanted to relocate some processes in China, where the main customer is, and thus expliting postponement possibilities. They assessed it considering stock levels, manufacturing costs, lead times and transportation costs. In this particular case-study, the lower labour cost in China compared to Singapore was a factor contributing to the redesign of supply chain configuration and positively affecting the push downstream of the customization process. As already highlighted in the 'Labour cost' section, this factor could be exploited in both ways. The results of the study showed that a global assembly postponement strategy leads to better responsiveness compared to the original process (full speculation and no offshore facilities) and, more importantly, provides savings. In the specific case it led to 1.72% reduction in costs which is an important goal for a contract manufacturing company, where margins are very low. Wong, et al. (2011) studied the benefits provided by applying a pure packaging postponement strategy for a Food & Beverage firm producing coffee in the UK. The company however had other manufacturing plants across Europe serving the UK market with packaging, labelling and delivery postponed in the UK Distribution Centers. Manufacturing countries are not specified, but the 'global packaging postponement' strategy of the framework can be traced in the supply chain structure. The company decided to postpone activities to the distribution center and not to perform them directly in the manufacturing plant, which are less than one day of travel away, to better exploit economies of scale in logistics. The strategy adopted led to considerable savings, measured in terms of cumulative reduction in safety, cycle and obsolete stocks of nearly 40%. However, they didn't take into account the costs sustained for the reconfiguration of the facility.

Postponement strategy can also be a strategic decision during the sourcing process. Wadhwa et al. (2008) proposed a case study in the automotive sector where a company exploited postponement in a chassis component by buying coils of raw material in bulk instead of pre-formed components. In this case, the geographical separation was between the supplier (a steel mill) and the production plant, which were about 3000 km apart. Since the cutting of the coil was the first differentiation stage, this strategy was very beneficial since enabled to delay the first cutting in the manufacturing plant, resulting in a postponement time of 2 to 6 months. In a sector like automotive where the number of components explode and sourcing is global, having the possibility to postpone assembly activities avoiding having 'dead' stock in the long oceanic freights can therefore be a source of competitive advantage. This is even more interesting considering the fact that postponement in automotive sector is relatively a new introduction compared to more heavily utilized strategies like Lean and JIT (Wadhwa, et al., 2008). Pure operational cost is not the only way to assess the benefits brought by postponement strategy. Carbonara & Pellegrino (2018) proposed a model to evaluate postponement strategy according to a real options approach. In fact, postponement strategy is significantly effective in case of disruptions, both upstream and downstream, because of its flexibility and possibility to reconfigure quickly the product. If disruptions do not happen (or demand remains always stable) the application of postponement could not be justified. A real option is "an option on a 'real asset' that consists in the opportunity to take actions in the future, whenever they prove valuable, by paying a predefined cost to maintain such a right". They confirmed the value of postponement under this approach as well.

Fan et al. (2017) included disruption possibilities in the assessment of operational costs for a supply chain with the possibility to have 'global assembly postponement' strategy.

Supply Chain performances are particularly affected by three components: duration of the disruption, probability of occurrence and vulnerability of the node. Their study showed numerically that the Supply Chain costs increase significantly when the duration of the disruption grows and its probability decreases. Obviously, a more predictable disruption is less impacting. Moreover, the vulnerability of a node has to be considered especially if the company can rely on one single downstream Distribution Center, since a disruption in that facility would cause incredible high damage. If the disruption occurs at the transportation level (blockage of the vessel, port delays, damages etc) the impact could be lower even if the transportation is a long international shipment, since different modes of transport could be exploited.

PRODUCT MODULARITY IMPLICATIONS FOR GEOGRAPHICAL POSTPONEMENT

Modularity refers to the modularization of the products to be produced, transported and sold, and requires a particular discussion.

Postponement strategy is closely related to the concept of modularization of products (Mikkola & Skjøtt-Larsen, 2004). Modular products, more precisely, are the key enabler to large-scale postponement, and a company pursuing such strategy should carefully consider components commonalities and product families (Wadhwa, et al., 2008; Yang, et al., 2004; Fixson, 2005). According to (Bonvoisin, et al., 2016), postponement can even be considered as a modularization driver, meaning that modular products can strategically contribute to postponement effectiveness.

Modularization is ''an approach for organizing complex products and processes efficiently by decomposing complex tasks into simpler portions so they can be managed independently and yet operate together as a whole'' (Mikkola & Skjøtt-Larsen, 2004).

In modular products, hierarchies of products variants are created through sub-modules which connect with standard interfaces (Parry & Roehrich, 2013). With such products, it is possible to design efficient linkage mechanisms in the constituent units so that any required combination can be conveniently assembled when needed (Huang & Li, 2008; Su & Chuang, 2011). This matches with postponement perspective and goals, since modules can be configured later in the process and provide a wide range of product variants to be delivered to the market. Product variants are created by changing different modules and this set of interchangeable modules creates the product family (Parry & Roehrich, 2013). In fact, modularization of the product is part of the DFx approaches in literature, where DFM (Design for Modularity) aims at subdividing a system in smaller parts which can be created in an independent way and then used in various systems (Tchertchian, et al., 2011). The high interchangeable capability relies on standardization of components, i.e. on the need to have several components replaced by one able to perform all of their functions. Standardization, as well as modular components, requires therefore a fundamental redesign of components, of functionalities and processes (Huang & Li, 2008; Fixson, 2005).

The need to redesign the product and manufacturing processes, however, is not a problem for big firms and can even turn into opportunities, since different aspects can be considered already at the design stage. In fact, modularization can provide many benefits to the company from development to production, such as economies of scale, increased feasibility of change, increased variety, ease of design and testing, decreased lead-times, and easier diagnosis and maintenance (Song, et al., 2015). Moreover, since modularity enables to limit the number of different components required to produce (Parry & Roehrich, 2013), it not only provides benefits for flexibility and responsiveness, but also enables economies of scale in design and manufacturing of common modules (Huang & Li, 2008). As concluded by Graessler & Yang, (2019), having such product architecture provides a range of benefits in reducing and managing internal diversity, while keeping costs and complexity under control within the firm. From an economic standpoint, exploiting postponement with modularity is expected to lead to a reduction in production costs, as stated by Bonvoisin et al. (2016). One successful example of application is HP, which implemented a standardization strategy for its LaserJet printer, and used it in a 'global assembly postponement' strategy serving its North American and European markets (Feitzinger & Lee, 1997). Instead of maintaining two power supplies, they created a universal one which suits both markets. Moreover, instead of customizing them at its factory in Asia, they shipped the common component and perform assembly, packaging, labelling and distribution from the downstream distribution center in the market region. In this way total manufacturing, shipping and inventory cost dropped by 25%.

In automotive manufacturing, where the final products consist of many assemblies and sub-assemblies, the number of components used is exorbitant, and customer requirements change frequently, the components need to be designed in such a manner that they can be used in more than one vehicle model (Wadhwa, et al., 2008). The automotive sector is indeed a capital intensive one, and implements modularity through the use of platform since the '60s (Lampón, et al., 2017). For example, Mercedes-Benz used modularity in the development of the Smart car, which comprised five modules and several sub-modules, enabling a quick lead time to the market (van Hoek, 1998). Volkswagen produces a lot of different cars modularly through the MQB platform, which allows variations in all longitudinal dimensions except from the distance from pedal to front axle (Lampón, et al., 2017).

However, postponement strategies applied jointly with modularity in automotive are still relatively new or under-developed. In this sector, more focus has been given to efficiency-based strategies such as Lean Manufacturing, exemplified by Toyota Production System (TPS) (Wadhwa, et al., 2008). Instead, standardization could be more extensively applied to geographical postpone customization, being automotive supply chains very global and dispersed. As suggested by Fixson et al. (2005), a product's architecture determines the processes required to develop and produce the product, and in turn, contributes to the definition of the firm's organisational structure. Doran & Roome (2005) applied it to the upstream supply chain, exploring how modularity affects first-tier suppliers. To conclude, modularity is an essential requirement for effective postponement strategies, and it reshapes the entire supply chain.

If the impact of modularity on postponement is extensively regarded as beneficial in literature, the relationship between modularity and sustainability, when applying postponement strategy in the supply chain, has not been largely discussed and requires further discussion. In the literature, generally modularity is associated with environmental benefit (Sonego, et al., 2018), since it implies a substantial redesign of the product which gives more engineering freedom and can lead to exploiting some opportunities for an eco-friendlier design (Jeong, et al., 2015). Having a modular architecture for a product, however, could also provide some emission-related challenges. Gumpinger & Krause (2011) studied that modularity is usually associated with an increase in weight and volume. This is due to three reasons: weight increase due to interfaces, over-sizing, and complex design interactions. Having different components that can serve multiple purposes requires that they have more interfaces, or bigger interfaces to suit more families, thus a reduction in weight and/or size incurs. Therefore, there is no evidence that modularity can benefit a lightweight design (Gumpinger & Krause, 2011). This is found also in Graessler & Yang (2019), who conclude that modularization needs a higher number of interfaces and the reuse of the modules in different products, which usually leads to oversizing. This oversizing, and the structural weak points associated with the interfaces, lead to substantial weight increase. This could have an adverse impact on sustainability, since heavier products cause the need to have more trips, and higher emissions during transport. Developing a lightweight product could be very complex and entail a long and iterative approach, which result in a longer time-to-market (Graessler & Yang, 2019). The benefits of it are however clear, since lightweight design improves functionality and saving costs in resource and energy consumption (Graessler & Yang, 2019).

REVERSE LOGISTICS IMPLICATIONS FOR GEOGRAPHICAL POSTPONEMENT

OVERVIEW

Reverse logistics, reverse supply chain management or returns management, refers to the control and implementation of backward flows of raw materials, in-process inventory, packaging or finished goods from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal (Quesada, 2003).

Several names have been used in literature to identify such concepts (see for example Quesada, 2003). Regardless of the terminology, reverse flows are connected with the management and proper disposal of wastes, and are critical for the potential maximization of reused materials thus decreasing the environmental impact. During the past century, the huge increase in population and consumerism led to the growth of a 'throw away' society (Loy & Tatham, 2016). Continuously new products were (and still are) introduced at fast pace, and when they are obsolete or malfunctioning, they are just discarded. The problem has been the lack of efficient system for retraining those materials and/or finding some ways to reuse the products. This led to a huge amount of waste thrown in the environment, on the soil, oceans and even space. This was especially significant for synthetic polymers, or plastic, which saw an onset of mass production in the 1950s and today exceed 348 million metric tons in annual production globally (Egger, et al., 2020).

Recycling rates for plastic packaging, for example, are still relatively low in all countries. According to McKinsey & Company (2020), in the United States recovery rates for packaging and food-service plastics are about 28 percent. In Europe, the plastic-packaging recycling rate reported was somewhat higher at approximately 40 percent, compared to approximately 80 percent for paperboard, metal and glass.

Wrong disposal and recycling of used materials have disastrous impact on the environment, especially when the amount of products consumed globally, and not just by an individual, is factored in. The greatest example is provided by the Great Pacific Garbage Patch (GPGP), the world's biggest mass of waste materials, mostly plastic, currently floating between Hawaii and the US West Coast.

	China	India	EU	USA
Currently in place	Banned or limited imports on packaging waste in 2017	Legislation favors recyclable substrates and formats	Packaging and waste directive	Important jurisdictions implementing bans on plastic bags
Recent moves or planned next steps	Proposal to ban single-use plastic bags by 2022	Pushing for increased number of awareness campaigns and collection points	Implementing a ban on selected single-use plastics	Introducing bills around reducing single-use packaging waste and increasing recycling

Figure 19: Current state of regulations for packaging recycling (own elaboration)

According to rough estimates, the GPGP began forming around the 50s and now comprises over 1.69 trillion of plastic pieces (Petersen & Hubbart, 2021).

Even if it can also give significant cost benefits, reverse logistics was born, and grew significantly, when manufacturers started to be concerned about the environmental impact of a product's life cycle (Huscroft, et al., 2013).

Reverse logistics for End-of-Life cycle, in fact, gained increasing attention during the last decades for social concern reasons and it begins whenever the product has a malfunction or has to be retired. The operations included in reverse logistics for EOL intend to gain value from retired components exploiting their reusability, remanufacturability, or recyclability opportunity (Kremer, et al., 2013).

Such practice falls under the 'triple bottom line' approach which will be more extensively discussed in the next sections, by which companies have to evaluate their performances not only from a pure financial perspective, but also considering environmental and social aspects. Reverse logistics, aiming to recycle or reuse existing products, would create obviously less environmental impact and improve the sustainability of the overall product life cycle (Mukherjee, 2016). In fact, end-of-life cyle of a product contributes significantly to its overall carbon footprint (Jeong, et al., 2015) and reverse logistics enable to have more efficient practices.

Several types of reverse logistics channels are identified expanding the study by Sharma & Singh (2013), focusing on downstream supply chains, as highlighted in figure 20.

- In transit order cancellation: a delivery is cancelled while it is traveling to its destination. Such possibility is usually decided beforehand.
- Unacceptance by customer: once delivered, a product is not accepted by the client.
- Packaging recovery for reuse: once a product has been delivered, its packaging is recollected by the company to be reused. Such practice is more profitable, safer and greener (Leblanc, 2020). An ideal packaging for reuse should be reusable, safe (protect the part) and environmentally friendly (Casper & Sundin, 2018).
- Packaging recovery for recycling: once a product has been delivered, its packaging is recollected to be properly recycled. Such practices are becoming increasingly critical and popular considering the amount of packaging used with home deliveries nowadays (McKinsey & Company, 2020). Figure 19 shows some of the actions currently developing around the world for proper packaging recycling.
- Warranties return: products under warranty must be returned to the Distribution Center if damaged or malfunctioning to be repaired.
- Product recalls: sometimes companies are forced to have recall campaigns due to defects in production. A huge reverse flow effort is needed to return all interested products to a central jub.
- Unsold/expired goods from retailer: products not sold by a retailer or distributor for a certain period of time which are recollected by the manufacturer. Such possibility is usually decided beforehand.
- EOL Value reclamation (recycling, reuse): recollection of products after the end of their usage period by the consumer. Such products can be disposed and recycled or reused (for example, be sold again in the used market).

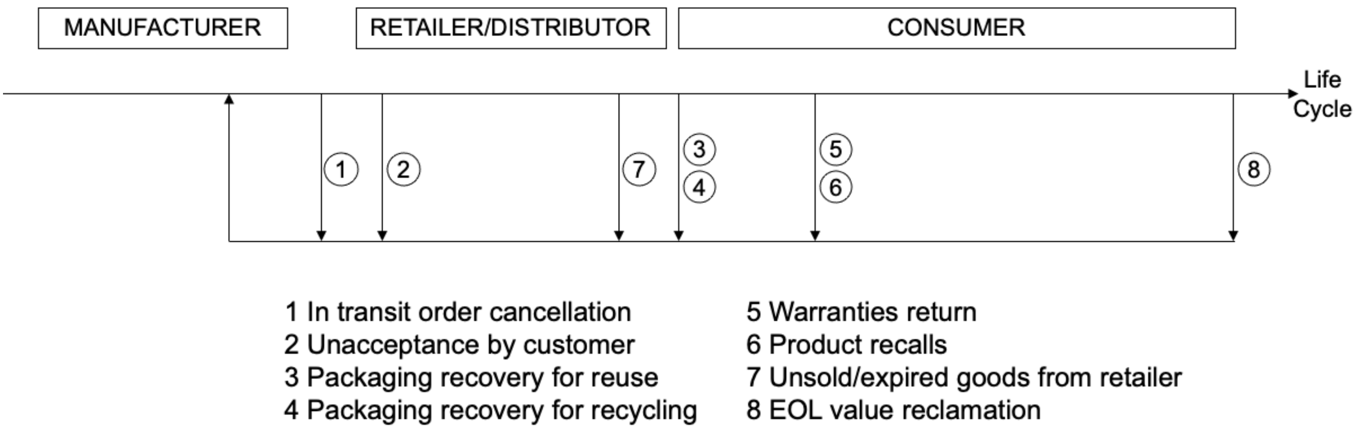


Figure 20: Different types of reverse logistics flows (own elaboration)

Reverse logistics practices appear to be not well penetrated, especially in developing, fast-growing countries. For example, Gorane & Kant (2016) found that Reverse logistics operations are among the least penetrated practices in Indian manufacturer, compared to more used ones like Lean Manufacturing. They concluded that there are several reasons that could prevent companies to implement return management practices:

- Lack of awareness: sometimes there is just not enough knowledge about the benefits potentially brought by reverse Supply Chain Management, both for financial and environmental goals. This is partially confirmed also by Sonego et al. (2018), who conclude that often there are no clear and rigorous evaluations of end-of-life correct disposal benefits for the environment, but just mere assumptions or hypothesis.
- Financial constraints: return management requires financial effort which could not be immediately balanced by the value retention. Skilled personnel related to reverse operations are essential to make it profitable, and they must be trained.
- Problems with product quality: in reverse logistics, the product quality is not the same as in the forward one. The returned product could be in any range between faulty, worn or broken. If the return has the purpose to re-introduce in the market the product, this could be perceived badly by customers. As found also by Sonego et al. (2018), customers may perceive products with upgraded systems to be of inferior performance from those introduced in the forward logistics, feeling the remaining parts as less

reliable, or look and feel obsolete. Customers however expect the same quality and companies cannot compromise on it to maintain its reputation in the market.

- Inadequate ICT system: an efficient system of data sharing is essential to support reverse logistics operations.
- Legal issues: in some countries the product, before re-entering the plant and eventually the market, must follow some legal certifications and declarations. This process could be very long and time consuming, making it less attractive for manufacturers.
- Limited forecasting and planning: if demand forecasts are inaccurate, returns forecasts are even more. Problems brought by returned products are uncertainty in timing, quantity, quality of the product and the need to balance them with the demand.
- Behavior of chain members: having non cooperative dealers, distributors and retailers could be an important barrier for the implementation of reverse logistics. As said, information sharing is an essential enabler of such strategy and if it lacks it could make it uneffective.

POSTPONEMENT FOR REVERSE LOGISTICS

The reverse channel has today huge attention, since it can provide gains in efficiency and reduction of costs. Reverse logistics is seen as a significant component of a firm's supply chain management processes, potentially being a market differentiator and profit center (Huscroft, et al., 2013).

Reverse logistics flows require a central location where to collect products. Warehouses are very important assets for the company and are needed to perform reverse logistics. In fact, one of the main functions of warehouses is also to host returned goods (Baker, 2011). In a traditional, 'home postponement' strategy, returned goods can be directed to some ad-hoc warehouses or to third parties who manages reverse flows in outsourcing. When pondering a geographical postponement supply network structure, the strategic decision regards whether to place a warehouse closer to the final market or not.

Therefore, a geographical postponement strategy could be integrated with reverse logistics to manage more efficiently the return of goods. In fact, a downstream Distribution Center with customization capabilities in the final market could be exploited as a return hub and product

repair center. The geographical factor is important from a sustainability standpoint too since governments, as well as customers, are becoming more and more environmentally aware and can provide barriers or incentives for reverse logistics. For example, the European Union requires companies to adhere to some waste management directives such as EPR (Extended Producer Responsibility, particularly for electrical and electronic equipment), and might influence a firm's Reverse Logistics operations (Huscroft, et al., 2013).
In the following section, the relationship between a geographical postponement strategy and Reverse Logistics is discussed. In particular, Reverse Logistics flows are divided in:

- Before end-of-life: all return flows taking place before the end of usage by the consumer, such as order cancellations, packaging recoveries and recalls.
- End-of-life cycle returns: these flows are a source of value reclamation by the manufacturer. Products are recollected after the usage to be recycled or re-sold.

