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The Supply Chain of PPEs during the Covid-19 pandemic:

A focus on the Italian and the French situation

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Abstract

Global supply chains have been seriously affected by the spread of the Covid-19. Among the others, the pandemic had a particularly large influence on the supply chain of PPE, the personal protective equipment. In fact, it caused severe disruption and supply shortages, as well as a massive spike in demand for such products. Since the beginning of the pandemic, literature has studied the phenomenon and explained the logistics changes that the supply chain has encountered and how it has adapted to overcome its limitations. However, the majority of studies focus on the early stages of the pandemic, limited to the 2020 and the 2021, and do not provide a comparison between different countries.

The aim of this work is to address these gaps by attempting to explore what changed after 2021, in 2022, and how it differs from the previous periods, by focusing on the Italian and French situations. In fact, these two countries were among the first in Europe to see the Covid-19 virus spread and, by consequence, to face the PPE supply shortages and the supply chain's disruption.

The first step was to analyze the literature by a method called "Systematic Literature Review" (SLR). The analysis allowed to identify some logistics factors considered the most affected by the Covid-19 pandemic by the articles' authors and to find the main strategies implemented by the companies to face the critical situation. The findings of the SLR were used to construct a questionnaire.

The survey was administered to a total of 314 companies, 174 Italian and 140 French, selected among the PPE producers, wholesalers, and distributors.

The results of the survey were then studied by applying descriptive statistics and Kruskall-Wallis tests (KW). The tests revealed some differences in the two countries' habits: an example is the implementation of the strategies to face the pandemic that in Italy are still used, according to its more conservative mentality, while France quickly abandoned them. As an example, the stock visibility level in the company's business in Italy is increasing, while in France its decreasing or remaining constant. France generally shows a more dynamic behavior to the

changes of the environment than Italy that is still applying some prudential policies.

However, it is clear from the results that both countries are experiencing a general decline in their PPE businesses as these products are no longer needed among the public.

This work has important academic and practical implication. It enlarges the literature knowledge about the effect of the pandemic on the supply chain in the last phases of it and open to several questions about the future of it: how will the supply chain readapt to the new situation? Will it return to the past or find a new equilibrium point?

Future research could try to collect new data from PPE companies in other countries, culturally and geographically distant from Italy and France in order to identify some typical patterns across the globe and the eventual differences. Furthermore, it would be interesting to add to the analysis other supply chain's stages – such as the retailers – and study the changes they experienced and how they reacted.

1. Introduction

1.1. Research background and motivation

Global supply chains have been significantly impacted by the COVID-19 pandemic, revealing a number of systemic weaknesses and vulnerabilities.

Sars-Cov-2, the virus that caused the Covid-19 disease, was identified at the end of the 2019 in Wuhan, China, and quickly led to a pandemic. The World Health Organization (WHO) declared the COVID-19 pandemic on March 11, 2020; more than 110,000 cases and more than 4000 deaths had been reported in more than 110 countries [1].

The world population faced an unprecedented challenge, which has not been experienced from the time of the Spanish flu and the two world wars [2]. Covid-19 rapidly escalated in a worldwide pandemic and after a few months from the beginning the number of infected were already 23 million. The pandemic impacted supply chains in a variety of industries, from consumer products and electronics to healthcare and food, resulting in shortages, delays, and price rises. The crisis emphasized the fragility of worldwide supply chains, the interdependence of economies, and the need for greater resilience and flexibility in the face of unforeseen catastrophes.

It took few weeks to report a shortage of personal protective equipment (PPE) in many hospitals and health facilities. This lack was one of the most critical issues that Covid-19 has spread all over the world and that causes several problems. [3,4]. By March 2020, the sudden surge in demand for these essential medical supplies has resulted in disruptions and shortages across the supply chain, leaving healthcare workers and the public vulnerable to infection.

Months later, PPE shortages continued as health workers still reused or rationed single-use PPE. [5] The pandemic causes the PPE prices to skyrocket: in April 2020, masks, gowns and N95 masks had risen 1500%, 2000% and 6136% respectively compared to the pre-Covid-19 levels [6].

It became critical to assess the supply chain weaknesses revealed by the pandemic and come up with mitigation measures, such as increasing supply chain visibility and transparency, diversifying sources, and using new technology.

This thesis takes place in order to extend the investigation that was begun in the paper [7]. The cited work discusses how several logistics factors, such as lead times, stock levels, demand rates changed in the supply chain of personal protective equipment during the Covid-19 pandemic in the first phases in Italy.

Starting from this point, the aim of the present thesis is to explore the impact of the pandemic in 2022, identify the key factors that led to the severe disruption, and which were the strategies employed by the companies to mitigate the impact of the Covid-19, including government intervention, diversification of sources, technological solutions, such as ICT technologies, inventory tracking, etc. and compare them to the previous periods.

Furthermore, the thesis will investigate the situation of two different European countries, Italy and France and show how they reacted to such an event. In fact, these two countries were among the first in Europe to see the Covid-19 virus spread and, by consequence, to face the PPE supply shortages and the supply chain's disruption.

The work is organized as follow: the aim of this chapter is to present the background about supply chain management, specifically the supply chain of PPE. The second chapter explains in detail the first stage of this work, the systematic literature review, from which were determined the primary gaps to investigate in the research. Then, the third chapter discusses the questionnaire design, including how it was structured and which respondents' sample were chosen. The fourth chapter illustrates the questionnaire administration as well as the statistical approaches used to assess the survey results, including descriptive statistics and the Kruskall-Wallis tests (KW). Finally, the fifth chapter summarizes the research findings, explains its implications and limitations, and suggests some possible future research.

1.2. Supply chain management

The supply chain is defined as all the parts involved, directly or indirectly, in fulfilling a customer request [8]; it includes not only the manufacturer and suppliers, but also transporters, warehouses, retailers and, finally, the customers. The flow of information and products in both directions connect the different stages and may be managed by one of them or an intermediary.

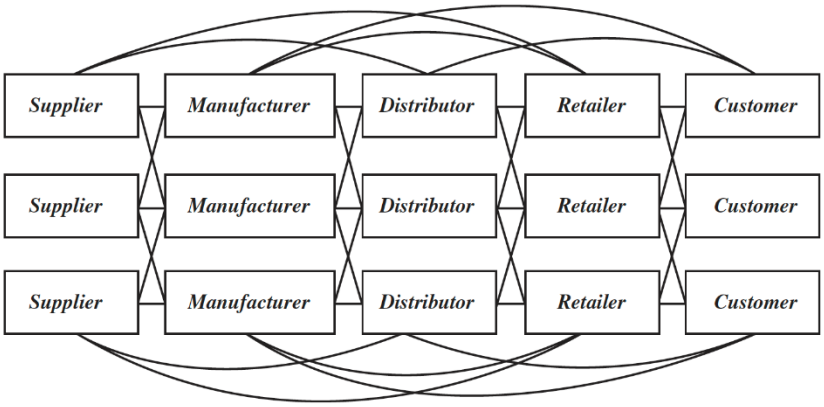

Figure 1: Supply chain stages (Chopra, Meindl, Supply Chain Management: strategy, planning and operation, 5th edition, Pearson Education, 2013)

The objective of the supply chain is to maximize the overall value, also called the supply chain surplus, that is the difference between the value of the final product to the customer and the costs to fill the customer's request.

The management of the supply chain is crucial since it heavily influences how successful businesses are. The weaknesses and vulnerabilities in the planning and architecture of the supply chain can be blamed for the failure of many companies.

The supply chain management involves integrating all the operations connected to the movements and transformation of goods, in order to obtain a sustainable competitive advantage [9].

The term Supply Chain Management (SCM) appeared for the first time in 1982. SCM and logistics have frequently been used interchangeably, however they are two different processes. The logistics management is defined as "the process of planning, implementing, and controlling the efficient, cost-effective flow and

storage of raw materials, in-process inventory, finished goods, and related information flow from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements. In reality, SCM goes beyond logistics: the integration of business processes from end users through original suppliers that provides products, services and information that add value for the customers is what we called supply chain management [10].

The supply chain presents a set of characteristics that should be necessary to the well organization of a company: SCM should be integrated, customer-centric, distributed, having interoperability, scalability, flexible infrastructure, autonomous, capable of self-organization and reconfiguration, coordination, and negotiation, adaptable to the dynamic market, synchronize and agile [11].

- Integration: all players and activities from the raw materials until the creation of the final product should be interrelated and work together in order to deliver the products to the customer at the right time at the right place.
- Customer centric: key SCM strategy to obtain a competitive advantage, SC customer-centric focuses on customers' needs and requests to fulfill its desires.
- Distribution: all supply chain applications are centered in a single global market.
- Interoperability: collaboration between the different stages of the supply chain, for example a manufacturer and a retailer that collaborates to determine the best forecast for each product.
- Scalability: the goal of a scalable supply chain is increasing the volumes and decreasing supply chain costs while maintaining its efficiency.
- Flexibility: SC must adapt dynamically and rapidly to the changes of the market in order to customize its service and cost offerings to meet the needs of distinct customer segments.

- Autonomous: an autonomous supply chain is a system capable of automating, digitizing, and robotizing all processes to guarantee efficiency in demand peaks and reduce waste of resources.
- Self-organization and reconfiguration: all parts of the supply chain network can be reorganized to adapt to the changing of supplier-customer chain.
- Coordination and negotiation: all stages of the chain take actions that are aligned and increase total supply chain surplus. Supply chain coordination requires each stage of the supply chain to share information and take into account the impact its actions have on other stages.
- Agility: SCM systems must be able to process transactions rapidly and efficiently through the entire supply chain stages.