Before end-of-life returns

Reverse flows before the end of life of the product can be of various types, ranging from the delivery to the retailer/distributor, to all the time span of usage from the final customer, such as:

- In transit order cancellation
- Unacceptance by customer
- Packaging recovery
- Warranties return
- Product recalls

Postponement goes hand in hand with modularity, which allows separated diagnoses of product components and isolation of wear parts, easing product maintenance (Bonvoisin, et al., 2016). Therefore, having a Distribution Center which already performs assembly of architecture components closer to the market could be beneficial in term of better responsiveness and less costs for maintenance. Without a downstream Distribution Center, returned goods would be directed to an additional facility or to an outsourcer.
In transit order cancellations can be relatively quickly returned to the Distribution Center and sold to another client, eventually exploiting the fee derived from the order cancel. If applying

global labelling or global logistics postponement, the system can quickly change an order destination.
Unacceptance by customers can be due to a non-compliance with product required characteristics. In this case the order can return to the downstream Distribution Center, be diagnosed and, eventually, be repaired just in few components as per Bonvoisin et al. (2016). Modularity gives the possibility to extend the life of the product and this is also beneficial in terms of reduced environmental load. Products can be upgraded or modified and the benefits for the environment are clear: no use/introduction of new materials, no usage of resources to produce the product from scratch, no emissions to ship a new product from manufacturing plant. Modifications or repair of modular products at the downstream Distribution Center, however, has to be done carefully by manufacturers, since sustainable modular products could be perceived by costumers as less reliable or safe, with upgraded systems to be of inferior performance or obsolete (Sonego, et al., 2018).
Packaging recovery for reuse can exploit the downstream Distribution Center, especially for a ‘global packaging postponement’ or ‘global assembly postponement’ strategy. The company can in this way perform the packaging operations downstream and exploit the returned packagings directly from the market. Being close to the market, the travel distance for returned packagings would be smaller, turning to less environmental impact and less cost for the company. Having a ‘third country postponement’ strategy could be used to collect packaging from different markets and re-use them, to smooth all the quantity of packaging which return damaged and unutilizable (Gorane & Kant, 2016), but would entail a longer delivery time to the final customer. However, from the travel damage point of view this is not a problem since reusable packaging are designed for strength for stacking and durability since they must be able to be used for several years, resulting in better protection for products during transports (Leblanc, 2020). Casper & Sundin (2018) identified four main reasons why, however, such strategy is not widespread: high initial investment for the packaging system, system not flexible enough, not space-saving and the financial loss when the packaging is not returned.
Packaging recovery for recycling could benefit from a Distribution Center close to the recycling destination, especially if the company deals with a huge amount of material from packaging. This case follows the same reasoning later developed for EOL cycle returned goods. If materials are recycled or sold and provide revenues, the company could think of exploiting a third country Distribution Center (‘third country postponement strategy’) to better serve the new destination for materials.

Warranties return follows the same reasoning of unacceptance by the customer. The defected or broken product can more efficiently return to a downstream Distribution Center close to the market to be inspected and repaired. Modularity and ability to perform maintenance could mean cost saving for the company which does not outsource the repair to a third party. As per Sonego et al. (2018), the manufacturer has to put enphasis on the final quality of the product.
Product recalls can benefit as well from a downstream DC able to perform the necessary modifications. Sonego et al. (2018) conclude that also upgrades, which can be easier or quicker with modular architectures, could result in bad perception by final customer and therefore needs to be done carefully.

End-of-life cycle returns

EOL cycle returns include, usually, two types of flows:

- Unsold/expired goods from retailer
- End of use by the consumer

In both cases, the flows of returned goods, in particular, could be directed to two destinations: be disposed and recycled or eventually be re-sold in a secondary market. In both cases the value reclamation is exchanged, usually, for a discount on a newer version of the product for the consumer who used it.
The following section will discuss both cases, considering the final destination of the product.

Products to be disposed and recycled:
If, at the end of use from the customer, the product is not usable anymore, it starts the reverse flow processes to be directed to recycling. The modularity required to have an efficient postponement strategy plays a fundamental role in this case, since it enables to better disassemble the product and divide materials more efficiently, sorting parts according to their most appropriate post-life treatment destination, thus avoiding unnecessary wastes and negative environmental load of the product (Bonvoisin, et al., 2016).
The process could be made internally or outsourced. The correct management and final disposal of wastes should be carefully considered when implementing a geographical

strategic decision in a company’s supply network, since its grew importance made it to be a source of competitive advantage.
Many wealthy countries in fact, send their recyclable waste overseas to lower income countries because it's cheap, helps meet domestic recycling targets and reduces domestic landfill. For developing countries receiving in the rubbish, it's a valuable source of income. But contaminated plastic and rubbish that cannot be recycled often gets mixed in and ends up in illegal processing centres (BBC, 2019). For years, China has been the major global importer of plastic waste. In january 2018, due to concerns about contamination and pollution, the Chinese government decided it would no longer buy recycled plastic scrap that was not 99.5% pure (BBC, 2019). This had a huge impact on the global trade of waste and Malaysia came up as the main importer. This is not always the case, however. Waste-to-energy (WtE) systems are increasingly growing importance as waste is seen as a renewable source of energy (WWF, 2012). Denmark is one of the leader in this field where 3.5 million tonnes of waste are incinerated annually and are the second largest source of renewable energy for the country, where MSW (metropolitan solid waste) is even acquired from foreign firms (WWF, 2012).
If the downstream DC is able to perform the disassembly it could be beneficial to locate it in a particular contry, if this provides some incentives for waste recycling. A company could have some agreements in a particular country and, in this case, could exploit a ‘third country postponement’ which would give an additional facility in the selected place to perform operations. An hypotetical example is given in figure 21.

Products to be re-sold as used:
For some products, the re-sell process in the same or another market is just unfeasible. However, for durable items sectors such as electronics or automotive this is a relevant channel to consider. For example, according to McKinsey, in the US the used-cars market is more than twice the size of the new-car segment (39.4 million used cars each year, versus 17.3 million new ones in 2018) and is also outpacing it in growth rate (McKinsey & Company, 2019). However, the re-sell of such products could be done also in a second market, different from the first one. For example, it could be still profitable to resell them in some lower income countries. A car manufacturer producing for Western Europe could think to resell used cars in poorer countries of the Eastern part of the continent, where consumers could be willing to accept older versions for a lower price. Since the market for used products could be very large, this secondary channel has to be considered when designing a distribution network.

Depending on the size of this market, it could also affect the strategic decision of where to place geographically the downstream Distribution Center. Having a 'third country' postponement strategy with a Distribution Center able to host return flows, it could be exploited to balance the distance from both markets, since the used-product one will eventually become a new effective market and source of revenues for the company.

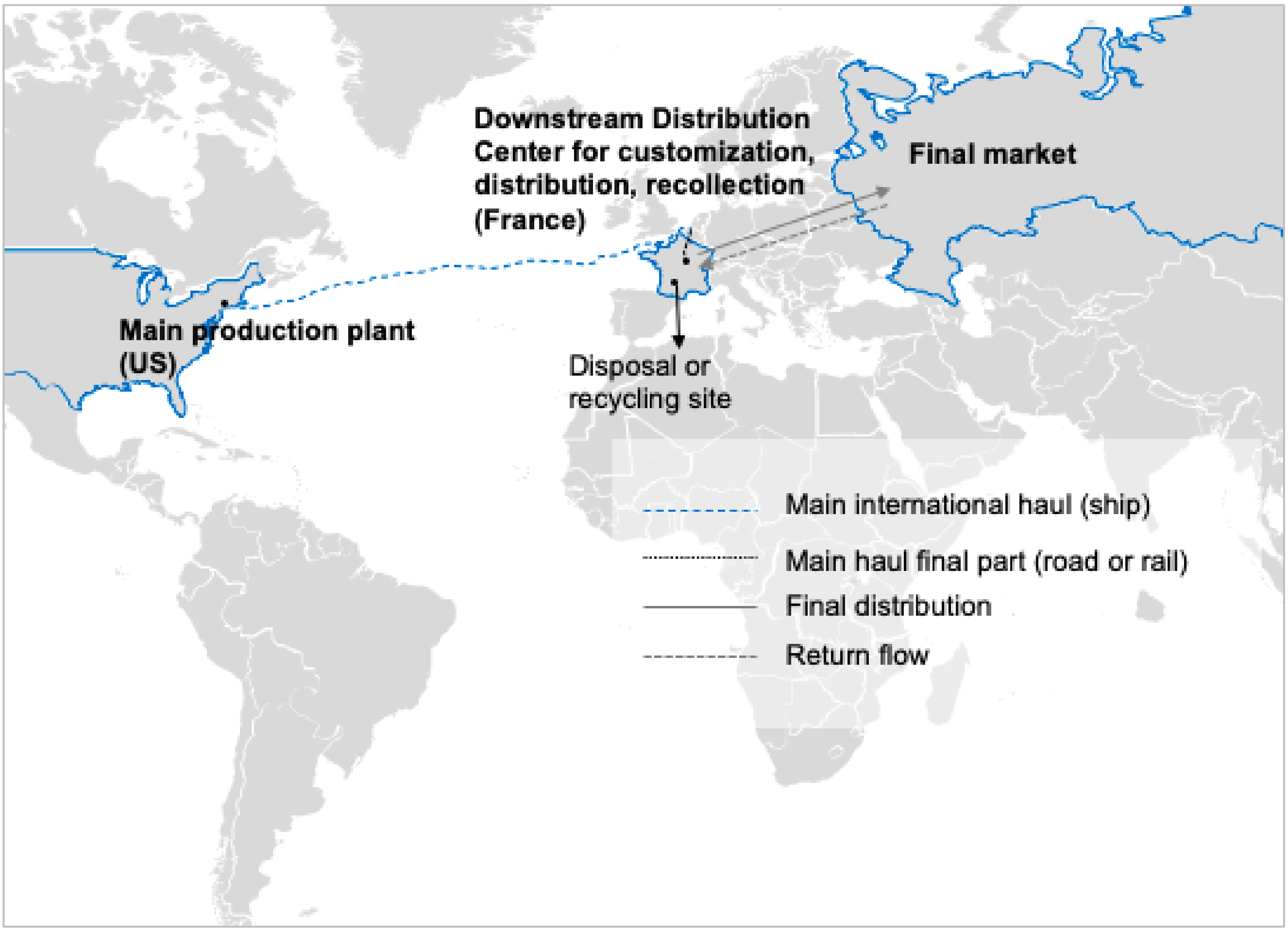


Figure 21: Third country postponement strategy for EOL reverse logistics example (own elaboration)

Theoretically, the resell could even take place in the home region, with a global and dispersed customer base. In this case, theoretically a 'home postponement strategy' exploiting a very huge manufacturing and distribution facility could better serve the return flows. However, this would entail a very huge logistics effort which has not empirical evidence of being profitable, nor case studies were found in literature providing examples of such strategy.

REASONS TO INTRODUCE THE ENVIRONMENTAL PERSPECTIVE: THE TRIPLE BOTTOM LINE APPROACH

EMISSIONS COMING FROM LOGISTICS

As stated by Loy & Tatham (2016), human society pushed towards a self-destruction ever since the end of the Industrial Revolution, continuously adopting more and more CO2 emission-intensive solutions and waste of materials. In fact, manufacturing policies, especially in the last century, were focused solely on economic growth and development (Sonego, et al., 2018). Such policies caused significant issues for the environment and ecosystem and, together with a huge growth in world's population, contributed to global warming as stated by Simão et al., (2016). Researchers and studies on environmental impact of industrial processes focus in particular on carbon-rich fuels such as coil, oil, gasoline and even natural gases, which when are burned produce GHG. Greenhouse gases (GHG), such as CO2 or methane, are those that can absorb and emit infrared radiation, which results in global warming and changes to the climate, causing also precipitation, rising sea levels, and extreme weather phenomena (Simão, et al., 2016; the balance, 2020). Moreover, the growth of global supply chains has increased the amount of transportation and logistics worldwide, which account for a significant portion of a supply chain's emissions (Ugarte, et al., 2016). In some consumer product supply chains, GHG emissions due to transportation are between 5% and 15% of total emissions over the product life cycle (World Economic Forum, 2009). With an increase in the amount of activity, the overall amount of emissions associated increase as well. Since transportation is a part of every consumer product supply chain, though, its aggregate environmental impacts are even more significant when considered as a whole. The World Economic Forum (2009) estimated that 5.5% of world's CO2 emissions are attributable to transportation and logistics, or 2800 mega-tonnes per year. The latest study by (IEA, 2020) concludes that more than 20% of world's global CO2 emissions are due to transportation, and more than 70% of this is related to road transports. This is especially significant when companies operate in geographically dispersed supply chain networks to fulfill customer demands, as in global supply chains, and the development of activity also causes environmental issues, such as increasing resource consumption and pollution production at a global level (Budiman & Rau, 2019).

Logistics activities, therefore, as stated also by Ugarte et al. (2016), create several environmental impacts, including increases in emissions which are related to climate change, eco- system quality damage, and human health issues.

The environmental deterioration caused by business activities has increased the awareness and pressure from various stakeholders in addressing the environmental issues, and the enforcement of environmental policies to mitigate the environmental damage in such activities (Budiman & Rau, 2019). The concern resulted in an international community's response, grounded in the 2015 Paris Agreement, which has the key objective of limiting future global warming to between 1.5 and 2 ℃ above pre-industrial levels, with economic and social transformation (UNFCCC, 2015).

If major and urgent efforts to slow accumulation of carbon dioxide (CO2) and other greenhouse gases in the atmosphere are not taken seriously by governments, companies and consumers, future generations will inherit a much warmer planet with risks of dangerous climate events, higher sea levels, and destruction of the natural world (Parry, 2019b).

The concern about a company's environmental impact covers various areas. As stated by Mukherjee (2016), the five basic sustainability indicators for a firm are:

- material intensity
- energy intensity
- water consumption
- toxic emissions
- pollutant emissions.

THE TRIPLE BOTTOM LINE APPROACH

Nowadays, it's becoming increasingly necessary for companies to factor environmental impact of business strategies into decision taking, as stated by Yang et al. (2005).

This concept is extensively found in literature: large scale emissions of greenhouse gasses is a top environmental concern, and companies are under varied and increasing pressure from governments and consumers to incorporate emissions reduction activities into their supply chain management practices (Jabbarzadeh, et al., 2019).

Companies started to integrate these aspects in their operations and the concept of 'Triple Bottom Line' came up. Triple Bottom Line refers to the three aspects that must be taken into account by a company aiming to grow sustainably: economic growth, ecology and social inclusion (Tseng, et al., 2018). Globalization and environmental problems urge the development of a supply chain system that has the capability of fulfilling a high variety of demands and has more environmentally friendly operations at the same time (Budiman & Rau, 2019).

Therefore, industries have an incredible opportunity to reduce GHG emissions through what is commonly referred to as 'green logistics' as stated by (Budiman & Rau, 2019; Ugarte, et al., 2016), and several studies show with data the potential benefits (see for example World Economic Forum, 2009).

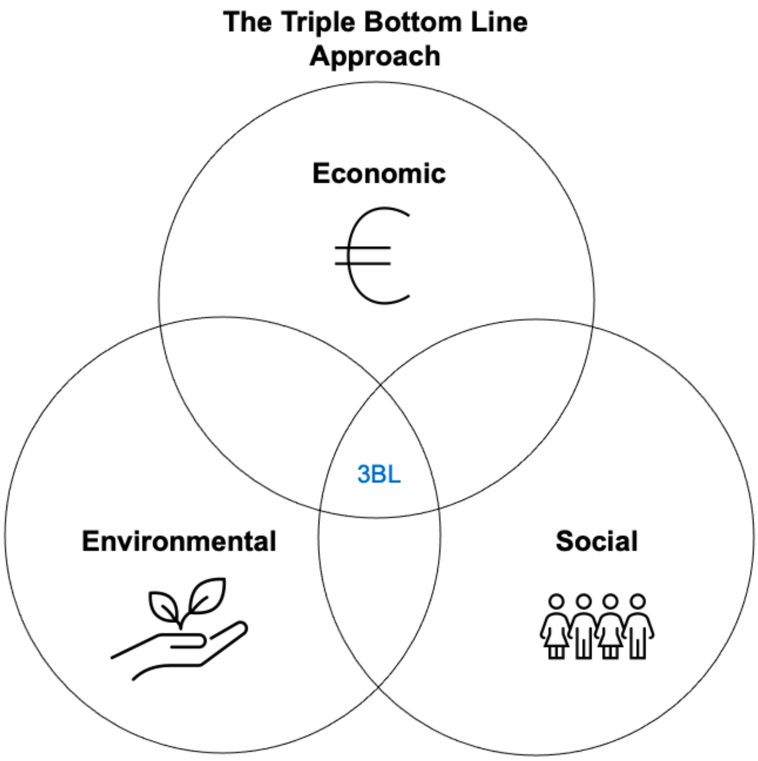


Figure 22: The Triple Bottom Line approach (own elaboration)

A definition of ‘Green Supply Chain Management’ can be found in Simão et al. (2016), as a system in which significant savings can occur in energy consumption, water use, and waste and gas generation, through the reconfiguration of the supply chain and the efficient management of material flow, achieved by an effective integration of logistics with the production process. Carbon management can in fact represent a route to lower costs and greater visibility (World Economic Forum, 2009).

Sustainable Supply Chain Management, instead, goes a step further to include also the social aspects into the equation. In Mukherjee (2016), the Triple Bottom Line is extended to Supply Chain Management with the concept of 3MeS. The ‘3M’ stand for the traditional goals of Supply Chain Management man, money, material, the ‘e’ stands for ecology and the ‘S’ includes a social concern.

This study wants to provide a practical framework to improve the environmental impact of supply chains with geographical postponement. Since it focuses on GHG emissions, the social perspective is out of the scope of this study and will not be discussed in details.

Obviously, Green SCM provides great opportunities but at the same time poses numerous challenges when confronted with reality, such as optimization in distances, lead time, fuel consumption, low GHG emission and cost (Khan, et al., 2011).

CO2 emissions of supply chains are generally divided in fixed and variable.

Variable emissions from production or transportation are proportional to the quantity of products that are produced or transported. Fixed emissions refer to a fixed amounts of equivalent carbon dioxide released, irrespective of the quantities produced or transported. Therefore, if the quantity produced or transported exceeds zero, fixed amounts of greenhouse gas are generated. Some examples of these sources are the electricity used for lighting, the energy utilized for setting up production lines, and the electricity used by cooling systems of refrigerated vehicles (Jabbarzadeh, et al., 2019).

With the increase in global logistics activities, both fixed and variable sources of GHG emissions grow (Budiman & Rau, 2019; Ugarte, et al., 2016).

Moreover, supply chains are responsible of three types of emission sources, referred to as ‘Scopes’: scope 1, scope 2, scope 3. This division has been set by the GHG Protocol Corporate Accounting and Reporting Standard. Scope 1 emissions are generated from operations under the direct company’s control, including onsite fuel combustion and fleet vehicles.

Scope 2 emissions come from usage of electricity, steam, heat and/or cooling purchased from third parties. Scope 3 emissions are often referred to as ‘supply chain emissions’ and are all the other sources of emissions along the value chain. For example, scope 3 emissions include transportation by suppliers, business travels or product disposal (World Economic Forum, 2021).

Postponement strategies, especially with a geographical perspective, deal hugely with supply chain structure or reconfiguration. Therefore, some studies began to study the relationship between postponement strategies and their level of sustainability or emissions produced.

The first paper analyzed introducing the sustainability perspective is by Abukhader & Jönson (2004), who nearly 20 years ago explained the importance of incorporating LCA in logistics and supply chain decisions.

SUSTAINABILITY-RELATED FACTORS

From the literature emerged that when designing a downstream supply network, implementing postponement with a geographical perspective, there are several factors related to sustainability which have to be considered. Such factors are output oriented: therefore they can be reconducted in the 'performance measures and expected goals' section of the factors seen in the traditional view. Moreover, sustainability-related factors can be divided in two categories:

- Direct environmental output factors: elements directly contributing to GHG emissions or other types of pollutant outputs. Such outputs must be progressively reduced by companies, under social and institutional pressure, and therefore are a critical factor to consider.
- Costs or revenues related to carbon emissions factors: policies related to sustainability which affect the profitability of corporations and therefore are of primary importance for business decisions. In particular, carbon cap-and-trade and carbon tax are discussed.

	Sustainability related factors	**References**
Direct environmental output factors	Transport and sc emissions	(Ugarte, et al., 2016) (Jabbarzadeh, et al., 2019) (Simão, et al., 2016) (Budiman & Rau, 2019) (van Zeller, et al., 2018)
	Facility footprint's environmental damage	(Ugarte, et al., 2016)
Costs or revenues related to carbon emissions factors	Carbon cap	(Budiman & Rau, 2019)
	Carbon tax	(Budiman & Rau, 2019) (Parry, 2019a)

Table 9: Sustainability-related factors (own elaboration)

TRANSPORTATION AND SUPPLY CHAIN EMISSIONS

In global supply chains huge logistics effort is put on transports, which constitute significant portion of GHG emissions. Several studies introduced the overall carbon impact from transportation in the equation when evaluating a postponement strategy (see for example, Ugarte et al. (2016); Jabbarzadeh et al. (2019); Simão et al. (2016); Budiman & Rau (2019); van Zeller et al. (2018)), testifying as this is a relevant factor to consider for firms operating globally. As previuously seen, today customers are more willing to buy from a company active toward a sustainable future. Moreover, several tools today enable a company to have a proxi of their expected carbon output from logistic processes, thus giving the eventual opportunity to reschedule the value network to minimize such output.

Scope 3 emissions are not of secondary importance as well: those emissions are indirectly generated by the company along the supply chain, by business travels, purchases, product travels, wastes etc. They indeed generated by far the largest amount of emissions compared to Scope 1 and 2. For example, for a big consumer brand company like Nestlè only 5% of emissions are generated from direct operations, while those generated by its suppliers are 10 times higher (World Economic Forum, 2021). When designing a global network, a company seeking sustainable goals should then consider carefully also the expected level of Scope 3 emissions. This includes selecting suppliers based on their sustainable practice levels, selecting countries based on recycling capabilities and so on.