All these characteristics are required for a successful supply chain and should be applied.

Supply chains are affected by several risks that can exacerbate its vulnerability. These risks can be internal or external to the supply chain.

Internals risks can arise from the interactions between the supply chain components, for example a lack of visibility, of ownership, just-in-time practices, and inaccurate forecasts.

External risks emerge from interactions between the supply chain system and its environment, the Covid-19 pandemic is only an example of this kind of risks that include also natural disasters, terroristic events, industrial accidents, etc.

Together these risks can affect the supply chain vulnerability: SC must be capable to prevent these risks and prepare some actions to recover and restore an equilibrium point [12].

1.3. PPE – Personal protective equipment

The personal protective equipment, PPE, is equipment worn to minimize exposure to hazards that cause serious injuries and illnesses (OSHA: Occupational Safety & Health Administration, 2004); it includes items such as gloves, safety glasses, surgical masks, non-surgical masks, goggles, face shields, gowns, N95 masks. To be certified and used safely, personal protective equipment must adhere to certain international, regional, and national standards. They must, in particular, have some quality, performance features to be applied in the context of the Covid-19 epidemic, during which PPE became critical to reducing viral transmission among the general public.

1.4. PPE supply chain

The goal of this section is to provide a complete outlook of the PPE supply chain, including all the relevant stages. The structure shown in Figure 2 has been constructed by merging the two supply chain structures proposed in [13] and [14].

The first actor is the supplier who provides the raw materials (nitrile, polypropylene, polyester, polyethylene, nylon, etc.) needed to produce the PPEs. The second step are the manufacturers, that receive the raw materials from their suppliers and through their production processes are able to manufacture the final products shipped to their clients. Then, the wholesalers are the centers where the PPEs are finally delivered to retailers – hospitals for the employees and patients, or pharmacy for the ordinary people. The Figure 2 represents this flow: the green arrow underlines the direction of the product, from the supplier to the final customers; the orange arrow refers to the information flow: in fact, the demand of products arrives from the clients downstream, based on their needs, while companies forecast or directly receive the requests upstream. It is very important to identify these main stages because, basing on this structure, the respondents of the survey were selected.

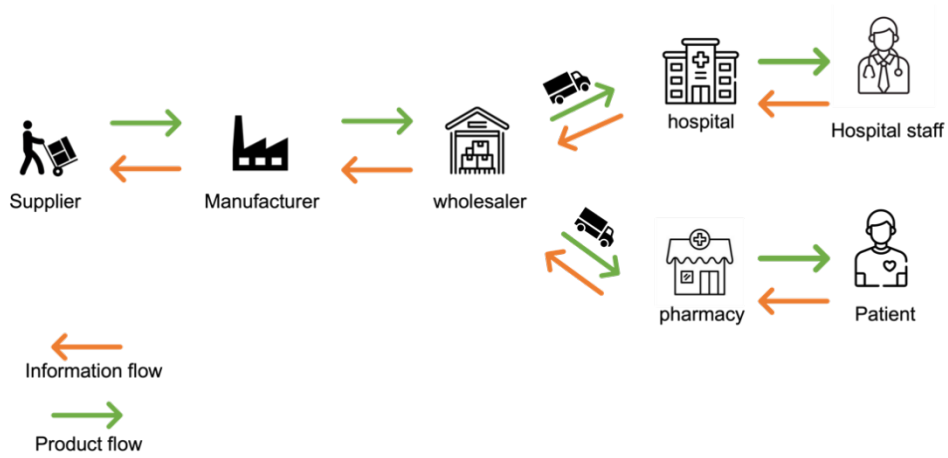

Figure 2: PPE Supply Chain

1.5. Thesis' contribution

The aim of this thesis is to better understand the changes caused by the Covid-19 pandemic in the PPE supply chains after the disruption after the first phases. To fulfill this aim, it is analyzed the existing literature on the topic, in order to highlight some possible gaps.

Then, a questionnaire is built using the findings of the systematic literature review. These findings are divided in two categories: the logistics factors most impacted – lead times, customer and supplier demand, stock level, etc. – and the strategies implemented – stock visibility, ICT solutions, diversification of sources, etc.

In particular, the SLR has highlighted a lack of information on these factors regarding the last period of the Covid-19 pandemic that coincides with the 2022. In fact, quite all the papers found concentrate on the supply chain changes during the pandemic outbreak, in 2020, and during the 2021. Fulfilling this gap is the primary motivation for the present research work, together with comparing the situation in two distinct countries, in order to study how different were the approaches, which can be considered the most useful to recover from the disruption or if improvements can be done in the organization of the supply chain.