Scope 3 actions can have a favourable climate impact in countries where regulatory pressure is low. For example, Western economies import significant volumes of emissions, especially from Asia. This means that supply-chain measures and suppliers selection put in place by relatively few end-consumer companies in Europe and the US can affect the emissions profile of growing Asian economies (World Economic Forum, 2021).

FACILIY FOOTPRINT

Production and logistics facilities such as plant, warehouses and Distribution Centers are among the biggest contributors of emissions for companies. In particular they contribute to Scope 1 emissions, those directly generated from the company’s activities on-site or by its fleet of vehicles (World Economic Forum, 2021).

The emissions generated by a facility can be split in variable and fixed: while variable emissions vary depending on the activities performed (fuel or energy consumption for machines), fixed emissions depend, under certain limits, on the size of the facility. These are typically derived from resource usage for ancillary services like air conditioning, cooling, or lighting. Besides pure carbon dioxide emissions, other types of negative environmental outputs are connected with logistics facilities such as Distribution Centers. First, the are responsible for light pollution and acustic pollution due to the huge amount of activites carried at all times. Moreover, facilities are also environmentally impacting beacause of their usage of soil and the required cementification. Ugarte, et al. (2016) pointed out that in some countries, like the United States, land regulations framework, tax policy, and economic development incentivized in the past years the establishment of big-box massive retailers, conveying the idea that bigger is better, thus requiring a lot of land out of major city centers. Generally speaking, a bigger facility is responsible for more negative impact from a sustainability perspective, both in terms of direct emissions and indirect impact on the society and the environment. The increase in facility footprint must be taken into account when considering a geographical postponement strategy, since more customization activities are performed downstream more space would be required. Customization operations postponement in fact requires additional space at the Distribution Center to both perform the customization and/or store final products (Ugarte, et al., 2016). While the postponement of more geographically dispersed production processes could concentrate customization activities in one single downstream location, thus reducing the overall resource usage due to assembly or packaging, it would still require to build a bigger facility in terms of footprint. In more recent years, a lot of attention has been given to the creation of greener, less impactful facilities and in some countries regulations are in place to limit building new facilities but rather use existing ones (Naeco, 2020).

CARBON CAP

Cap-and-trade is an alternative regulation that countries are adopting to control carbon emissions. In particular, cap-and-trade is recognized as one of the most effective, market-based regulation, to tackle the GHG emission problem (Xu, et al., 2021). While a carbon tax sets a price for fossil fuels usage, a carbon cap is the opposite. It sets a maximum level (a 'cap'). Under cap- and- trade regulation, the government firstly gives a certain quantity of free emission credits to the manufacturers, who can buy more or sell the allocated emission credits later with a carbon trading price through a carbon trading market. Under the cap-and-trade regulation, a manufacturer receives a carbon quota from the government and can sell its excess carbon credits or buy extra carbon credits from other firms (Xu, et al., 2021). Cap-and-trade was first implemented by the European Union in 2005, and today is present also in US and China (Lu & Sun, 2021). For example, European Union Emissions Trading Scheme (EU ETS), which is the largest carbon trading market in the world, covers over 50% of the total carbon emissions in EU (Xu, et al., 2021).

When designing a global supply chain a company should consider the implementation of such regulation. Especially if pondering if to postpone activities downstream, geographically closer to the market. In fact, EU, US and China are primary markets and also regions where cap-and-trade is adopted. These regulations are very effective since can provide an additional revenue opportunities for companies using green and sustainable solutions, selling regulatory credits to automakers that need help complying with emissions rules. For example, electric car maker Tesla's business selling carbon credits valued $1.4 billion in 2020 and is expected to rise to $2 billion in 2021 (Trudell, 2021), with credits being bought above all by GM and FCA (now part of Stellantis), which are less advanced in electrification process. Budiman & Rau (2019) proved as the carbon cap, upon which a company can rely, can drive the firm's decision on the level of green technologies adopted. With higher carbon cap value available, supply chain strategies adopted tend to utilize facilities with less sustainale technologies. More efficient and green technologies are utilized more as the carbon cap gets lower. Carbon cap, as carbon tax, impacts both the geographical perspective on postponement and the overall supply chain sustainability level for a firm.

Country	Carbon price ($/ton. eqCo2)	Carbon cap-and-trade implemented or scheduled	Carbon tax implemented or scheduled
Sweden	137	x	x
Norway	69	x	x
France	52	x	x
EU ETS market	50	x	
Canada	32	x	x
UK	24	x	x
California	18	x	
Shanghai*	6	x	

* China pilot test

Table 10: Carbon price in some major economies. Source: World Bank, 2021

CARBON TAX

One of the main factors that companies consider when implementing a postponement strategy in a global supply chain, aiming to introduce a sustainability perspective as well, is the carbon tax (Budiman & Rau, 2019).

A carbon tax is a fee that a government imposes on any company that burns fossil fuels, trying to reflect their true cost, per each ton of fuel producing polluting emissions. Coal, oil, gasoline, and natural gas are among the most used, since when they area burned produce emissions and consequently heating or extreme weather events (the balance, 2020).

Carbon emissions are a negative externality, particularly non-pecuniary because generates a non-economic cost for the whole population. Governments are trying to address this issue imposing carbon taxes, trying to incentive in this way the use of greener processes and solutions (He, et al., 2021). This is not just a spontaneous push towards a greener supply chain from the company, since carbon tax entails a cost or a saving for the company which has to be incorporated into the equation when designing its global structure. The reduction of emissions creates indirect benefits also for local population, such as reduction in the number of people dying prematurely from exposure to local air pollution caused by fossil fuel combustion (Parry, 2019b). According to the IMF (Parry, 2019a), carbon taxes can discourage the use of fossil fuels and accelerate the shift towards less-polluting ones, and particularly can help countries achieve their pledges under Paris 2015 Agreements. Currently, global average carbon tax is at 2$ per ton, which is less than what it is needed. To reduce effectively emissions is heavily-pollutant countries like China, India and South Africa a 35$ price per ton would be required (Parry, 2019a).

There are several arguments supporting a carbon tax introduction, besides the direct benefits for the environment, as suggested by Parry (2019b). First, carbon taxes provide revenues for countries, typically 1-2% of GDP for a 35$ per ton tax in 2030 projections. This can benefit the local economy and potentially offset the loss of occupation in carbon-based sectors. However, the decline in occupation is also progressively counterbalanced by an increased number of jobs in greener sectors. Second, carbon taxes are straightforward to apply, administer and collect, since are integrated into existing exercises.

Country	CPS (Carbon Pricing Score) at EUR60 benchmark
Norway	68%
France	55%
Italy	51%
UK	47%
Canada	34%
Japan	24%
US	22%
China	9%
Russia	7%
Indonesia	2%

Table 11: Carbon Pricing Scores. Source: OECD, 2021

When designing a global supply chain, a company should therefore consider the application and the level of carbon tax in different countries. For example, Budiman & Rau (2019) studied the overall level of supply chain costs and emissions for a notebook manufacturer applying postponement strategy, under different carbon tax policy levels. They proved that the carbon tax influences a company's decision in the level of green technologies used: an higher carbon tax level applied in the country is directly proportional to the effort in adopting greener technologies. Performing customization processes in a selected country means producing additional emissions there and, therefore, be subject to different carbon tax policy levels. The carbon tax level in place, decided by the government, should therefore be considered when pondering the geographical relocation of postponement activities.

Obviously, this factor could be softened by using non polluting fuels such as biofuels or electricity. However, the transition towards total green and sustainable consumption of energy has just started and companies will have to consider it for a long period.

Table 11 represents the Carbon Pricing Score (CPS) of some major economies, i.e. the percentage of emission-related sources which are priced, either through explicit taxes or excise taxes.

ECDM (ENVIRONMENTALLY CONSCIOUS DESIGN AND MANUFACTURING)

Postponement application is strongly related with modularity of products which, as previously examined, can have a trade off with respect to the final carbon footprint generated. Modularity in fact, could have bad impact on overall emissions related to the increase in weight. However, modularity implies a substantial redesign of the product which gives more engineering freedom and can lead to exploiting some opportunities for an eco-friendlier design. In fact, literature generally associates modular design to environmental benefits for this reason (Sonego, et al., 2018). In this section, the re-design requirements and related possibilities are further discussed. For a sustainable product and supply chain this is a relevant perspective to consider: the redesign needed provides freedom in the development, and therefore space for sustainable solutions embedded in the product, considering both functionality and environmental performance. This is generally regarded as eco-design for product life cycle (Jeong, et al., 2015). In fact, during the design stage most of the life cycle costs, as well as environmental impact, are determined (Chung, et al., 2014). Such environmental impact manifests as pollutant emissions, which may be generated at all stages in the whole primary life cycle of a product, which includes manufacturing, assembly, consumer service, disassembly, as well as the recycling or reuse stage (Qian & Zhang, 2003). The life cycle of a product, more specifically, ranges from the initial specifications to the withdrawal from the market. To have a comprehensive and complete sustainable view, it is important to consider the whole life cycle and also the end-of-life options (Philip, et al., 2013; Sonego, et al., 2018). End-of-life options (EOL) determine if a component can be recycled, reused or disposed after it is withdrawn from the market and it depends on the material and from the design (Philip, et al., 2013). Due to growing environmental concern in the past decades, also EOL practices at product retirement stage garnered attention from researchers (Chung, et al., 2014), and big institutions already made some moves to include EOL operations in the design stage. For example, ISO introduced ISO 140040 standards and LCA (Life Cycle Assessment) was born. LCA is a methodology used to assess the potential environmental footprint as well as the resources used throughout the whole life cycle of a product (Lee & Inaba, 2004). Governments are pushing for a LCA of firms' products as well: Europe introduced EPR (Extended Producer Responsibility), as a set of policies and standards for an efficient disposal and minimization of waste, to be considered by the manufacturer (BIO by Deloitte, 2014).

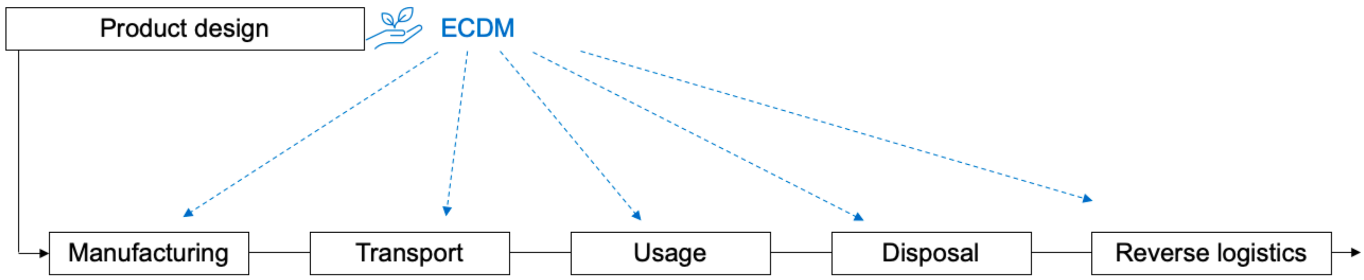


Figure 23: Phases of product's life cycle and ECDM (own elaboration)

Considering the environmental output of the whole product's life cycle at design stage is today one of the most critical aspects of product engineering, and this is well found in literature with different names and forms.

Sonego et al. (2018) state that redesign of industrial practices, together with services and infrastructures, is required to achieve sustainable consumption and production.

Kremer et al. (2013) introduce it in the form of ECDM (Environmentally Conscious Design and Manufacturing). In general literature it falls under the concepts of 'DFx' approaches, which describe design philosophies and methodologies that focus on the improvement of products at different stages of the life cycle, where the 'X' represents the objectives of the design (Sonego, et al., 2018). It was studied for example by Qian & Zhang (2003) who referred to it as DFE (Design For Environment). Such approaches are, however, often very broad and provide little details on the actual implementation phase. Instead, they give general advice on where the focus has been put in design stage and, as suggested by Sonego et al. (2018), modularization is a key component of DFx. Since postponement is strongly related with modularity, environmentally conscious design can be integrated with a postponement strategy. In literature, also the terms Ecodesign and Green Design have used (see for example Jeswiet & Hauschild, 2005). Besides the terminology, it refers to the concept of taking into consideration environmental factors as early as possible at the design stage of products, integrating environmental concerns in the product development. The key concept of sustainable design, to be actually implementable, is that it must develop solutions aiming to be effectively green and sustainable, but balancing private interests of the companies with environmental, economic and social concerns (Sonego, et al., 2018).

ECDM does not refer only to the modularization of the product, but to all aspects which can impact the overall carbon footprint. For example, the material used to manufacture the product is a critical factor for sustainable production. However, modularization of the products is always the first step towards a sustainable design (Tchertchian, et al., 2011) and postponement strategy is strongly connected to modularization concept (Mikkola & Skjøtt-Larsen, 2004; Wadhwa, et al., 2008). Therefore, the main focus of this study will be on the modular perspective of Environmentally Conscious Design and Manufacturing.

There are several strategic objectives which modularization can contribute to, generally referred to with the concept of modularization drivers (Bonvoisin, et al., 2016). With a ECDM perspective in mind, this study will refer to carbon footprint of the product as a modularization driver: the strategic objective it helps achieving is improving the environmental friendliness of the product. Modular products require a substantial redesign of product families, their characteristics, functionalities and production processes and, compared to classical products, the design of modular products is more expensive, time-consuming and requires more efforts (Sonego, et al., 2018; Huang & Li, 2008).

Therefore, if on the one hand modularity will mean typically larger volume or weight, on the other hand the redesign needed provide freedom in the development, and therefore space for sustainable solutions embedded in the product, considering both functionality and environmental performance. This is generally regarded as eco-design for product life cycle (Jeong, et al., 2015). The way in which a product is structured in modules and assembled is called architecture and can impact hugely the overall carbon footprint generated by the product during the whole life cycle, besides influencing the cost and revenues associated. As stated by Bonvoisin et al. (2016), the product architecture affects the efficiency of the product design on all three dimensions of sustainability: economic, ecologic and social. Therefore, product architecture can be an influencing aspect of sustainable product design.

The political agenda of the last decades has been pushing for an eco-pluralistic approach, and clients are accepting more and more products if they are eco-designed (Loy & Tatham, 2016). Postponement strategy can be useful in reducing the overall impact of a product throughout all its life cycle. In fact, the modularization and consequent redesign required provide a huge opportunity for businesses to work with designers to slow environmental degradation (Loy & Tatham, 2016). Companies (manufacturers) aiming to become greener can, in this way, consider also the aftermath of their products upon completion of their useful life (Philip, et al., 2013). For example, products can be better disassembled, reused or recycled.

USAGE PHASE

The use phase plays an important role in determining the environmental impact of a product, since a lot of a product's life cycle emissions happen in this phase. This value can reach the 90% of the total life cycle carbon footprint for products such as refrigerators, television sets and vacuum cleaners (Sonego, et al., 2018). Usage phase starts with the purchase and includes the activation, actual use, maintenance/repair and decommissioning. Sonego et al. (2018) note as modularity in the use phase matches with sustainability as far as it can extend the product's useful lifespan through upgrades, easier maintenance, and repairs. This is found also in Bonvoisin et al. (2016), who state that the possibility brought by modularization to upgrade, adapt or modify just one or few components can extend the life of the product and therefore reduce its environmental load. Also, modularity allows separated diagnoses of product components and isolation of wear parts, easing product maintenance and growing the environmental friendliness of the product design (Bonvoisin, et al., 2016). Moreover, in a geographical postponement strategy a downstream Distribution Center could be able to perform quick maintenance and upgrades, having already assembly lines and components required by the modular architecture. In this case the maintenance phase would be in-house and potentially quicker. Sonego et al. (2018), however, pointed out that repetitive maintenance has to be done carefully by manufacturers, since sustainable modular products could be perceived by costumers as less reliable or safe, with upgraded systems to be of inferior performance or obsolete.

LOGISTICS PHASES

Design for logistics (DFL) refers to the relationship between the product architecture and the supply chain, being it already existent or new. These two components should consider the characteristics of both and adapt to each other (Chung, et al., 2014).

Modularization can have huge impact on delivery and logistics decisions, since product characteristics and supply chain management are interdependent. In a postponed supply chain designing logistic-friendly products to minimize costs and environmental impacts in the product life cycle can be an important subject (Sonego, et al., 2018). A correct design could be beneficial even for disposal phases and return management: manufacturing in the past centuries have increased the 'consumerism' phenomenon (Loy & Tatham, 2016) and, together with a move towards a 'throw-away society', increased incredibly the amount of waste present in the environment, both on the soil, ocean and even space. To reduce the overall environmental impact of a product it is therefore critical to consider the whole life cycle and the end-of-life options. End-of-life options (EOL) determine if a component can be recycled, reused or disposed after it is withdrawn from the market, and it depends on the material and on the design (Philip, et al., 2013). This is not a new concept: one of the first methods for modularization including not only physical aspects of a product but also life cycle concerns regarding the product EOL, such as post-life disassembly or recycling is from Newcomb et al. (1998). Thanks to growing social and environmental concern in the past decades, EOL practices at product retirement stage garnered attention from researchers (Chung, et al., 2014). EOL cycle is present in DFx approaches as well: Qian & Zhang (2003), for example, introduced DFD (Design for disassembly) and DFR (Design for recycling). Product modularity affects the ability to disassemble the product and ease the EOL process. It gives ability to sort parts according to their most appropriate post-life treatment (repair, reuse, remanufacturing, recycle and disposal), thus avoiding a negative environmental load of the product (Bonvoisin, et al., 2016). Some components with complex geometry are expensive for disassembly, whereas components with similar structures can be arranged together into one module as disassembly becomes easy (Philip, et al., 2013).

In practice, however, the implementation of EOL practices like reverse logistics are today still not well penetrated, especially in big, developing and fast-growing countries like India (Gorane & Kant, 2016), even if Ma and Kremer’s (2016) paper verified that research in modularity applied to environmental management has increased.

To conclude, the SLR confirmed the conclusions by Sonego et al. (2018) that there is a lack of studies monitoring whether the benefits and goals set by modularization methods and methodologies are being actually met with a structured, rigorous, scientific method. Most papers assert the support for green modularization and defend the efficiency of their methods in hypothetical scenarios, but concrete evidence of the environmental impact of products monitored with that method are rarely provided.

GEOGRAPHICAL POSTPONEMENT STRATEGIES ASSESSMENT WITH TRADITIONAL AND ENVIRONMENTAL APPROACH

Postponement strategies, by shifting upstream the push-pull boundary, generally lead to a more efficient use of resources, less wastes and unnecessary activities, thus reducing emissions. In this sense, the more the CODP is moved upstream the less unwanted processes are carried out and the overall manufacturing can become sustainable. Therefore, ideally BTO should be used to prevent the production of unwanted finished goods and therefore lower CO_2 emissions (Parry & Roehrich, 2013). Systems as such requires to be very fast and not every company, or sector, can sustain it. Moreover, a faster system in the delivery phase could require a quicker, more pollutant transportation mode, rising the variable part of emissions and potentially offset the reduction in the fixed one (Simão, et al., 2016). This could be managed with greener transportation system, which however could be more expensive making it not profitable (Jabbarzadeh, et al., 2019).

Besides its benefits, some argue that postponement strategy can affect adversely the environmental performances. More specifically, it could require more frequent transportations, to maintain the desired service level, and over longer distances, since usually the path from the main plant to the final market is shorter than the path from the main plant to a secondary Distribution Center and then to the final market, thus raising the overall emissions produces, as stated by (Jabbarzadeh, et al., 2019).

The effect of postponement on the overall emissions, considering both variable and fixed, can lead to a trade-off and requires a deeper analysis of the single application case. Moreover, the two configuration factors, 'where' and 'what' to postpone can both influence the supply chain emissions. Moreover, measuring and evaluating the impact of postponement strategies on green supply chain performances is a new field of study which came up only in recent years (Simão, et al., 2016), therefore few publication (9 out of 22 papers with mathematical model development, or the 40%) address the supply chain costs including also environmental-related ones, such as GHG emissions.

The following section will compare the performances of different geographical postponement strategies under both a traditional and a sustainable view.

Given a 'geographical strategy' (i.e. decision of postponing in home, third, or destination country), different types of postponement (the 'what' to postpone) can influence the overall impact on the environment and the sustainability level of the whole supply chain.

Simão et al. (2016) investigated the emissions related to different types of postponement strategies applied by a Germany-based producer of printers. They explored the best among pure logistics, pure packaging and pure assembly postponement strategy considering three elements: delivery time, total supply chain inventories and total CO_2 emissions (in kg per tranport). The finished goods in the case study were shipped to two dealers, one in Germany for the local market and one in Brazil. They found that, regarding CO_2 emissions, the best strategy is the logistics postponement, followed by pure packaging and pure assembly. The different ecological impact of each strategy resulted primarily by a change in capacity utilization during travels, which forced more or less number of shipments and therefore different overall CO_2 emissions. However, they didn't take into consideration the reduction in resource usage due to the different type of strategy adopted. They also recorded a reduction in supply chain inventories, which could be used as a proxi. In fact, compared to logistics postponement, assembly postponement brought 88% less inventory and packing postponement 27%. The evaluation of the energy and resource wastes brought by logistics postponement was missing and could therefore be the starting point for an additional study.

Regardless of where they are performed, customization activities closer to customers require bigger Distribution Centers in term of footprint, to have the space in which to perform these processes. In addition, it is reasonable to assume that the more activities need to be performed at the Distribution Center, the more additional footprint it requires. For example, Ugarte et al. (2016) considered a +5% factor in the size of the Distribution Center when performing labelling or packaging postponement. Bigger facilities mean more usage of soil and more fixed emissions for energy for services such as lighting or cooling. In this sense, the 'assembly postponement' strategy is associated with the highest emission level, followed by packaging and labelling, while logistics postponement don't require additional space. This reasoning is suitable for an established company aiming at restructuring its downstream supply chain, opening a new Distribution Center or changing an existing one to perform customization activities. In fact, it is based on the assumption that the additional footprint required downstream is added to the existing soil utilization of the company. If the firm is designing its downstream supply chain from scratch, it could consider having a smaller production plant upstream since some activities are not to be performed on site. Anyway, this provides a useful factor to consider when designing or restructuring a downstream supply chain.

The study by Ugarte et al. (2016) concluded that postponement strategy slightly increases the fixed, infrastructural emissions but at the same time can reduce a lot the variable emissions related to transportation, since acting on a better inventory management.

Budiman & Rau (2019) introduced a model comparing different postponement strategies considering both economic costs and environmental costs. Their study is significant in the literature found since it compares different postponement strategies considering both economic costs and emissions, then including carbon policies and different demand deviation levels. They included in particular: procurement cost, transportation cost, facility utilization cost, processing cost, energy cost (used in transportation and manufacturing), carbon emission cost (monetizing the carbon emissions caused by processes in manufacturing and tranport) and overstock penalty. In their model, the company can rely on downstream Distribution Centers in the final market, able to perform various final stage configurations (assembly, packaging or distribution), thus making it a 'global postponement' strategy. They introduced in the model four possible strategies: BC SP strategy (which postpone the beginning of the assembly), SFG1 strategy (postpone assembly at a later stage, speculating a first assembly of basic components), SFG2 strategy (packaging postponement) and FG strategy (logistics postponement). Moreover, they included a greener transport decision: the supply chain has the options of choosing technology based on their greenness and cost, and the higher the greenness of the technology the higher the cost to utilize them. This technology is incorporated into the facility utilization decision, which indicates as strategical decision related to the greenness (technology 3 is the greenest but more expensive, while technology 1 the opposite). They utilized a notebook supply chain to test the model, initially in a single-period and then with a multi-period experiment.

In the single period analysis, they found that both costs and emissions are higher when more activities are speculated instead of postponed. In particular, they found that FG strategy (logistics postponement), compared to BC strategy (assembly postponement) led to a 4% increase in total cost per unit produced and 5% increase in emissions per unit (measured in kg eq.CO2/unit). More speculative strategies produced more emissions both in transportation and in production. This result confirms the conclusion previously analyzed by Simão, et al. (2016). In the multi period model the situation changes, since the extra work required to forecasts data is modelled to increase the emissions produced. In this case, SFG2 strategy (packaging postponement) performs worse than FG strategy (logistics postponement) in both costs and emissions. Similarly, BC strategy (initial assembly postponement) produces more emissions than SFG1 strategy (postpone the secondary assembly, but speculate the first, family-related, assembly). Their study concluded that applying more postponement is not always a guarantee of achieving less costs and emissions simultaneously, but it is important to consider each case separately.

In a further step they included carbon policies in the study, modelling different possible levels of policies in place and their implications for the sustainability of the supply chain. They found that carbon policies (carbon tax and carbon cap) provide a significant reduction in total emissions with a minor increase in cost. Carbon policies in particular can drive technologic decisions: with less restricting policies (low carbon tax or high carbon cap value), supply chains tend to have less sustainable and advanced technologies, whereas greener solutions are utilized more as the carbon tax value gets higher or the carbon cap available gets lower. This was the only study exploring methodologically the impact of carbon policies.

In their study, cost and emissions values are also affected by the level of standard deviation in the demand. In particular, more standard deviation requires more effort and/or extra processes, thus negatively affecting the emissions produced. Their study confirms that the FG strategy (logistics postponement) has the worst performance, in terms of costs and emissions, against the increase in demand standard deviation. BC strategy (assembly postponement) instead reduces both cost and emissions, and is the best solution under any level of demand uncertainty.

A different point of view is found in Jabbarzadeh et al. (2019), which explored the potential trade off brought by postponement applying a by-objective optimization model to Pars Darou Company (PDC), one of the leading pharmaceutical companies in Iran, belongs to Tamin Pharmaceutical Investment Holding, the top pharmaceutical supply chain in the country and one of the largest pharmaceutical groups in Asia. In this model manufacturing plants, Distribution Centers and final destion regions are all concentrated in the Middle East, even if in different countries. They observed that total supply chain cost increases as emissions decrease, because of the very expensive cost of greener solutions. Greener solutions, in their model, did not include facility emissions, making greener transportation the biggest source of cost inflate. They also found a low steepness curve for higher level of emissions. This means that higher pollutant supply chains have greater opportunities to reduce significantly the overall CO_2 emissions with only a slightly increase in cost (14% reduction in emissions requires only 1% increase in cost).

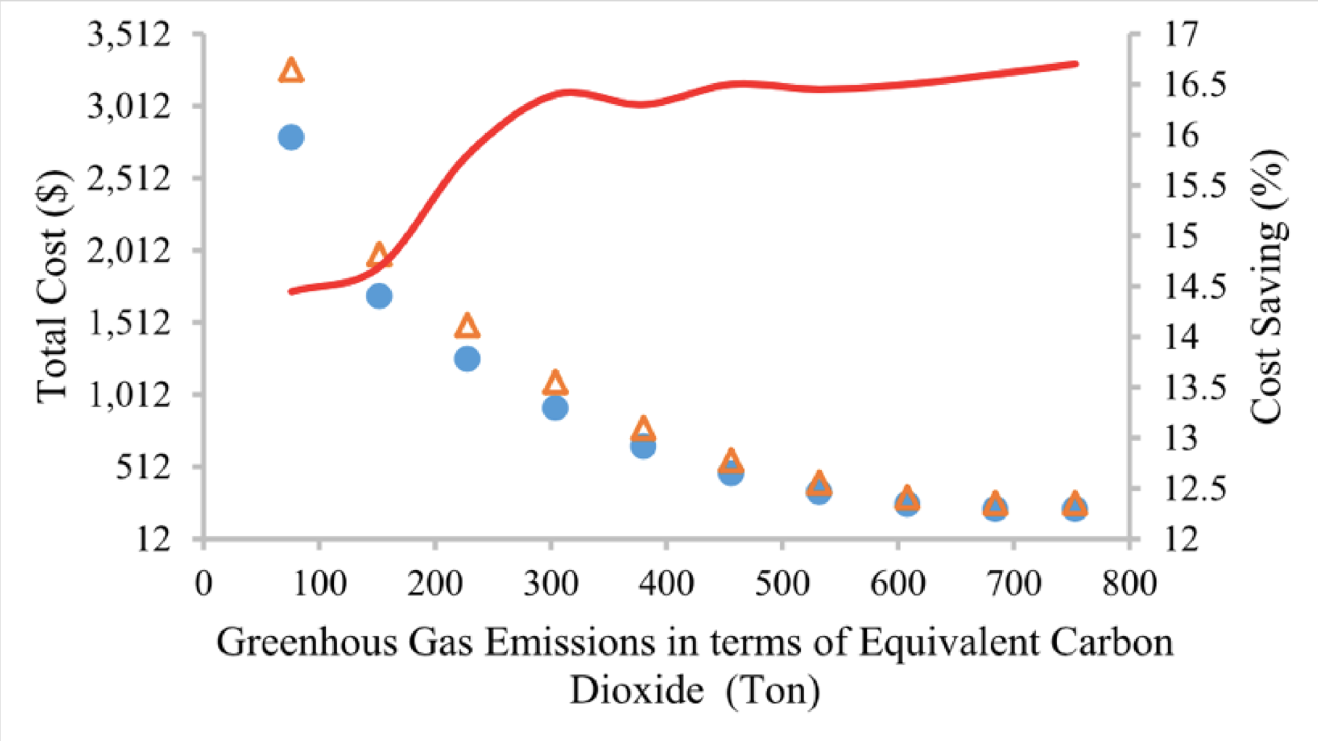


Figure 24: GHG emissions and total Supply Chain cost relationship (15% demand variability assumed). Source: Jabbarzadeh, et al., 2019

Moreover, they also highlighted the cost savings that can be reached thanks to postponement at any level of GHG emissions. Independently from the amount of greenhouse gas emissions, the postponement strategy can consistently provide cost savings for the supply chain. Similarly, the postponement strategy is useful in tackling the total greenhouse gas emissions irrespective of the amount of total costs. Figure 24 shows the emissions and cost relationship for 15% demand variability level, as well as the cost savings provided by postponement application (with the red line). However, the study also showed that the greater the degree of the demand variability is, the larger the benefits of the postponement strategy will be, and postponement strategy therefore is more effective when the supply chain is subject to higher variations in demand. All these papers lacked to introduce the environmental impact caused by the reconfiguration effort which, as previously explained, is a significant concern when implementing a geographical postponement strategy. This is introduced by van Zeller et al. (2018), who compared different geographical postponement strategies for a tissue paper company. The standard component was a jumbo roll, which was then converted into the final product (toilet paper, tissues etc). For the portugal-based company, the decision was wheter to perform the conversion of the rolls in the portuguese plant (home packaging postponement), or to postpone it downstream in a conversion site in the UK, which is the final market (global packaging postponement). If from an economic perspective it was cheaper to ship jumbo rolls (thus postponing the final packaging), from an environmental point of view sending directly the finished products is better and gives a significant 24.5% emissions reduction. The main cause of this is the installation of the converting facility in the UK, which has to be built and occupies land, causing environmental footprint and social impact. Even if in the model they considered jobs creation as a positive factor, this could not be offset by the environmental damage caused. They also concluded that there are no solutions which improve the social implications without compromising too much both economical and environemtal impact. Therefore, the best solutions lies in the tradeoff between the three aspects of the triple bottom line. Moreover, it should be considered that in this particular supply chain, even if it is a global postponement, the distance between home country and final region is relatively short (Portugal to UK). For more dispersed supply chains, distances are usually larger and the reconfiguration effort or relocation of assembly lines can require even more logistic effort, thus compromising the environmental impact.

To conclude, it should be stressed that the geographical location of the customization process influences the overall environmental impact as well. Transporting products in semi-finished form can usually enable a better capacity utilization of whichever transportation mode it has been using, be it a container or a truck. Therefore, in ‘pure postponement’ performing some customization in the home country means that in general the products will be transported in a more finished form compared to the corresponding ‘what’ strategy in the third-country or destination region strategy, resulting in less utilization and more emissions per transport.

FUTURE TRENDS FOR SUSTAINABLE SUPPLY CHAINS WITH GEOGRAPHICAL POSTPONEMENT STRATEGIES

Some possibilities for future trends or improvements have been found in literature, which postponement strategy could benefit from. These are:

- Digitalization: in particular, data sharing and Cyber-Physical Systems (CPS)
- E-commerce
- 3DP

DIGITALIZATION

Yang et al. (2005b) argued that one of the reasons of the relatively low implementation of postponement strategies over the past decades was the inadequacy in technology development, particularly, in transportation, manufacturing, and information technology.
As seen, customization required by consumers is growing, value chains are more and more dispersed and service level gets stricter. Therefore, only companies effectively able to digitize all their processes and control them remotely can compete and have a competitive advantage.
Global supply chains with geographical postponement strategies have the potential to further improve their performances and reduce emissions thanks to digitalization. In particular, in the following section two trends emerged from the literature, which can enable a sustainable transition and development are discussed: data sharing and Cyber-Physical Systems (CPS).

Data sharing

Data sharing is, in particular, a critical element which can boost or lower the performances of a geographical postponement strategy, both internally and with all stakeholders involved. Shi (2014) discussed the importance of having proper information sharing and to integrate the ERP in a postponed planning and manufacturing system.
With data sharing it is possible to have more reliable forecasts from the client and from suppliers. While digitalization is already used, progresses in communication technologies could further develop the speed and sustainability of supply chains. The digitalization will no

longer be limited to communications and dematerialization of documents, but will involve every element of the value chain.

The IoT (Internet of Things) is projected to grow constantly in the next years and decades, thanks to which companies can remotely control every single aspect of their supply chains, have instant push alerts, update their assets or send instructions in real time. Yang et al. (2004), as well, stated as a more efficient informations sharing system, especially of customer orders, can benefit postponement. In a geographical postponement context with long international shipping, new, faster data sharing can enable better optimization of some part of travels. The advent of 5G technology will enable even faster, real-time data sharing, visualization of flows and ports congestion's optimization, and many others. This is confirmed in practice by major logistics operators as well, which are putting digitalization and data sharing technologies as a top priority for the next years, to achieve both cost optimization and reduced emissions. For example, Mediterranean Shipping Company (2019) states as shared visibility, enabled by digitalization and data sharing, can benefit all their operations and particularly PCO (Port Call Optimization), reducing both costs and overall emissions. PCO uses data sharing among different players (shipping lines, agents, ports, industries) to reduce unnecessary waiting times and implement, for example, JIT Arrival. JIT (Just-in-time) is a concept coming from Lean Manufacturing which is expanded to maritime shipping to reduce carbon footprint of vessels and ports. Through data sharing, ships may optimize their voyage speed to arrive at the port when availability of the berth, fairway and port nautical services is assured. This requires real-time data, and 5G implementation could further improve this system. The reduction in fuel consumption is twofold. By knowing in real time when the destination port is ready, a vessel can adjust its navigation plan to minimize fuel consumption, for example reducing its speed not to arrive early. Similarly, reduced anchorage time and maneuvering, which comprises usually 5-10% of waiting time, can be reduced (Mediterranean Shipping Company, 2019). As said, digitalization provides huge benefits both economical end environmental for individual companies, but even more when several players collaborate, creating a network of information available for all. In shipping, several organizations are in place to achieve long term goals of more sustainable trade by sharing data and invest in technologies. DCSA (Digital Container Shipping Association) aims at fostering global collaboration between players, the widespread use of Internet of Things (IoT) solutions, operational efficiencies and interoperability. The broader goal is to make shipping services easy to use, flexible, efficient, reliable and environmentally friendly (Mediterranean Shipping Company, 2019).

Cyber-Physical Systems

CPS (Cyber-Physical Systems) enable the synergy between computational and physical components and are expected to drive innovation and competition in future manufacturing, as well as in other sectors such as transportation, buildings and medicine. CPS enable to generate “smart” systems which can transform the way people interact with engineered systems, just as the Internet did to the way people interact with information (Dumitrache & Caramihai, 2013). Related to CPS, there are all possibilities of remote and virtual experiences connected with the modularization of products. Calle et al. (2016), for example, explored the concept of VBTO (Virtual Built to Order) introduced by Agrawal et al. (2001) applied to the automotive sector, and extended it with i-VBTO.

VBTO refer to the idea of connecting customers via internet to the products already existing, including those on dealer’s lots, in transit, on assembly line, and scheduled for production, with the expectation that ‘customers are likely to find a vehicle with the colour and options they most want (Calle, et al., 2016). The VBTO relies on the concept of Floating Decoupling Point (FDP) and works as follows. Firstly, when a customer requests a product, the system tries to deliver a product stored in the FGI (Finished goods Inventory), as in a conventional system where the DP is located at the FGI. Secondly, if the customer’s order could not be supplied by the FGI, the system looks for a non-assigned product along the production line, which is being produced or assembled and is not already linked to a client. Lastly, if there is no availability of a non-assigned product within the production line, the system releases a new production order. I-VBTO integrates an inventory control system to avoid over-production and stockouts. This system minimizes the over-use of resources and therefore the total carbon footprint. While it was an interesting solution, it was not studied on a real case application and therefore its benefits remain understudied (Calle, et al., 2016). This concept is introduced also by Wikner (2014) in the form of Decoupling Zones (DZ). The production separation from speculation to commitment to customer is made through a Customer Order Decoupling Zone (CODZ), and a Customer Order Decoupling Point (CODP) which is its final time. Similarly, he introduced Customer Adaptation Decoupling Point (CADP) and Customer Adaptation Decoupling Zone (CADZ) for the differentiation flow responsible for the uniqueness of the product, from standard, to market unique, to customer order unique. Purchase Order Decoupling Point (PODP) and Purchase Order Decoupling Zone (PODZ) delimit the reach of controllability of customer order. These zones overlap between each other, giving the possibility to expand the view introducing the i-VBTO introduced by Calle et al. (2016). These concepts could eventually be integrated in a Cyber-Physical System. For example, a customer could use her smartphone to customize the product, see if it is available and eventually the system could automatically place an order. The more the supply chain goes towards an Internet-of-things (IoT) environment, the more this could eventually be beneficial in terms of tracking better emissions and environmental performances as well. Ballarino et al. (2017), moreover, explored how CPS can be exploited to improve the sustainability of the company's manufacturing process and supply chain. They identified five hierarchical levels in which CPS can be implemented, from a simpler one to a deeper one. At the same time, they provided a progression of functions for real-time analysis of environmental impact that can be linked with the LCA of the product. Put it simply, a deeper level of connection can provide more complete information about the environmental impact of a specific product, regarding its whole Life Cycle. These layers of connections are, from the simpler to the deepest:

- Smart connection level
- Data-to-information conversion level
- Cyber level
- Cognition level
- Configuration level

When a potential customer looks for a product, she could know not only if the product is already made, in progress or to be ordered, but also the environmental impact associated to that specific product's life cycle at any time. If a product is still at home country to be manufactured, the customer would know how many CO2 would require its delivery, besides how much time. If the product is already assembled or is undergoing final stage configuration at destination region, the customer would immediately know, before purchasing, the environmental impact required to finish the manufacturing process and/or shipping and usage life. Each of these layers includes a number of prerequisites regarding the different elements involved, such as the sensors, the data management systems, the simulation methods, and the standardization and optimization criteria (Ballarino, et al., 2017). As stated by Ugarte et al. (2016), customers are becoming more and more aware of environmental concerns and the emissions produced by the products drive their decisions. According to (World Economic Forum, 2009), 67% of consumers in the UK are most likely to buy a low-carbon product, with similar trends also being seen in much of the EU. Therefore, a system enabling a consumer to know in real time the amount of emissions the product she's buying cause could be a source of competitive advantage. Ballarino et al. (2017) conclude that CPS can have positive and remarkable effect in the implementation of Sustainable Manufacturing policies and systems. In today's world, CPS can provide huge benefits both for firms and for the customer experience, as it is confirmed also in a study by the Boston Consulting Group (2018). Potential customers can now see, feel and customize their products directly from their smartphones, thus the ability to have an online store and potentially a virtual configurator is becoming important due to distances and could be exploited in events such as the current pandemic. Apparel company conquered this years ago, with applications able to see what a particular clothe would look like on your body type, together with other policies like free deliveries and easy returns. Bigger and more expensive products today can be suitable to online purchases and configuration as well. Automakers are continuously experimenting with digital technologies that put shoppers in the virtual driver's seat (of a new or used vehicle), making them explore a virtual showroom and see what their potential car would look like in a different color or configuration.

E-COMMERCE

Last years, with the advent of Internet and information technology, saw the rise of e-commerce, and customers are continuously increasing their requirements for unique products which companies try to satisfy (Li & Liu, 2017). The industry is booming: the B2C market online reached € 2,500 billion globally in 2018, marking a +20% from 2017 (Siragusa, et al., 2020). The biggest market was China, followed by USA and Europe. In 2019, e-commerce sales in China reached the equivalent of 5.09 trillion US dollars, one quarter of which is from online retail sales of physical goods (He, et al., 2021). E-commerce can provide opportunities for lower costs, higher efficiency, and an unlimited reach, but many enterprises find themselves dealing with an excessive request for custom-designed products, pushing 'Mass Customization' at its extreme (Su & Chuang, 2011).
This is an issue proposed also by Li & Liu (2017), who pointed out that manufacturers, to face internet-generated problems like demand forecasting, inventory control, and high quality service for customers, exploit component generality in a postponed supply chain.

Yang et al. (2004) observed as e-commerce can be exploited by manufacturers applying postponement, which are using it extensively. Given the time lag between the moment when the customer places an order and the time she is willing to receive the product, the manufacturer has a time window to exploit to perform customization operations. They pointed out as this could enable, more efficiently, to stock basic components and perform final configurations just after receiving the customer order. Stocking basic components, indeed, is cheaper and more environmentally friendly for the shipment thanks to the better utilization of space provided by bulk stocking. The time window that customers are willing to accept before receiving the order is getting more and more strict, and a source of competitive advantage for companies in the sector. However, the huge numbers that firms can get from online customers could enable economies of scale in modular products and in assembly capacity. Therefore, if the assembly time is quick enough the time window can still be exploited to perform some final stage configuration operations, thus leading to a competitive advantage for the firm, resulting from less speculated and potentially wasted components. Moreover, as previously seen, delaying such operations results in less resource usage thus positively affecting the environmental output.

On the other side, to occupy the time window allowed by the customer doing production or assembly operations implies to have less time for the final delivery. This could mean having the need to schedule faster last mile transportation, which are usually costly and more pollutant. The negative carbon emission output of last mile deliveries could be avoided using green technologies such as electric vehicles, which are increasingly popular and suits well for transportation inside city centers and the immediate proximities, where last mile deliveries are concentrated.

To conclude, e-commerce implications on geographical postponement, especially when a sustainable approach is factored in, pose numerous questions which are a relevant field of study for future research.

3D PRINTING

Loy & Tatham (2016) suggested the use of additive manufacturing technologies, in particular 3D Printing, to create better manufacturing processes and supply chain under both a cost and environmental perspective. According to their proposal, ‘3DP is part of the changes that are happening through the reorganization of business using the Internet, and the disruption of conventional supply chain and logistical practices’. They suggest that 3D Printing could be used in Distribution Center to quickly perform final stage configuration after receiving the customer order by adding material, thus saving a significant quantity of material (since additive production is significantly less material consuming than traditional one) and increasing the transport efficiency.

However, they suggested that 3DP could be taken even a step further: it could be used by final customers through home printers. The manufacturer could send a standard component and consumers could use their own purchased 3D printers to add the features they desire. From a manufacturer perspective applying a geographical postponement, this would mean sending only standard components (or family-related components, more likely) directly to the final costumer, with instructions on how to customize their product. The shipping could in this case be performed from the main factory or from the downstream Distribution Center, but the latter would lose its competitive advantage coming from the ability to perform customization. However, it still would entail quicker deliveries. In their study, Loy & Tatham (2016) state that sales of 3D printers were forecasted to double every year from 2014 until at least 2017. From that time, the 3D printer market actually grew considerably, passing from 3.3 B$ in 2016 to almost 6B$ in 2021, and is expected to increase until 2027 up to reaching almost 20B$ (Fortune, 2020).

However, such numbers are related to industrial, B2B market and evidence of increasing market size for home 3D printers were not found.

SURVEY

DESIGN PHASE

Since the 80s, there has been an increasing adoption of empirical studies in operations management research, and particularly of surveys, since it has been realized that the scope of operations management cannot be captured and properly investigated in its entirety by purely deductive tools (Yang, et al., 2005b). Therefore, today survey papers are a widespread method in scientific research. Such papers enable to reach, potentially, huge audiences and to investigate the area under study in the real-world context. In this way, if the number of respondents reached is large enough, the survey can validate statistically the results. For these reasons, for this research it has been decided to develop a survey to further investigate the concepts of geographical postponement and sustainability. However, surveys require strong effort in the preparation phase and in the pilot testing phase, to ensure that all questions are easily understandable and centered on the research topic (Bartolini et al., 2019; Staudt et al., 2015). The design phase of the survey started from the SLR results: the main constructs emerged from the literature were taken and provided the basis for the questions of the survey. In particular, attention was given to develop a survey which was concise and easy, but covering all aspects emerged from the SLR. For these reasons, several design trials have been done and examined by both the author and the co-supervisor, before validating the potential questions. The survey questions, however, were validated with the first respondents during a pilot test to check the full comprehensions and clarity. After several trials, both the author and co-supervisor agreed on thirteen questions to be checked with the pilot test. Before each question, a keyword specifies the SLR’s construct to which it refers. The survey questions are:

1. GOALS - When choosing a country where to perform some final stage configuration operations, one of the driving goals is operational cost minimization. For example, labor cost and transportation cost varies depending on the chosen country. How much would you consider the importance of operational cost minimization when choosing a country/region where to perform final stage configuration operations?
2. GOALS - When choosing a country where to perform some final stage configuration operations, one of the driving goals is fiscal cost minimization. The most relevant forms are: the possibility to exploit lower tariffs (duties) when shipping through that country

and lower tax levels (third countries are often chosen for fiscal optimization). How much would you consider the importance of fiscal cost minimization when choosing a country/region where to perform final stage configuration operations?

3. GOALS - Some countries apply carbon taxes, a tax to pay for the CO2 produced. A particular country could be chosen for final stage configuration operations because it has lower carbon taxes in place. How much would you consider the importance of minimizing tax-related costs (e.g. carbon taxes) in the country/region chosen for assessing final stage configuration operations?
4. FACTORS - Overall supply chain emissions come from different sources (transportation, facilities, suppliers...). The country/region where final stage configuration operations are done can change the overall level of emissions produced (for example, different transportations are used or new facilities are required). To improve the sustainability of your company, how important would you consider the overall amount of emissions produced by your supply chain, when choosing a country/region for final stage configuration operations?
5. FACTORS - The infrastructures of a country (roads, rails, ports) affect the performances and reliability of a supply chain, and different countries have different level of infrastructures. How important would you consider the level of infrastructures present in the country/region chosen for final stage configuration operations?
6. RECONFIGURABILITY - Moving some final stage configuration operations closer to the market is proved to provide cost benefits and lower lead times. However, it requires a strong initial effort and cost to re-configure the supply chain (for example building a new distribution center, moving some equipments there and train new people). This effort could vary depending on the chosen country. How important would you consider this initial 'reconfigurability' effort when deciding the country/region where to perform final stage configuration operations?
7. STRATEGY RELEVANCE - Given all precedent factors as a reference, in designing a supply chain aiming to delay some final stage configuration operations (assembly, packaging, labeling or distribution), how much importance would you give to the geographical perspective (the place or region where these configuration operations are held)?
8. COST BENEFIT - Given all precedent factors as a reference, how important do you think that performing final stage configuration operations (assembly, packaging,

labeling or distribution) in a place geographically closer to the final market is, to reduce the overall cost?

9. SUSTAINABILITY BENEFIT - Given all precedent factors as a reference, how valuable do you think that performing final stage configuration operations (assembly, packaging, labeling or distribution) in a place geographically closer to the final market is, to reduce overall supply chain emissions?
10. FURTHER DEVELOPMENTS - Reverse logistics refers to the return flow of the product (or the packaging) after the use by the consumer, to be recycled or re-used, thus improving sustainability of the product's life cycle and potentially lowering company's costs. Having a distribution center, close to the destination market, where final stage configuration operations are performed could be exploited for reverse logistics flows. How much valuable and feasible do you think this solution could be, for a more sustainable supply chain?
11. FURTHER DEVELOPMENTS - How would you rate your company's effort to implement reverse logistics (refer to the description in the previous question)?
12. FURTHER DEVELOPMENTS - 3D Printing is considered a future solution for mass customization, where the final stage configuration operation is done directly by the final consumers at home with their printer. In a geographical postponement perspective, the manufacturer would send a standard component from the distribution center and consumers could use such method to add the features they desire. How important would you consider 3D printing, as a valid and feasible solution?
13. FURTHER DEVELOPMENTS - ECDM (Environmentally Conscious Design and Manufacturing) means considering the environmental impact of a product already at the design stage. In this way, it is possible to consider all the product's life cycle: production, transportation, usage and disposal, trying to design the product in such a way that optimizes the CO_2 emissions in all phases of the product's life. How would you rate the level of ECDM in your company (how importantly do you consider the environmental impact already at the design stage)?

For each question, the Likert scale (rate from 1 to 5) was used as the response method to make the filling process and the data analysis phase easier.

Moreover, some introductory questions have been placed to identify and contextualize the respondents, checking they are on target respective to the area under study. The introductory questions are:

- Company name
- Interviewee's job title
- Interviewee's country of work
- Company's 2020 revenues

DATA COLLECTION PHASE

It has been decided to send the survey through Google Forms, being it a simple and widespread software. The target audience is composed by large manufacturing firms, with a size big enough to justify a geographical postponement strategy. In fact, as previously seen, only firms with a certain size are suitable for such kind of strategy. Therefore, the survey has been sent only to companies active at global level and with multiple manufacturing facilities spread in different countries (and, usually, different continents).
First of all, a pilot test was developed with four companies, to check mainly two things: first, that the survey was simple and understandable, and questions could not be misleading. Especially since we were targeting companies in different world regions, it has been important to verify the full comprehension. Second, that the research area was clear and the questions were on target, clearly making the respondents understand what the purpose of the study was.
The pilot test was conducted with four companies, which did not highlight potential issues with the survey structure and confirmed the full comprehension of the questions. With one of the four companies, the check phase has been also conducted more deeply with a phone confrontation. During such meeting, all thirteen questions have been carefully read together by both the author and the company's respondent.
After the pilot test phase, the survey has been sent to a wider range of companies, for a total of 80. The survey link has been sent via mail to corporate channels found online.

RESULTS

The data collection phase lasted from April 29th to June 30th, 2021, and nine companies participated in the survey. Such number does not enable to provide statistical validity of the results. However, the results are interesting and valuable for three main reasons. First, this is the first time that the relationship between geographical postponement and sustainability has been investigated in a structured way. Second, all respondent firms have a huge size and are active globally with a dispersed supply chain. Therefore, the target audience have been reached properly. Third, the present study can create a pilot test for a future survey,

Company ID	Founding year	Country (Global HQ)	Revenues range	Sector	Main product	Geographical reach
A	1969	France	> 250 mln	Aerospace	Commercial aircrafts	Worldwide
B	1933	Italy	50 mln - 250 mln	Manufacturing	Injection systems	Europe
C	1995	Italy	> 250 mln	Apparel	Shoes	Worldwide
D	1979	Italy	2 mln - 10 mln	Manufacturing	Mechanical equipments	Europe
E	1941	Liechtenstein	> 250 mln	Manufacturing	Mechanical equipments	Worldwide
F	1984	China	50 mln - 250 mln	Electronics	Computers	Worldwide
G1	1996	Switzerland	50 mln - 250 mln	Pharmaceutical	Drugs	Worldwide
G2	1996	Switzerland	50 mln - 250 mln	Pharmaceutical	Drugs	Worldwide
H	1915	Switzerland	50 mln - 250 mln	Pharmaceutical	Pharmaceutical packaging	Worldwide

Table 12: Survey respondent companies overview

massively spread through corporate channels.

As the sample of respondents is quite small no statistical validity could be guaranteed, thus the answers were analyzed manually. This means that the structure of the analysis has an interview style, and each question's answers are explored to highlight the possible reasons and connections between them.

In the following section, all answers are analyzed.

First question

GOALS - When choosing a country where to perform some final stage configuration operations, one of the driving goals is operational cost minimization. For example, labor cost and transportation cost varies depending on the chosen country. How much would you consider the importance of operational cost minimization when choosing a country/region where to perform final stage configuration operations?

Company	Q1 score
A	3
B	4
C	4
D	3
E	4
F	5
G1	4
G2	4
H	4

Table 13: Q1 results

Operational cost minimization was found to be a relevant factor for all the companies, with no scores reported below 3. As previously explored, such cost minimization is still the primary goal for all firms, especially with big global corporations relying on huge amount of workforce, and sustainability-related aspects must be able to integrate in it. Company G1 alone reported the maximum level of importance for cost minimization. This could be explained since the firm is active in the electronics industry and is very consumer oriented, therefore in a market where prices are a source of competitive advantage. Similarly, the decision to give a score of 3 by Company A can be explained by the same approach, but in reverse: since it is a big player in the aerospace industry, its sector is not affected by strict cost requirements. The other companies gave a score of 4, testifying as cost minimization is still a primary goal, but is not the sole focus of big corporations nowadays. To conclude, cost minimization was a mid-high important factor for every respondent company.

Second question

GOALS - When choosing a country where to perform some final stage configuration operations, one of the driving goals is fiscal cost minimization. The most relevant forms are: the possibility to exploit lower tariffs (duties) when shipping through that country and lower tax levels (third countries are often chosen for fiscal optimization). How much would you consider the importance of fiscal cost minimization when choosing a country/region where to perform final stage configuration operations?

Company	Q2 Score
A	2
B	4
C	4
D	2
E	3
F	5
G1	3
G2	3
H	4

Table 14: Q2 results

The responses to this question have been different, ranging from 2 to 5. As previously explained in the 'Factors' section, cost minimization is a primary goal for all organizations. However, the fiscal management for a company is really dependent on the organization of the firm and the countries where it operates. Therefore, a geographical component is taken into account and the size of the different firms can play a role in such aspect. Company F, for example, rated 5 the fiscal optimization importance. This could be expected since it operates in a sector where a huge number of product components are present and has various facilities across the globe. Moreover, it is a consumer-oriented sector, where service level and time-to-market is critical. Therefore, more downstream warehouses in foreign countries are present compared to other sectors, which inflates the relevance of fiscal optimization. Company D, at the opposite, was the respondent company with the most limited reach both for production and distribution. As a result, it reported a score of 2, and the same did Company A. The rest of respondents reported a score of 3 or 4, testifying as the fiscal optimization is a relevant aspect to consider for globally dispersed companies with international supply chains.

Third question

GOALS - Some countries apply carbon taxes, a tax to pay for the CO2 produced. A particular country could be chosen for final stage configuration operations because it has lower carbon taxes in place. How much would you consider the importance of minimizing tax-related costs (e.g. carbon taxes) in the country/region chosen for assessing final stage configuration operations?

Company	Q3 Score
A	3
B	4
C	4
D	3
E	1
F	1
G1	5
G2	5
H	3

Table 15: Q3 results

As expected, this question led to very different answers, ranging from 1 to 5. This is not surprising since, as previously explained and reported in the question's text, only some countries apply carbon taxes in their territory. Moreover, even among the countries which does reckon on a carbon tax, there are significant differences between the amounts to be paid by companies. Therefore, different companies have different sensitivities to such requirement based also on the location of their manufacturing and assembly facilities. Some companies could have had an old plant or facility in a country where a carbon tax was implemented afterwards, as often happens to big and long-lasting corporations. Therefore, carbon tax in such case would not be something upon which the company can make some geographical decisions.

The different importance given to such factor is, moreover, given to the fact that the respondents companies are active in different regions. Therefore, different political and social concern is currently present in the corporate environment. The two divisions of Company G, in fact, reported the same score.

The average importance score given was 3.2 which collocates the carbon tax applied in downstream facilities as a mid-relevant factor for the respondent companies.

Fourth question

FACTORS - Overall supply chain emissions come from different sources (transportation, facilities, suppliers...). The country/region where final stage configuration operations are done can change the overall level of emissions produced (for example, different transportations are used or new facilities are required). To improve the sustainability of your company, how important would you consider the overall amount of emissions produced by your supply chain, when choosing a country/region for final stage configuration operations?

Company	Q4 Score
A	3
B	4
C	3
D	5
E	3
F	5
G1	5
G2	5
H	5

Table 16: Q4 results

The responses to this question have been high, with an average score of 4.22 which places it among the highest. In fact, all companies are large manufacturing players and have huge logistics operations to manage. It is natural therefore that the emissions coming from such operations must be critically considered. In particular Companies D, F, G1, G2, H reported the maximum level of importance. Supply chains and distribution channels, for all respondent companies, are transnational. Therefore, they do not concentrate on one single country or even region but are more often spread worldwide. As a result, also the environmental concern is not coming just from one institution, but from more than one and/or from international agreements. Such supply chains are therefore more subject to social and political concern. It must be considered that usually more emissions in transport, as said, are associated with worst utilization of spaces which requires more trips. Therefore, this could result in a direct cost for the company, besides the environmental output, which is often considered with more attention.

Fifth question

FACTORS - The infrastructures of a country (roads, rails, ports) affect the performances and reliability of a supply chain, and different countries have different level of infrastructures. How important would you consider the level of infrastructures present in the country/region chosen for final stage configuration operations?

Company	Q5 Score
A	3
B	5
C	4
D	5
E	3
F	5
G1	5
G2	5
H	3

Table 17: Q5 results

Infrastructures present in different countries are critical for the logistics processes of a company, as it is testified by this question. Five companies reported the maximum score with 5 out of 5, while three firms gave a mid-importance with 3. The average answer score was 4.2, witnessing the high concern present in the respondent companies. Overall, in fact, all firms are active and operating at a global level, and rely hugely on external infrastructures.

Sixth question

RECONFIGURABILITY - Moving some final stage configuration operations closer to the market is proved to provide cost benefits and lower lead times. However, it requires a strong initial effort and cost to re-configure the supply chain (for example building a new distribution center, moving some equipments there and train new people). This effort could vary depending on the chosen country. How important would you consider this initial 'reconfigurability' effort when deciding the country/region where to perform final stage configuration operations?

Company	Q6 Score
A	3
B	4
C	4
D	4
E	3
F	5
G1	4
G2	4
H	5

Table 18: Q6 results

The responses to this question have been various. The average score was 4, therefore the concern about reconfiguration is found to be high overall. The reconfiguration effort is, as previously explored, one of the main factors to consider when implementing a postponement strategy, especially with geographical shift downstream of customization operation. However, the level of reconfiguration effort and cost can vary depending on the size of the firm, its possibilities, its strategy, the chosen country and many more factors. Therefore, each individual case would need to be examined to have a detailed measure of the effort, and firms aiming to restructure their supply chains can have just estimates before the implementation, after which they could achieve a more detailed overview. Regardless from the cost, the reconfiguration effort (and time) is a top concern for a company's board and must be effectively justified with estimations of the benefits. This is testified in the respondent's answers which rate as high concern such effort.

Seventh question

STRATEGY RELEVANCE - Given all precedent factors as a reference, in designing a supply chain aiming to delay some final stage configuration operations (assembly, packaging, labeling or distribution), how much importance would you give to the geographical perspective (the place or region where these configuration operations are held)?

Company	Q7 Score
A	3
B	3
C	4
D	3
E	4
F	5
G1	4
G2	4
H	4

Table 19: Q7 results

The geographical perspective has been addressed as a mid-high concern from the respondent companies. Given the fact that this is a new field of study, this is a very important result. All companies gave a score of 3 to 4, besides Company F which ranked the geographical perspective as a maximum importance in a postponement strategy. As already highlighted in question 2, Company F has a strong presence in all continents and operates in a consumer-oriented market which requires to customize products efficiently to achieve a good service level. Given its customer centricity and its worldwide presence, it comes natural a strong concern for geographical postponement strategies.

Eight and ninth question

Questions number 8 and 9 will be discussed together:

COST BENEFIT - Given all precedent factors as a reference, how important do you think that performing final stage configuration operations (assembly, packaging, labeling or distribution) in a place geographically closer to the final market is, to reduce the overall cost?

SUSTAINABILITY BENEFIT - Given all precedent factors as a reference, how valuable do you think that performing final stage configuration operations (assembly, packaging, labeling or distribution) in a place geographically closer to the final market is, to reduce overall supply chain emissions?

Company	Q8 Score	Q9 Score
A	3	3
B	5	4
C	3	2
D	5	5
E	4	4
F	5	5
G1	4	4
G2	4	4
H	5	5

Table 20: Q8 and Q9 results

Questions number 8 and 9 are discussed together as they analyze the postponement implications in the two most important themes of the research, cost and emissions, and also because a strong relationship between the two has been found. The answers of the companies regarding the two topics were very similar, and both scored quite high. In particular, the average for question 8, regarding the postponement benefits for supply chain cost is 4.2, while the average for question 9, regarding postponement benefits for supply chain emissions is 4.

This is relevant for few reasons. First, companies realized that both aspects, the economic and environmental one, can be improved and optimized thanks to an efficient geographical postponement implementation. In fact, almost all companies answered with the same score to both questions. Second, all answers are quite high, testifying as the respondent companies understood as a proper geographical postponement strategy can be really effective to boost the performances of their supply chain, both from an economic and environmental point of view. The economic aspects prevailed on the environmental one, which could be explained from the fact that the sustainability aspect in postponement studies and applications, especially with geographical perspective, is relatively a new field and a lot of companies do not know already all the potentialities, while the cost benefits provided by such strategies are well studied as already explored and found in literature.

Tenth and eleventh question

Questions number 10 and 11 will be discussed together:

FURTHER DEVELOPMENTS - Reverse logistics refers to the return flow of the product (or the packaging) after the use by the consumer, to be recycled or re-used, thus improving sustainability of the product's life cycle and potentially lowering company's costs. Having a distribution center, close to the destination market, where final stage configuration operations are performed could be exploited for reverse logistics flows. How much valuable and feasible do you think this solution could be, for a more sustainable supply chain?

FURTHER DEVELOPMENTS - How would you rate your company's effort to implement reverse logistics (refer to the description in the previous question)?

Company	Q10 Score	Q11 Score
A	3	3
B	5	4
C	4	4
D	5	2
E	4	4
F	5	3
G1	5	4
G2	5	4
H	3	1

Table 21: Q10 and Q11 results

Question number 10 and 11 will be discussed together since they relate to each other and provide interesting insights when considered jointly.

In the first one, the importance and the potentialities of reverse logistics in geographically postponed supply chains are clearly reflected. In fact, the average response for this question has been 4.3, the highest among all questions. Therefore, all companies recognized as a sustainable supply chain in not achieved only by reducing the emissions, but considering the whole Life Cycle of a product and including the downstream development which is Reverse Logistics.

On the other end, the second one testifies as the degree of actual implementation of Reverse Logistics practices among the respondent companies is not very high. The average score given was 3.2, which only collocated it as a mid-implemented practice overall. However, it has to be noticed that the responses are not homogeneous: Company H, for example, implements it in just a 1 out of 5 degree. Whereas Company B, C, E, G have advanced Reverse Logistics practices and scored 4 out of 5. The results confirm what found in literature: Reverse Logistics practices are becoming increasingly implemented, considering their huge potentials, but a lot of realities are slow or reluctant to implement them properly and deeply for a variety of reasons.

The combination of the two answers in interesting as highlights as, even in the small sample of our pilot test, there is a gap between the expectations, potentialities and need of Reverse Logistics practices and the actual implementation in reality.

Twelfth question

FURTHER DEVELOPMENTS - 3D Printing is considered a future solution for mass customization, where the final stage configuration operation is done directly by the final consumers at home with their printer. In a geographical postponement perspective, the manufacturer would send a standard component from the distribution center and consumers could use such method to add the features they desire. How important would you consider 3D printing, as a valid and feasible solution?

Company	Q12 Score
A	2
B	3
C	1
D	5
E	1
F	1
G1	5
G2	5
H	2

Table 22: Q12 results

The responses to this question varied a lot, ranging from a minimum of 1 up to 5. This if not surprising considering that 3D Printing for downstream customization is just at a nascent stage and is not well known in corporate environments. Such result is interesting, therefore, since it reflects the need to further examine the potentialities brought by 3D Printing in geographical postponement, and to match such studies with companies' needs and possibilities.

Thirteenth question

FURTHER DEVELOPMENTS - ECDM (Environmentally Conscious Design and Manufacturing) means considering the environmental impact of a product already at the design stage. In this way, it is possible to consider all the product's life cycle: production, transportation, usage and disposal, trying to design the product in such a way that optimizes the CO2 emissions in all phases of the product's life. How would you rate the level of ECDM in your company (how importantly do you consider the environmental impact already at the design stage)?

Company	Q13 Score
A	4
B	4
C	n/a
D	1
E	4
F	5
G1	4
G2	4
H	1

Table 23: Q13 results

This question's answers are interesting since they reflect, even in this case, the different level of environmental concern and sensibility in different corporate environments. In fact two companies, D and H, reported a minimum level of implementation of ECDM practices. Instead, all other firms reported high or very high levels of implementation. As previously explained, such practices are increasingly becoming popular and spread but some sectors and organizations, limited by corporate decisions or product's constraints, are slower in the implementation of radical changes for the sustainability of the overall Life Cycle of the product. On average, however, the responses have scored 3.37, which is a mid-high level of implementation.

DISCUSSION

RESEARCH STRUCTURE

The results obtained during the study, both from the SLR and from the pilot survey, have been particularly interesting since they fill a literature gap about the geographical postponement. As previously explored, the geographical component in logistics strategies, and postponement as well, is an important aspect and a relevant concern for companies since many years. However, this is the first study examining postponement strategies under a geographical perspective in a structured way. Moreover, it includes the sustainability perspective which is even more new in such research field. The results presentation and structure that this study followed is represented in figure 25. The arrow in the left part follows the steps of a product's Life Cycle, while the central arrow describes the research methodology. The first step was to introduce the geographical postponement concept and strategies, which relates to the operations area. Then, such strategies have been vertically extended along the product's Lyfe Cycle: from pure operations, the study concentrated first upstream (with modularity implications on postponement) and later downstream (with postponement and reverse logistics). In this way geographical postponement strategies, which are already a new field of study, have been confronted vertically to have a complete LCA of a product. In a second phase, a horizontal expansion has been introduced. In this phase, the sustainability theme was factored in: postponement strategies were not discussed as a factor for logistics cost or financials, but as a driver to achieve sustainable supply chains and Triple Bottom Line-based organizations.

In this regard, several factors have been examined which need to be considered when implementing a geographical postponement strategy. Such factors have been presented and their implications in a Supply Chain strategy with geographical postponement explored. Following the horizontal expansion, the factors related to the economic and fiscal management have been examined first. In a second moment, all factors related to sustainability have been proposed. All these factors create a practical framework to follow for an organization aiming to explore the possibility to introduce a geographical postponement strategy following a Triple Bottom Line approach. The survey results confirmed the importance of the factors found, but the responses highlighted as each case should be carefully addressed individually and the sensitivity towards one factor could be influenced

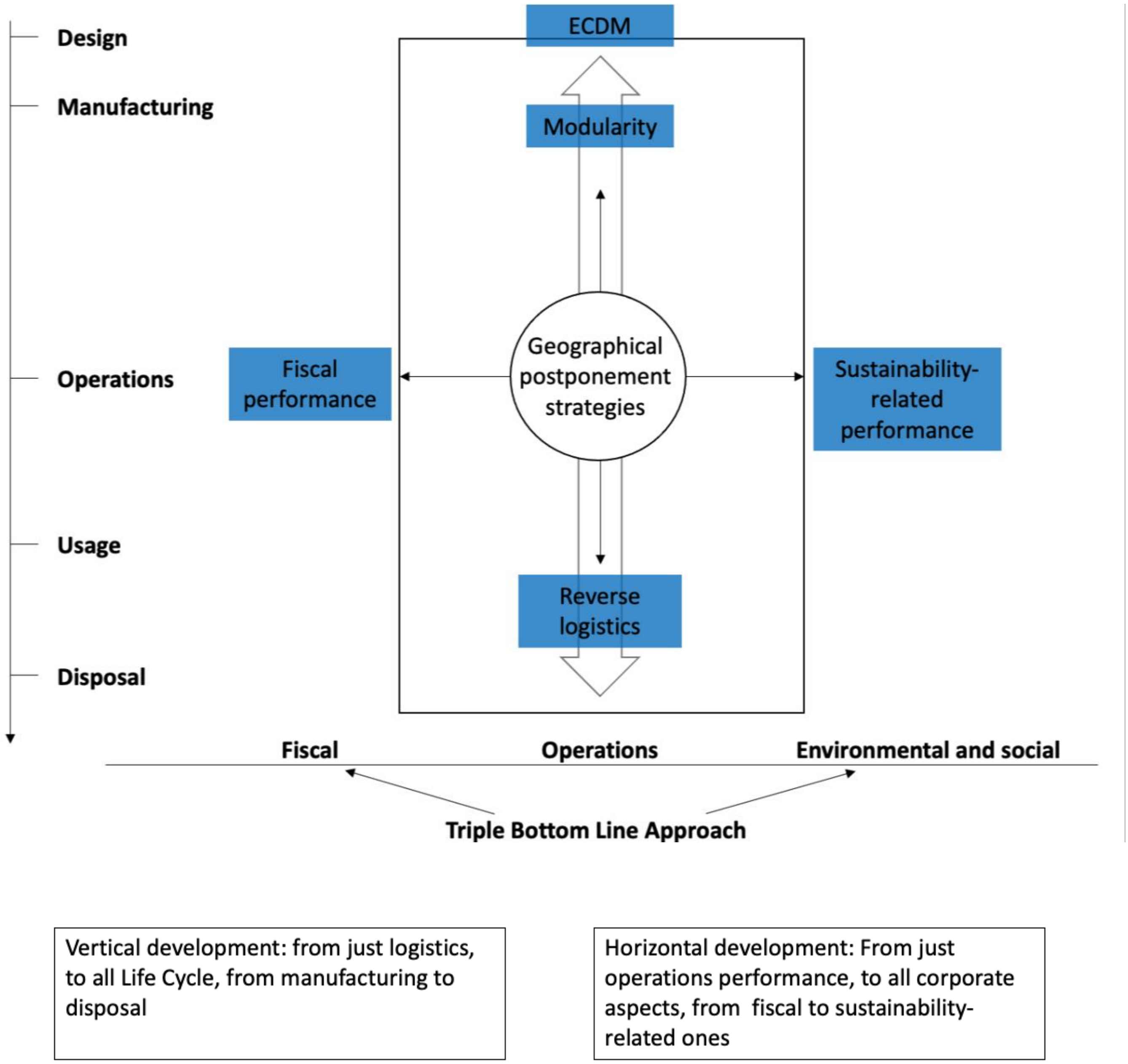


Figure 25: Representation of the study's structure: vertical and horizontal expansion

by the corporate environment and the country in which the company operates. If the factors are a valuable instrument during the design phase of the Logistics strategy, the different geographical postponement strategies comparison concerned the operational phases. Here, the results are interesting for two main aspects.

First, the decision to apply geographical postponement in the supply chain always leads to economic benefits from a pure profit optimization point of view. Instead, when the sustainability is introduced as a factor under the form of supply chain emissions minimization or social concern, a geographical postponement strategy is not always a guarantee of better results. Different strategies have different environmental outputs on average, and each individual company case should be specifically addressed to give exact insights. Moreover, even concentrating on each strategy, the decision to apply geographical postponement for an organization with an international supply chain leads usually to a trade off in terms of emissions. The main international haul sees normally a reduction in carbon emissions, thanks to the better utilization of space that postponed activities enable, and such saving in emissions strictly depend on the strategy adopted. Whereas, the final delivery must become quicker or utilize more vehicles, which leads to an increase in carbon emissions. Emissions during the main haul and during final delivery are dependent on each other and provide a trade-off: with more customization activities done downstream, main haul emissions decrease and final delivery emissions increase. This reasoning is based on the assumption that all transports are done with high pollutant vehicles with combustion engines. Obviously, if transportations could become green this trade-off could be offset. This could be done with biofuels and, gradually, with full electric fleets. In fact, the transition to greener source of transportation is a critical challenge for the twenty-first century and the Logistics Sector, especially for last mile deliveries which are mainly concentrated in urban areas, could benefit from it a lot. The adoption of green vehicles was only partially found in literature and included in the analysis, but its impact and implications would be an important theme for future studies about geographical postponement. In the following section, an introduction on how to achieve greener transportation is given.

ACHIEVING GREENER TRANSPORTATIONS

To achieve a greener and sustainable supply chain under postponement strategy, in fact, it is undoubted that a strong effort should be devoted to greener transports. The amount of transportation from manufacturers to customers increased hugely with the emergence of global supply chains and is still growing at fast pace (Ugarte, et al., 2016). As a result, environmental impact of transportation and other logistics strategies needs to be considered into decision making (Yang, et al., 2005). Emissions connected to transportation happen as part of ‘scope 1 emissions’, by the fleet of vehicles used by the manufacturing company to move goods, or by ‘scope 3 emissions’, in the form of all transports incurred along the supply chain by suppliers and other stakeholders, all contributing to the flow of goods from raw materials to the final customer. Therefore, in this study, as it wants to be a practical guide to supply chain managers and executives in designing a more sustainable networks for their companies and for society, the focus has been on scope 1 and 3. In global, dispersed supply chains, which are the focus of this study, usually manufacturing players rely on intermediaries/carriers to ship goods internationally (Masson, et al., 2007). Therefore, when referring to scope 3 emissions, the focus will be on such components of emissions attributed to carriers.

Moreover, for scope 1 emissions the following section will provide a practical introduction and overview on how it is possible to reduce the environmental impact caused by a firm’s own fleet. Regarding scope 3, instead, tracking supply chain emissions due to external players is complex and is justified only in few cases. For example, as previously explored, a company could rely on a ‘sustainable certification label’ on its product as a competitive advantage, which ensures that the whole life cycle of such product, including the phases outsourced, follows a sustainable approach. The following section, however, wants to give a critical discussion on the results obtained and to develop an overview on how it is possible to reduce the environmental impact in transportation, to be used by all players in this sector.

A study by the World Economic Forum (2009) found that transports and logistics produce 2.800 Megatonnes of CO_2 greenhouse gas emissions annually, or around the 5% of the 50,000 mega-tonnes produced globally by the whole world. As highlighted in figure 26, transportation accounts for the majority of it. The different types of transportations used in supply chains for the movement of goods (road, rail, ocean freight and air freight) do not account for the same share either.

Road freight accounts, in absolute term, for the greatest part producing 57% of the total. Ocean freight is the second with around 17% of total overall contribution, then follow air freight with 7% and rail with 3.5%. However, road transport is not the least efficient mode of transport in terms of CO_2 carbon emissions, and in general the absolute values of carbon

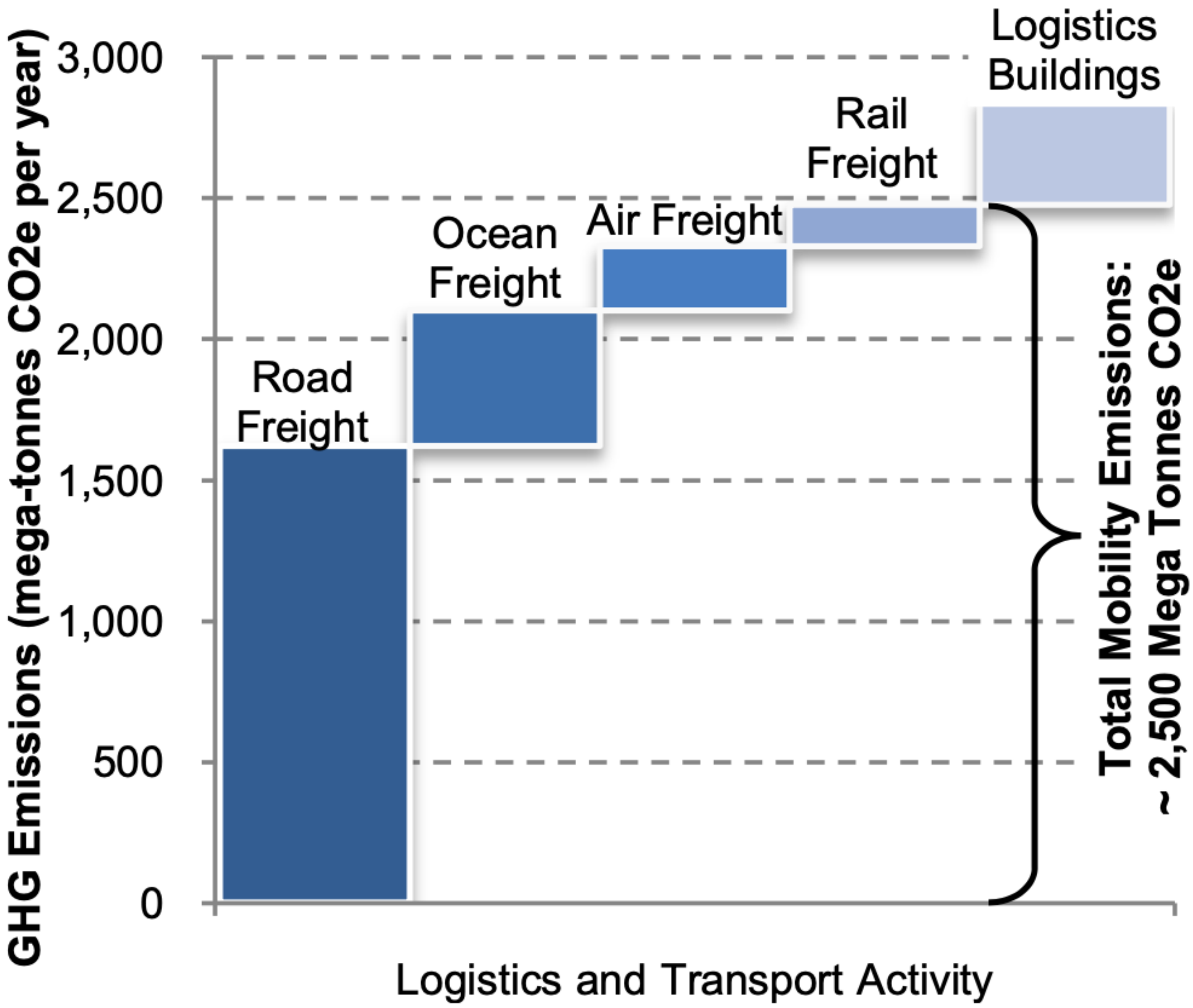


Figure 26: GHG emissions due to different logistics activities and transportation modes. Source: World Economic Forum, 2009

footprint don't give the overall picture. It is interesting to observe the values of emissions intensity per tonne-km, as highlighted in figure 27. In this case, air freight is the most carbon intensive mode at around 1.3 Kg/tonne-km of CO2 and overcomes road freight as the most pollutant. Road is the second mode in terms of efficiency while rail and ocean freight the greener ones. In particular, the last two generates one sixth of the footprint of road freight, or one hundredth of that of airfreight (World Economic Forum, 2009). Therefore, the present study reflects the need to reduce the amount of use of more pollutant modes of transports like road freight in favor of greener ones. However, the study didn't take into account the use of green mode of transports such as biofuels or electric. Based on these studies, it's crititical that all sources of transportation in supply chains need to transition gradually to green solutions.

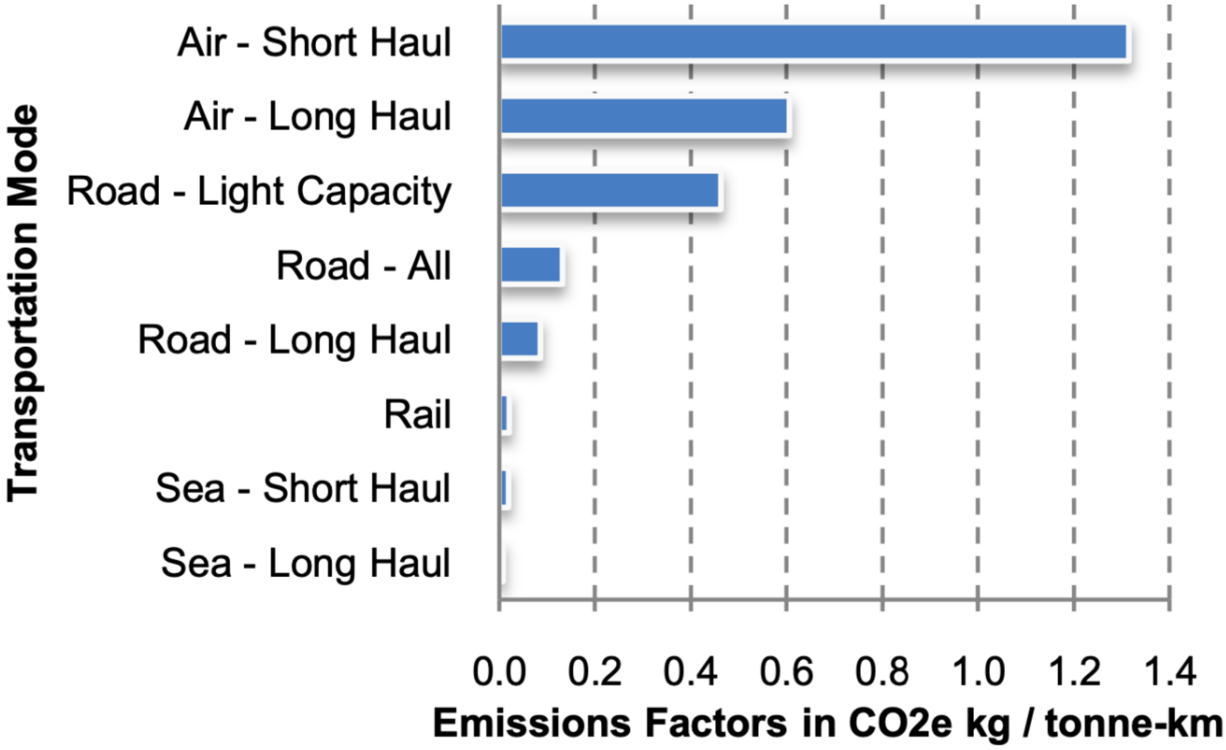


Figure 27: Emissions efficiency for transportation mode. Source: World Economic Forum, 2009

Basing on the study by the (World Economic Forum, 2009), three main areas of improvement for greener transportation are identified and explored. These opportunities offer the most potential for environmental benefit out of thirteen proposal, which have been ranked by both potential abatement of CO_2 and an index of feasibility (or ease of implementation).

1. Clean vehicles technologies
2. Despeeding Supply Chains
3. Optimized networks (reduce km travelled)

To have a more comprehensive overview of sustainable supply chains, the following section will discuss them in a geographical postponement perspective. First of all, the two main transportations involved in a global postponed supply chain are the long international haul and the delivery in the final market. Therefore, these are the transportation modes that most likely need to be considered. The former is typically done by ship or, in some cases, air, while the latter is usually performed via road or in an intermodal combination of truck and train. These are generally outsourced to carriers. However, scope 3 emissions account for the majority of the overall carbon footprint of the Supply Chain, therefore they will be discussed as a practical introduction on how to achieve a greener shipping industry. While there has been a 73% increase in world GDP from 2000 on, seaborne trade which hosts the majority of international hauls in postponed supply chains has increased by more than 112% over the same period (Mediterranean Shipping Company, 2019).

Clean vehicles

In the last years, the push towards an eco-friendlier way of shipping goods has been huge. As pointed out by Yang et al. (2005), environmental impact of transportation needs to be considered into decision making. They identified two main ways which can be exploited to shift towards a more effective transport system: direct mitigation and modal shift. The former reduces the rate of emission of vehicles, the latter moves freight transport to more environmentally effective modes. Regarding the international haul, it is usually done by ocean freight by ship which is already the most environmentally friendly mode compared to the other, as well as the cheapest. But there are several challenges even in this sector. Ship carriers are pushed by regulations and social awareness to apply greener solutions. MSC (The Mediterranean Shipping Company) already has introduced in 2019 a biofuel blend which enable to achieve an average CO_2 reduction of 15% compared to traditional fuel. This blend is composed by a biofuel made of vegetable oils, fats or greases and standard petroleum-based fuel, which can run in present diesel engines without modifications. It also has used extensively shore power, to run all the ship's equipments during the long waiting at port, in order to reduce the amount of fuel burned onboard. Further steps are being explored, such as hydrogen fuel cells, complementary battery power, alternative fuels and, possibly, wind and solar to power vessels (Mediterranean Shipping Company, 2019). Apart from pure carbon emissions, other sources of environmental impact must be taken into account. Underwater noise, for example, is relevant and can produce damages to fishes. Biofouling is the accumulation of aquatic plants, animals and microorganisms on vessel surfaces, which introduces some real challenges. It causes encrustations which requires more power and can cause an increase in fuel consumption up to 40%. It also is an ecological threat since biofouling on ships can contribute to the transfer of alien (invasive) species, often related to biodiversity loss or extinction of present species. Regarding the final market delivery, the use of road transport is extensive. Here the transition towards electric vehicles could push an electric fleet introduction for many companies. Electric vehicles (EVs) can drastically reduce the emissions, noise pollution and lifecycle costs due to lower feeding and maintenance cost. As of today, this is not extensively used due to concerns about range, recharge times and initial cost (Siragusa, et al., 2020). While they are already a feasible solution for last-mile delivery in urban centers, in the future electric vehicles could eventually be an useful solutions for mid-range road freight if the major barriers are overcome. Currently, the discussion for greener last-mile deliveries is strongly related to the increase of the e-commerce sector, as previously examined during the SLR. The increasing phenomenon of e-commerce, in fact, with everything done from home, provides other challenges as well, such as the increased number of home deliveries, resulting in more vans in urban city centers causing emissions, and more packaging utilized (Siragusa, et al., 2020). Therefore, if on the one hand e-commerce could lead to cost and emission savings before customer order, it could imply having more carbon footprint during final deliveries, in terms of CO2 emissions, acoustic pollution and over-use of packaging material, thus negatively affecting the sustainability of the supply chain. However, home deliveries are eco-friendlier compared to the previous alternative of having all customers driving to the retailer to purchase their own product. According to a study by the World Economic Forum (2009), home deliveries are around four times more efficient in terms of carbon emissions. Siragusa et al. (2020) tried to assess the feasibility of using electric vehicles for last mile deliveries from a both economic and environmental perspective, since it seems an interesting enough solution. From an economic point of view, an EV is beneficial overall, since it is more expensive initially but significantly cheaper in terms of energy cost and maintenance. Not surprisingly, also from an environmental point of view EV are better, since they create less carbon footprint and far from the city center (during the production of that energy). If today e-commerce is used for small products like electronic devices or apparel (among many others), in the future online sales could include all kinds of goods, even more durable and bigger, potentially providing new challenges and opportunities for manufacturers aiming to exploit postponement strategies. According to the Boston Consulting Group (2018), consumers are increasingly getting confident in buying a car online and several automotive companies are introducing near-online-only and direct sales. Ulrich et al. (2019) proposed a modular electric vechicle for urban transportation, made of a common standard driveboard and several tranportation modules to attach. This could fit both passenger and cargo tranportation, and the modular capsules could be easily switched between operations. This could potentially avoid a lot of idle times and could be shared between different players. Even if this kind of vehicles are far from being widespread nowadays, this framework could be an efficient solution to be taken into account when designing a more sustainable supply chain. The growth of sharing economy and data sharing can accelerate the advent of such strategies. A lot of big players are moving to more efficient transports: just to give an example, already in 2009, the world's largest retailer, Walmart, stated it would have made its truck fleet 25 percent more efficient in three years, and double by 2019, also through internal initiatives and engagement with its suppliers (World Economic Forum, 2009). Another solution to achieve further environmental efficiency inland is by using intermodal transportation. There are several ways to reduce inland emissions by switching mode, for example exploiting more use of rail or inland waterways (canals, rivers) instead of trucks, which are far more pollutant.

The European Union for example is hugely increasing the concern about inland intermodal transportation. It is increasing the effort to develop a reliable rail infrastructure to connect all parts of the continent, coining the motto 'modern rail, modern Europe' (European Commission, 2008). Moreover, it is pushing for a broader use of waterways such as canals and rivers using barges, which enable to have energy consumption per km/ton of transported goods approximately 17 % of that of road transport and 50 % of rail transport (European Commission, 2020).

Despeeding the Supply Chain and Optimized networks

Despeeding the supply chain and optimize the network to reduce the length travelled are solutions aiming to reduce the environmental impact indirectly, by either reducing the speed or the amount of miles covered.

What was found in literature and confirmed during the survey highlighted that consumption, as well as consumer needs, are only going to increase in the next decades. Therefore, most probably ships or trucks (or all vehicles) can't be slowed down without compromising the service level. One alternative would be to have ships with more capacity. Even assuming that the forecasting possibilities of a company enables it, the size of the ship would have to increase obviously, and consistently. This eventuality provides some points for discussion. First, such solution would require a considerable investment which will take years before seeing the results. Even after the new ship introduction, the existing vessels would not be realistically eliminated from the fleet before several years, if not decades.

But the most critical aspect is probably represented by the size limit. For several years, container ships have continuously grown in size, which led to more capacity. Now, the size of such vessels seems to have reached a limit. This is not due to materials limits or safety requirements, but to the fact that ships which are too big can't access some Canals which are crucial for the world's economy and *de facto* set the limit for ships size.

In the SLR another approach to reduce the environmental impact indirectly was found, which is digitalization along the supply chain. Such concept, together with cooperation between actors in the supply chain, goes in the directions suggested by the World Economic Forum in 2009 but introduce innovative concepts and technologies which twelve years ago where not mature enough. Instead with today's capabilities, a geographical postponement context with long international shipping can exploit new, faster data sharing to achieve better optimization of some parts of travels and reduce downtimes.

For example, shared visibility, enabled by digitalization and data sharing, can benefit PCO (Port Call Optimization), reducing both costs and overall emissions. PCO pursues interoperability of players (shipping lines, agents, ports, industries) to reduce unnecessary waiting times. For example, as stated by Mediterranean Shipping Company (2019), for JIT Arrival. JIT (Just-in-time) is a concept coming from Lean Manufacturing which is expanded to maritime shipping to reduce carbon footprint of vessels and ports. Through data sharing, ships may optimize their voyage speed to arrive at the port when availability of the berth, fairway and port nautical services is assured. This requires real-time data, and 5G implementation could further improve this system. The reduction in fuel consumption is twofold. By knowing in real time when the destination port is ready, a vessel can adjust its navigation plan to minimize fuel consumption, for example reducing its speed not to arrive early. Similarly, reduced anchorage time and maneuvering, which comprises usually 5-10% of waiting time, can be reduced. During a trial test in 2019 between Bremerhaven and

Rotterdam, the travel with continuous speed adjustment and data communication brought to a 23% less fuel consumption than normal.

It is interesting to point out that in shipping several organizations are already in place to achieve long term goals of more sustainable trade. Just to give an example regarding digitalization, DCSA (Digital Container Shipping Association) aims at fostering global collaboration between players, the widespread use of Internet of Things (IoT) solutions, operational efficiencies and interoperability. The broader goal is to make shipping services easy to use, flexible, efficient, reliable and environmentally friendly (Mediterranean Shipping Company, 2019). Many other organizations are however already trying to tackle the issue of environmental damage related to shipping.

Name	Aim	Data
IMO (International Maritime Organization)	Design and develop maritime transport standards, to make it more safe and structured	Part of ONU, has now 172 members.
GIA (Global Impact Association)	Develop trade professionals and scholars with inclusive and sustainable thinkings	Part of the Global Trade Institute, based in Bern.
Clean cargo working group	Business to Business initiative to reduce the environmental impact of international shipping	Represents around 85% of global cargo capacity today
MARPOL	Reduce all forms of pollution caused by ships	First edited in 1973. More than 98% of world cargo capacity has agreed
Enhancing Cetacean Habitat and Observation60 (ECHO)	Reduce damages caused by ships to whales	Created and carried by Port of Vancouver

Table 24: Associations and agreements to pursue sustainable trade (own elaboration)

Associations aiming to reduce environmental negative impact are not confined to international shipping. Many organizations and agreements grew considerably during the last decades and will continue to increase. Sustainable development, as stated by ONU Secretary-General Ban-Ki-Moon in 2013, is the most critical challenge of our time and will characterize our century (United Nations, 2013).

The study provides, to conclude, a practical and structured framework for companies which approach the geographical postponement concept. The present study wanted, as declared initially, to deepen and expand the considerations about this logistics strategy provided by Prataviera, et al., (2020). If their publication was really helpful to introduce the strategy, this study will be a guideline for the implementation. The framework initially concentrates on economic and fiscal optimization. Here, all relevant factors to consider can be consulted and the different strategies are compared. Then, the sustainability theme is factored in. Again, with a larger view all factors are presented and the different strategies' performances are compared.

CONCLUSION

ACADEMIC CONTRIBUTION

The present study has relevant academic contribution since help filling a literature gap regarding geographical postponement strategies. Relatively a new concept, geographical postponement was introduced by Prataviera, et al., (2020) as the focus, for international supply chains, on where customization operations take place. Their study, moreover, provided a relevant framework to classify different geographical postponement approaches and strategies, together with recommendations for future studies. The present research took that study and, exploiting the framework proposed, deepened it to have a broader view of geographical postponed strategies opportunities and implications. Following a SLR, all factors relevant to the implementation of geographical postponed supply chains have been presented, and their implications for logistics and overall corporate performances are given as a practical reference to consider. Such factors compose a new source of information for geographical postponement future studies or implementation. Then, all papers on the topic found in literature were used to compare the different strategies from a traditional, cost minimization point of view. In this phase, the framework proposed by Prataviera, et al., (2020) was used as well. In this way, the strategies proposed have been further examined and their performances were assessed from best to worst. In the second phase, factors to consider have been expanded to include the sustainability-related ones. Moreover, all strategies were evaluated not just from a traditional point of view, but with a Triple Bottom Line approach, i.e. including the environmental and social aspects in decision making. Therefore, the study has relevant academic contribution since explores the geographical postponement implications for sustainable supply chains, which is a critical aspect in today's Logistics Management. To conclude, the study presented some future trends for geographical postponement found in literature, which can provide the basis for future research on this topic. All the results, moreover, were practically assessed in a pilot survey which features some very important manufacturing companies at a global level.

MANAGERIAL CONTRIBUTION

One of the main goals of the present study was to provide a practical framework and guideline to be consulted by Operations Manager when evaluating the possibility to introduce a geographical postponement strategy in their supply chains. With this work as a reference, they could understand and explore the different possibilities and challenges provided by the different types of strategies under observation, which were previously introduced by Prataviera et al., (2020). Operations Managers could first have an understanding of all the factors which must be considered before choosing the best strategy, and apply them to their specific case. If in their corporate decision-making process it is important to include also the sustainability aspect, they have the sources to do so as well. Then, they could compare some options and assess the different performances that would result from their decision. Again, this phase could include or not the sustainability aspects, specifically environmental and social ones, depending on the corporate policies. As previously explored, companies are under heavy political and social pressure to improve their sustainability level. Therefore, the majority of organizations already include sustainability in decision making. However, different companies could put more effort in some processes and less in others, depending on various factors such as the sector or the size of the firm. The study expanded the geographical postponement implications on sustainability vertically, covering all aspects of a product's life cycle. In this way, Operations managers could have an overview on geographical postponement sustainability-related implications on the desired phase of the company's activity.

RECOMMENDATIONS FOR FUTURE STUDIES

The present study provided a practical overview about geographical postponement strategies assessment and implications. However, it has some limitations and hints for future research can be recommended.

All factors driving postponement decisions could be further studied, and expanded both vertically and horizontally (with respect to Figure 25 offered in the discussion section). Vertically, deepening each individual factor to explore the different implications that each one could have in specific cases. In fact, as previously seen, the factors impact can vary significantly in different real-world applications depending on geographical locations and the firm's sector. Horizontally, introducing new relevant factors to consider, both from an economic and sustainable point of view. In fact, the cited factors were found in literature based on the research keywords selected. Other factors could be introduced and explored. Just to give an example, the European Union is evaluating the introduction of a new border carbon tax to encourage other countries to take strong climate actions (The New York Times, 2021). Such eventuality would be carefully considered by corporations when pondering geographical postponement strategies related to the EU.

Also, the electrification of transportations could be factored in when comparing the different geographical postponement strategies. As previously seen, biofuel-based or electrified vehicles are growingly important for logistics strategies and will continue to increase. Therefore, all strategies could be assessed considering also electrified supply chains to evaluate their performances and see if the environmental trade-off that at the moment is created by geographical postponement is offset.

Moreover, the survey presented in the present study was a pilot test for future studies. It confirmed the importance and potentialities of geographical postponement strategies in real world applications, but does not provide statistical evidences considering the volume of responses which was limited. Therefore, it provides the basis for a more spread and comprehensive survey which could create statistical evidences and strong constructs.

Global macrotrends with sustainable implications could not be discussed in the present study and could be explored in future research. For example, global warming is opening up new possibilities for international routes, specifically the northern route through the artic. Due to the increase in average temperatures, ice that years ago was permanent in the Northern Sea is now melted during summer months. This could be a very interesting solution for geographical postponement since it enables to cut several days or weeks of travel (BBC, 2018). However, this would be disastrous for the environment and some shipping companies, such as MSC, already stated that they will not exploit such route (Mediterranean Shipping Company, 2019). Therefore, the economic and sustainable trade off of such alternative route related to geographical postponement could be explored.

Finally, the future trends proposed provide a base for discussion. Such trends have been only introduced since it was found in literature that they could be a relevant direction for geographical postponement. Each of them could be further explored considering other resources and confronted with the respective sectors. In particular, 3D Printing for geographical postponement is just at a nascent stage. The survey results confirmed that there is a lack of knowledge about this solution possibilities, which validate the need for further discussion.

BIBLIOGRAPHY

Abukhader, S. & Jonson, G., 2011. Horizontal Environmental Assessment of Postponement Strategy – A Delphi-based Investigation. *International Journal of Management Science and Engineering Management ,* 6(5), pp. 382-392.

Abukhader, S. M. & Jönson, G., 2004. E-commerce and the environment: a gateway to the renewal of greening supply chains. *International Journal of Technology Management,* Vol. 28(No. 2), pp. 274-288.

Agrawal, M., Kumaresh, T. V. & Mercer, G. A., 2001. The false promise of mass customization. *The McKinsey quarterly,* Issue No. 3, pp. 62-71.

Alderson, W., 1957. Marketing Behavior and Executive Action: A Functionalist Approach to Marketing Theory. *The American Economic Review,* 47(6), p. 1058–1060.

Baker, P., 2011. The Role and Design of Warehouses in Modern Supply Chains. In: *Global Operations Management.* s.l.:Lee R. Hockley, pp. 85-98.

Ballarino, A., Brondi, C., Brusaferri, A. & Chizzoli, G., 2017. *The CPS and LCA modelling: An integrated approach in the environmental sustainability perspective.* s.l., IFIP Advances in Information and Communication Technology, p. 543–552.

Bartolini, M., Bottani, E. & Grosse, E., 2019. Green warehousing: Systematic literature review and bibliometric analysis. *Journal of Cleaner Production,* Volume 226, pp. 242-258.

BBC, 2018. *Is the Arctic set to become a main shipping route?.* [Online]
Available at: https://www.bbc.com/news/business-45527531
[Accessed 14 July 2021].

BBC, 2019. *Why some countries are shipping back plastic waste.* [Online]
Available at: https://www.bbc.com/news/world-48444874
[Accessed April 2021].

BIO by Deloitte, 2014. *Development of Guidance on Extended Producer Responsibility (EPR),* s.l.: s.n.

Bonvoisin, J., Halstenberg, F., Buchert, T. & Stark, R., 2016. A systematic literature review on modular product design. *Journal of Engineering Design,* Vol. 27 (No. 7 DOI: 10.1080/09544828.2016.1166482), pp. 488-514.

Boston Consulting Group, 2018. *It's time for a new way to sell cars.* [Online]
Available at: https://www.bcg.com/publications/2018/new-way-to-sell-cars
[Accessed April 2021].

Budiman, S. D. & Rau, H., 2019. A mixed-integer model for the implementation of postponement strategies in the globalized green supply chain network. *Computers & Industrial Engineering,* Volume Vol. 137.

Calle, M., González-R, P. L. & Pierreval, H., 2016 . Impact of the customer demand on order fulfilment strategies based on floating decoupling point: a simulation analysis. *International Journal of Production Research ,* Vol. 54(No. 24), p. 7359–7373.

Carbonara, C., Costantino, N. & Pellegrino, R., 2016. *Assessing the Benefits of the Product Postponement Strategy to Mitigate Supply Chain Risks: A Real Options-Based Computational Model.* s.l., s.n., pp. 1648-1652.

Carbonara, N. & Pellegrino, R., 2018 . Real options approach to evaluate postponement as supply chain disruptions mitigation strategy. *International Journal of Production Research,* Vol. 56(No. 15), p. 5249–5271.

Casper, R. & Sundin, E., 2018. Reverse logistics Transportation and Packaging concepts in automotive remanufacturing. *Procedia Manufacturing,* Volume Vol. 25 , p. 154–160.

Ceglowski, J. & Golub, S. S., 2012. Does China Still Have a Labor Cost Advantage?. *Global Economy Journal,* Volume 12(Issue 3), p. Art. 6.

Chang, C.-H., 2012. Analyzing Postponement/Speculation Strategic in a Two-Echelon Supply Chain with Considerations of Uncertainty Profiles. *WSEAS TRANSACTIONS on BUSINESS and ECONOMICS,* Vol. 9(Issue 3), pp. 150-159.

Chou, M., Chua, G. & Zheng, H., 2014. On the Performance of Sparse Process Structures in Partial Postponement Production Systems. *Operations Research,* Vol. 62(No. 2).

Christensen, B., Brunoe, T. D. & Nielsen, K., 2018. *A Conceptual Framework for Stage Configuration.* s.l., I. Moon et al., pp. 101-109.

Chung, W.-H., Kremer, G. E. O. & Wysk, R. A., 2014. Life cycle implications of product modular architectures in closed-loop supply chains. *International Journal of Advanced Manufacturing Technology,* Volume Vol. 70, p. 2013–2028.

Craighead, C., Ketchen Jr, D. J. & Darby, J. L., 2019. Taking AIM at Theoretical and Pragmatic Impact: A Call for Actionable, Insightful, and Measurable Research. *Journal of Business Logistics,* 40(4), p. 289–298.

Dai, F., Yang, J., Guo, H. & Sun, H., 2021. Tracing CO2 emissions in China-US trade: A global value chain perspective. *Science of the Total Environment,* 775(145701).

de Keizer, M. et al., 2017. Logistics network design for perishable products with heterogeneous quality decay. *European Journal of Operational Research,* Volume Vol. 262, pp. 535-549.

Denyer, D. & Tranfield, D., 2009. Producing a systematic review. In: *The Sage handbook of organizational research methods.* s.l.:D. A. Buchanan and A. Bryman (Eds.), p. 671–689.

Doran, D., 2003. Supply chain implications of modularization. *International Journal of Operations & Production Management,* Vol. 23(No. 3), pp. 316-326.

Doran, D. & Roome, R., 2003. An evaluation of value-transfer within a modular supply chain. *Journal of Automobile Engineering,* January, Vol. 217(No. 7), pp. 521-527.

Dumitrache, I. & Caramihai, S. I., 2013. *The Enterprise of Future as a Cyber-Physical System.* Saint Petersburg, Russia, International Federation of Automatic Control.

Durach, C. F., Kembro, J. & Wieland, A., 2017. A new paradigm for systematic literature reviews in supply chain management. *Journal of Supply Chain Management,* Vol. 53(no. 4), p. 67–85.

Egger, M., Sulu-Gambari, F. & Lebreton, L., 2020. first evidence of plastic fallout from the North Pacific Garbage Patch. *Nature Scientific Reports,* Vol. 10(No. 7495).

Er, M. & MacCarthy, B., 2006. Managing product variety in multinational corporation supply chains - A simulation study. *Journal of Manufacturing Technology Management,* Vol. 17(No. 8), pp. 1117-1138.

Establish, 2010. *Logistics Cost and Service.* s.l., Annual Global Conference 2010.

European Commission, 2008. *Modern rail, modern Europe,* s.l.: Directorate General for Energy and Transport.

European Commission, 2020. *Mobility and Transport, transport modes.* [Online]
Available at: https://ec.europa.eu/transport/modes/inland_en
[Accessed April 2021].

Fan, Y., Schwartz, F., Voß, S. & Woodruff, D. L., 2017. Stochastic programming for flexible global supply chain planning. *Flexible Services and Manufacturing Journal,* Volume Vol. 29, pp. 601-633.

Feitzinger, E. & Lee, H. L., 1997. Mass Customization at Hewlett-Packard: The power of postponement. *Harvard Business Review,* Volume January-February.

Ferdows, K., 1997. Making the Most of Foreign Factories. *Harvard Business Review,* Vol. 75(No. 2), pp. 73-86.

Ferdows, K., 2018. Keeping up with growing complexity of managing global operations. *International Journal of Operations & Production Management,* Vol. 38(No. 2), pp. 390-402.
Fernandes, R., Pinho, C. & Gouveia, B., 2015. Supply chain networks design and transfer-pricing. *The International Journal of Logistics Management,* Vol. 26(No. 1), pp. 128-146.
Fixson, S. K., 2005. Product architecture assessment: a tool to link product, process, and supply chain design decisions. *Journal of Operations Management,* Volume Vol. 23, p. 345–369.
Fixson, S. K., Ro, Y. & Liker, J. K., 2005. Modularisation and outsourcing: who drives whom? A study of generational sequences in the US automotive cockpit industry. *International Journal of Automotive Technology and Management,* Vol. 5(No. 2), pp. 166-183.
Fortune, 2020. *3D printing market.* [Online]
Available at: https://www.fortunebusinessinsights.com/industry-reports/3d-printing-market-101902
[Accessed June 2021].
Gorane, S. & Kant, R., 2016. Supply chain practices - An implementation status in Indian manufacturing organisations. *Benchmarking: An International Journal,* Vol. 23 (No. 5), pp. pp. 1076-1110.
Graessler, I. & Yang, X., 2019. *Product life cycle cost approach for modular lightweight design.* s.l., s.n., pp. 1048-1053.
Guericke, S., Koberstein, A., Schwartz, F. & Voß, S., 2012. A stochastic model for the implementation of postponement strategies in global distribution networks. *Decision Support Systems,* Volume Vol. 53, pp. 294-305.
Gumpinger, T. & Krause, D., 2011. *Development of modular products under consideration of lightweight design.* s.l., Technical University of Denmark.
Harrison, A. & Skipworth, H., 2008. Implications of form postponement to manufacturing: a cross case comparison. *International Journal of Production Research,* 1 January, Vol. 46(No. 1), p. 173–195.
Henkow, O. & Norrman, A., 2011. Tax aligned global supply chains: environmental impact illustrations, legal reflections and crossfunctional flow charts. *International Journal of Physical Distribution & Logistics Management,* Vol. 41(No. 9), pp. 878-895.
He, P., Wang, Z., Shi, V. & Liao, Y., 2021. The direct and cross effects in a supply chain with consumers sensitive to both carbon emissions and delivery time. *European Journal of Operational Research,* Volume Vol. 292, pp. 172-183.
Huang, H. & Liang, G.-q., 2007. *Designing the Supply Chain by Postponement Strategy.* Harbin, P.R.China, International Conference on Management Science & Engineering (14th).
Huang, Y.-Y. & Li, S.-J., 2008. Suitable application situations of different postponement approaches: Standardization vs. modularization. *Journal of Manufacturing Systems,* Volume 27, pp. 111-122.
Huang, Y.-Y. & Li, S.-J., 2009. The application situation and determinants of postponement: A field survey for large manufacturers in Greater China. *Journal of Manufacturing Technology Management,* Vol. 20(No. 6), pp. 787-803.
Huscroft, J. R. et al., 2013. Reverse logistics: past research, current management issues, and future directions. *The International Journal of Logistics Management,* Vol. 24(No. 3), pp. 304-327.
IEA, 2020. *CO2 Emissions from Fuel Combustion: Overview,* s.l.: s.n.
Interbrand, 2011. *Best Global Brands 2011* [Online]
Available at: www.interbrand.com

Jabbarzadeh, A., Haughton, M. & Pourmehdi, F., 2019. A robust optimization model for efficient and green supply chain planning with postponement strategy. *International Journal of Production Economics,* Volume Vol. 214 , p. 266–283.

Jeong, M.-G., Morrison, J. R. & Suh, H.-W., 2015. *Product Modularity to Jointly Address Functional and Ecological Requirements in the Early Design Stage.* Gothenburg, Sweden , s.n., pp. 33-38.

Jeswiet, J. & Hauschild, M., 2005. EcoDesign and future environmental impacts. *Materials and Design ,* Volume Vol. 26 , p. 629–634.

Khan, R. W. A., Khan, N. & Chaudhary, M. A., 2011. *Green Supply Chain Management – Global Opportunities and Challenges.* Dalian, China, s.n., pp. 5-9.

Khan, S. A. R. et al., 2020. A state-of-the-art review and metal-analysis on sustainable supply chain management: Future research directions. *Journal of Cleaner Production,* Issue 123357.

Kochhar, R., 2015. A global middle class is more promise than reality. *Global Attitudes & Trends*, 8 July.

KPMG, 2021. *Corporate tax rates table.* [Online]
Available at: https://home.kpmg/it/it/home/services/tax/tax-tools-and-resources/tax-rates-online/corporate-tax-rates-table.html
[Accessed 2 June 2021].

Kremer, G. E. O., Ma, J., Chiu, M.-C. & Lin, T.-K., 2013. Product Modularity and Implications for the Reverse Supply Chain. *Supply Chain Forum: An International Journal,* Vol. 14(No. 2), pp. 54-69.

Lampón, J. F., Cabanelas, P. & Frigant, V., 2017. *The new automobile modular platforms: from the product architecture to the manufacturing network approach,* s.l.: Munich Personal RePEc Archive.

LeBlanc, L. J., Hill, J. A., Harder, J. & Greenwell, G. W., 2009. Modeling uncertain forecast accuracy in supply chains with postponement. *Journal of Business Logistics,* Vol. 30(No. 1), pp. 19-31.

Leblanc, R., 2020. *What is reusable packaging?.* [Online].

Lecher, C., 2016. Inside Nevada's $1.3 billion gamble on Tesla. *The Verge*, 8 February.

Lee, K.-M. & Inaba, A., 2004. *Life Cycle Assessment: Best Practices of ISO 14040 Series,* s.l.: Center for Ecodesign and LCA.

Li, L. & Liu, S., 2017. Analysis of postponement problem in supply chain of customized products. *Journal of Interdisciplinary Mathematics,* Vol. 20(No. 4), p. 1153–1166.

Loh, H. S. & Thai, V. V., 2015. Managing port-related supply chain disruptions (PSCDs): a management model and empirical evidence. *Maritime Policy & Management.*

Loy, J. & Tatham, P., 2016. Redesigning Production Systems. In: *Handbook of Sustainability in Additive Manufacturing.* s.l.:Environmental Footprints and Eco-design of Products and Processes, pp. 145-168.

Lu, J. & Sun, X., 2021. Carbon regulations, production capacity, and low-carbon technology level for new products with incomplete demand information. *Journal of Cleaner Production,* February.Vol. 282(124551).

Ma, J. & Kremer, G. E. O., 2016. A systematic literature review of modular product design (MPD) from the perspective of sustainability. *International Journal of Advanced Manufacturing Technology ,* Volume Vol. 86, p. 1509–1539.

Masson, R., Iosif, L., MacKerron, G. & Fernie, J., 2007. Managing complexity in agile global fashion industry supply chains. *The International Journal of Logistics Management,* Vol. 18(No. 2), pp. pp. 238-254 .

McKinsey & Company, 2012. *Mobilizing for a resource revolution,* s.l.: s.n.

McKinsey & Company, 2019. *Used cars, new platforms: Accelerating sales in a digitally disrupted market.* [Online]
Available at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/used-cars-new-platforms-accelerating-sales-in-a-digitally-disrupted-market
[Accessed 7 April 2021].

McKinsey & Company, 2020. *The drive towards sustainability in packaging - beyond the quick wins,* s.l.: s.n.

Mediterranean Shipping Company, 2019. *Sustainability report.* [Online].

Mikkola, J. H. & Skjøtt-Larsen, T., 2004. Supply-chain integration: implications for mass customization, modularization and postponement strategies. *Production Planning & Control,* June, Vol. 15(No. 4), p. 352–361 .

Morgan Stanley, 2018. *Inside China's plan to create a modern silk road* [Online]
Available at: https://www.morganstanley.com/ideas/china-belt-and-road

Mukherjee, K., 2016. An integrated approach of sustainable procurement and procurement postponement for the multi- product, assemble-to-order (ATO) production system. *Production,* 26(2), pp. 249-260.

Naeco, 2020. *Green warehouses: why bet on this logistics trend and how to apply it.* [Online]
Available at: https://naeco.com/en/news/green-warehouses-why-bet-on-this-logistics-trend-and-how-to-apply-it/
[Accessed 3 June 2021].

Newcomb, P. J., Bras, B. & Rosen, D. W., 1998. Implications of modularity on product design for the life cycle. *Journal of Mechanical Design,* Volume Vol. 120, pp. 483-490.

OECD, 2001. *Glossary of statistical terms.* [Online]
Available at:
https://stats.oecd.org/glossary/detail.asp?ID=3128#:~:text=A%20free%20trade%20area%20is,examples%20of%20free%20trade%20areas.
[Accessed 20 May 2021].

Okumura, S., Hashimoto, N. & Fujita, T., 2021. Production Planning of Remanufactured Products with Inventory by Life-Cycle Simulation. *EcoDesign and Sustainability I,* pp. 217-231.

Oracle Corporation and Cap Gemini Ernst & Young, 2003. *The Adaptive Supply Chain: Postponement for Profitability,* s.l.: s.n.

Parry, G. C. & Roehrich, J., 2013. Automotive enterprise transformation: Build to order as a sustainable and innovative strategy for the automotive industry?. *Journal of Enterprise Transformation,* Vol. 3(No.1), pp. 33-52.

Parry, I., 2019a. What Is Carbon Taxation?. *Finance and Development Magazine,* June, Vol. 56(No. 2), pp. 54-55.

Parry, I., 2019b. Putting a price on pollution. *Finance and Development Magazine,* December , Vol. 56(No. 4), pp. 16-19.

Petersen, F. & Hubbart, J. A., 2021. The occurrence and transport of microplastics: The state of the science. *Science of the Total Environment,* Vol. 758 (No. 143936).

Philip, N., Okudan, G. E., Haapala, K. R. & Kim, K.-Y., 2013. *A Comparison of Modularity Methods for Their Implications on Sustainability.* s.l., A. Krishnamurthy and W.K.V. Chan,, pp. 3805-3814.

Prasad, S., Tata, J. & Madan, M., 2005. Build to order supply chains in developed and developing countries. *Journal of Operations Management,* Volume Vol. 23, p. 551–568.

Prataviera, L. B., Perotti, S., Melacini, M. & Moretti, E., 2020. Postponement Strategies for Global Downstream Supply Chains: A Conceptual Framework. *Journal of Business Logistics,* Vol. 41(n. 2), pp. 94-110.

Qian, X. & Zhang, H. C., 2003. *Design for Environment: An Environmental Analysis Model for the Modular Design of Products.* Boston, MA, s.n., pp. 114-119.

Quesada, I. F., 2003. *The concept of reverse logistics, a review of literature.* Oulu, Finland, s.n.

Shabah, A., 2015. HUMANIT3D for disaster response: an assessment of mass customization on organizational performance under turbulent environments. *Procedia Engineering,* Volume Vol. 107, pp. 223-236.

Sharma, S. & Singh, G., 2013. Reverse Logistics: Design implications on the basis of product types sharing identical supply chain member motivations. *Uncertain Supply Chain Management,* Volume Vol. 1 , p. 33–44.

Shi, Y., 2014. The Planning System Based On The Postponement Manufacturing Theory. *Applied Mechanics and Materials,* Volume Vols. 571-572, pp. 1195-1201.

Simão, L. E., Gonçalves, M. B. & Taboada Rodriguez, C. M., 2016. An approach to assess logistics and ecological supply chain performance using postponement strategies. *Ecological Indicators,* Volume Vol. 63, pp. 398-408.

Siragusa, C., Tumino, A., Mangiaracina, R. & Perego, A., 2020. Electric vehicles performing last-mile delivery in B2C e-commerce: An economic and environmental assessment. *International Journal of Sustainable Transportation,* Issue DOI: 10.1080/15568318.2020.1847367.

Sonego, M., Soares Echeveste, M. E. & Galvan Debarba, H., 2018. The role of modularity in sustainable design: A systematic review. *Journal of Cleaner Production,* Volume Vol. 176, pp. 196-209.

Song, W., Wu, Z., Li, X. & Xu, Z., 2015. Modularizing product extension services: An approach based on modified service blueprint and fuzzy graph. *Computers & Industrial Engineering,* Volume Vol. 85, p. 186–195.

Staudt, F., Alpan, G., Di Mascolo, M. & Rodriguez, C., 2015. Warehouse performance measurement: a literature review. *International Journal of Production Research,* 53(18), pp. 5524-5544.

Su, C.-J. & Chuang, H.-C., 2011. Toward Mass Customized Product Deployment in E-Commerce: The Modularization Function and Postponement Strategy. *ournal of Organizational Computing and Electronic Commerce,* Volume Vol. 21, pp. 24-49.

Tan, W. P. (. & Goh, S. H., 2015. *Incorporating Postponement in an Offshoring Strategy: A case study of a Singapore-China cross border manufacturing supply chain.* Dubai, United Arab Emirates (UAE), Proceedings of the 2015 International Conference on Industrial Engineering and Operations Management.

Tchertchian, N., Millet, D. & Pialot, O., 2011. *Modular Grouping Exploration to design Remanufacturable Products.* Technische Universität Braunschweig, Braunschweig, Germany, J. Hesselbach and C. Herrmann (eds.), pp. 413-418.

the balance, 2020. *Carbon Tax, its purpose and how it works* [Online]
Available at: https://www.thebalance.com/carbon-tax-definition-how-it-works-4158043

The Conversation , 2020. *Ships moved more than 11 billion tonnes of our stuff around the globe last year, and it's killing the climate. This week is a chance to change.* [Online]
Available at: https://theconversation.com/ships-moved-more-than-11-billion-tonnes-of-our-stuff-around-the-globe-last-year-and-its-killing-the-climate-this-week-is-a-chance-to-change-150078
[Accessed 2 June 2021].

The Diplomat, 2019. *China in Djibouti: The Power of Ports.* [Online]
Available at: https://thediplomat.com/2019/03/china-in-djibouti-the-power-of-ports/
[Accessed May 2021].

The New York Times, 2021. *Europe Is Proposing a Border Carbon Tax. What Is It and How Will It Work?.* [Online]
Available at: https://www.nytimes.com/2021/07/14/climate/carbon-border-tax.html
[Accessed July 2021].

Tranfield, D., Denyer, D. & Smart, P., 2003. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management,* Volume 14, pp. 207-222.

Trudell, C., 2021. *Tesla Emissions-Credit Revenue May Boom Again in 2021: Analyst.* [Online]
Available at: https://www.bloomberg.com/news/articles/2021-01-27/tesla-credit-revenue-may-rise-to-2-billion-credit-suisse-says
[Accessed March 2021].

Tseng, M.-L.et al., 2018. A framework for evaluating the performance of sustainable service supply chain management under uncertainty. *International Journal of Production Economics,* Volume Vol. 195 , p. 359–372.

Ugarte, G. M., Golden, J. S. & Dooley, K. J., 2016. Lean versus green: The impact of lean logistics on greenhouse gas emissions in consumer goods supply chains. *Journal of Purchasing & Supply Management,* Volume Vol. 22, pp. 98-109.

Ulrich, C., Friedrich, H. E., Weimer, J. & Schmid, S. A., 2019, . New Operating Strategies for an On-the-Road Modular, Electric and Autonomous Vehicle Concept in Urban Transportation. *World Electric Vehicle Journal ,* Vol. 10(No. 91; doi:10.3390/wevj10040091).

UNFCCC, 2015. *The Paris Agreement.* [Online]
Available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

United Nations, 2013. *Sustainable Development Challenges,* New York, USA: s.n.

van Dijk, M., Weyzig, F. & Murphy, R., 2006. The Netherlands: A Tax Haven?. *Centre for Research on Multinational Corporation, SSRN Electronic Journal.*

Van Hoek, R., 1996. VAL, The functional and spatial organization of businesses. *Tildschnfi uoorEronomzscheenSonale Geografie,* Val. 87(No. 1), pp. 32-43.

van Hoek, R., 1997. Postponed manufacturing: a case study in the food supply chain. *Supply Chain Management,* Issue no. 2, pp. 63-75.

van Hoek, R., 1998. Logistics and virtual integration. Postponement, outsourcing and the flow of information. *International Journal of Physical Distribution & Logistics Management,* Vol. 28(No. 7), pp. 508-523.

van Zeller, B., Mota, B. & Póvoa, A. B., 2018. *Design and Planning of Sustainable Supply Chains: The Case Study of a Tissue Paper Business.* Valenca, Portugal, Springer Proceedings in Mathematics and Statistics, pp. 411-421.

Villareal, B., Elizondo, G., Villareal, A. & Rocha, A., 2000. *Achieving Agility Through Postponement: An Application.* Cancun, Mexico, s.n.

Wadhwa, S., Bibhushan, Bhoon, K. S. & Chan, F. T. S., 2008. Postponement strategies for re-engineering of automotive manufacturing: knowledge-management implications. *International Journal of Advanced Manufacturing Technology,* Volume Vol. 39, p. 367–387.

Wang, W.-P., 2010. Determining product differentiation strategies under uncertain environment. *International Journal Of Technology Management,* Vol. 50(No. 2), pp. 169-181.

Wikimedia, 2009. Free Trade Areas.
Available at: https://commons.wikimedia.org/wiki/File:Free_Trade_Areas.PNG

Wikner, J., 2014. *Supply Chain Management Strategies in Terms of Decoupling Points and Decoupling Zones.* s.l., B. Grabot et al. (Eds.), p. 371–378.

Wong, H., Potter, A. & Naim, M., 2011. Evaluation of postponement in the soluble coffee supply chain: A case study. *International Journal of Production Economics,* Volume Vol. 131, pp. 355-364.

World Economic Forum, 2009. *Supply Chain Decarbonization: the role of logistics and transport in reducing supply chain carbon emissions,* Geneva, Switzerland: Doherty, S; Hoyle, S..

World Economic Forum, 2021. *Net-Zero Challenge: The supply chain opportunity,* s.l.: s.n.

WWF, 2012. *Denmark waste to energy.* [Online]
Available at: https://wwf.panda.org/?204596/Denmark-waste-to-energy
[Accessed 7 April 2021].

Xu, X. et al., 2021. The selection of marketplace mode and reselling mode with demand disruptions under cap-and- trade regulation. *International Journal of Production Research,* Issue DOI: 10.1080/00207543.2021.1897175.

Yang, B. & Burns, N. D., 2003. Implications of postponement for the supply chain. *International Journal of Production Research,* vol. 41(no. 9), p. 2075–2090.

Yang, B., Burns, N. D. & Backhouse, C. J., 2004b. Management of uncertainty through postponement. *International Journal of Production Research,* 42(6), pp. 1049-1064.

Yang, B., Burns, N. D. & Backhouse, C. J., 2004. Postponement: a review and an integrated framework. *International Journal of Operations & Production Management,* Vol. 24(No. 5), pp. 468-487.

Yang, B., Burns, N. D. & Backhouse, C. J., 2005b. The Application of Postponement in Industry. *IEEE Transactions on Engineering Management,* May, Vol. 52(No. 2), pp. 238-248.

Yang, B., Yang, Y. & Wijngaard, J., 2005. Impact of postponement on transport: an environmental perspective. *The International Journal of Logistics Management,* Vol. 16(No. 2), pp. 192-204.

Yin, R., 2014. Case study research design and methods. *Canadian Journal of Program Evaluation,* Volume 30.

Yoo, J. J.-W., Kumara, S. & Simpson, T. W., 2012. Modular Product Design Using Cyberinfrastructure for Global Manufacturing. *JournalofComputingandInformationScienceinEngineering,* Volume 12.

Yu, C. et al., 2018. A delayed product differentiation model for cloud manufacturing. *Computers and Industrial Engineering,* Volume 117, pp.60-70.

Zheng, Y. & Mesghouni, K., 2011. *Using Postponement as a Rescheduling Strategy in the Supply Chain Management under Uncertain Demand Environment.* Hong Kong, s.n.

Zinn, W. & Bowersox, D. J., 1988. Planning Physical Distribution with the Principle of Postponement. *Journal of Business Logistics,* 9(2), p. 117–136.

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