2. Systematic Literature Review

The aim of this chapter is to present how the knowledge base of this thesis was built. The methodology applied is the Systematic Literature Review (SLR) that helped to synthetize research findings in a systematic, transparent, and reproducible way and to uncover areas in which more research is needed [15].
The chapter is organized as follow: the first section identifies the steps addressed in the SLR, with a focus on the inclusion and exclusion criteria. The section 2.3 presents the key words selection, useful to identify the papers composing the corpus of the research while the 2.4 gives an overview of the papers chosen. The 2.5 explains the Snowballing approach, used to complete the corpus. Finally, the 2.6 synthetizes the review and explains the findings.

2.1. Research methodology

The aim of this section is to review the existing literature on the supply chain of PPEs during the Covid-19 pandemic in order to identify any gaps that may exist before conducting the survey later on the research.

As anticipated in the introduction of this chapter, the method used is the SLR. This is a rigorous technique to review relevant literature in a field using a systematic approach based on clearly formulated questions, identifying relevant studies, appraising their quality, and summarizing the evidence by use of the explicit methodology (A. Siddaway, A. M Wood, L. V Hedges, How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses, Annu Rev Psychol, 2019). In doing so, the results of the literature review allowed the identification of the main logistics aspects to be taken into account in the following step, the questionnaire.
The inclusion and exclusion criteria, the selection of the keywords, the selection of the articles, and the Snowballing technique, were all stages that have been

addressed during this phase, as it will be discussed in detail in the following sections. In Figure 3, the steps of this approach:

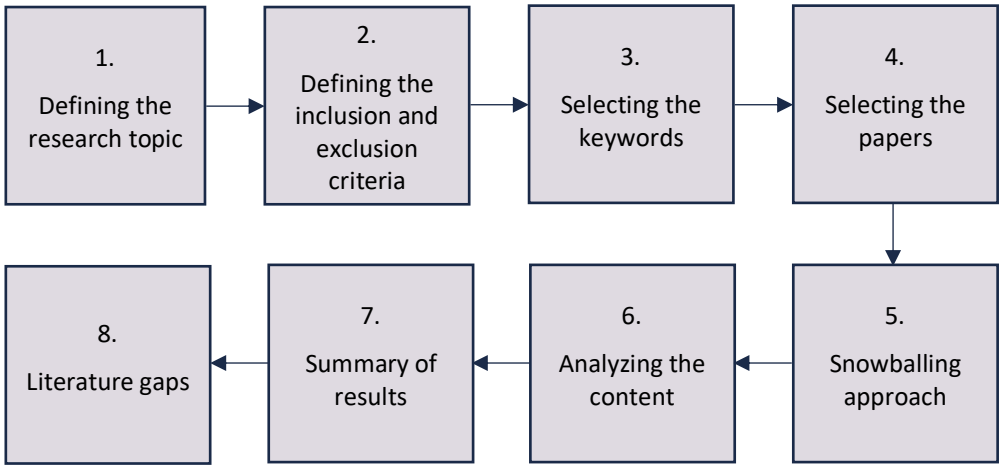

Figure 3: Work method

2.2. Inclusion and exclusion criteria

Before beginning the investigation, the criteria employed to select the papers were chosen. The first criterion is language; in fact, every publication is written in English.

Due to the topic being relatively new and the literature not being as well established as others, no type of papers, from journals, in most cases, to conferences, has been excluded.

The research focuses on papers published during the different phases of the pandemic, between 2020 and 2022.

The reference source chosen is Scopus that is a worldwide database[1] containing more than 25000 papers and articles, constantly updated. It was used not only for its importance, but also because it can be easily accessed through academical account, as in this case, the Politecnico di Torino's account and the INSA's account.

Table 1 presents the complete list of inclusion and exclusion criteria used to select the papers in the SLR corpus:

Inclusion criteria	**Description**
Keywords	*See Section 2.3*
Language	English
Document types	Journal, Conference
Source	Scopus
Time interval	2020-2022
Topic	Focus on PPE supply chain during the Covid-19 pandemic
Exclusion criteria	**Description**
Topic	Focus on general disruptions in supply chain. Focus on PPE supply chain with no reference to Covid-19
Language	Not in English

Table 1: Exclusion and inclusion criteria

[1] https://www.elsevier.com/en-in/solutions/scopus

2.3. Keywords' selection

Concerning the choice of keywords to use in the search, the way of proceeding was from the most general to the most detailed. In this way, the first research on Scopus gave back most papers in line with the topic; going deeply in the keywords' tree (Figure 4), the more specific words allowed to complete the rest of the literature. The tree can be read by vertical; each branch constitutes a string of research. For example, one of the strings was "PPE SUPPLY CHAIN – COVID-19 – INVENTORY – STOCKPILE".

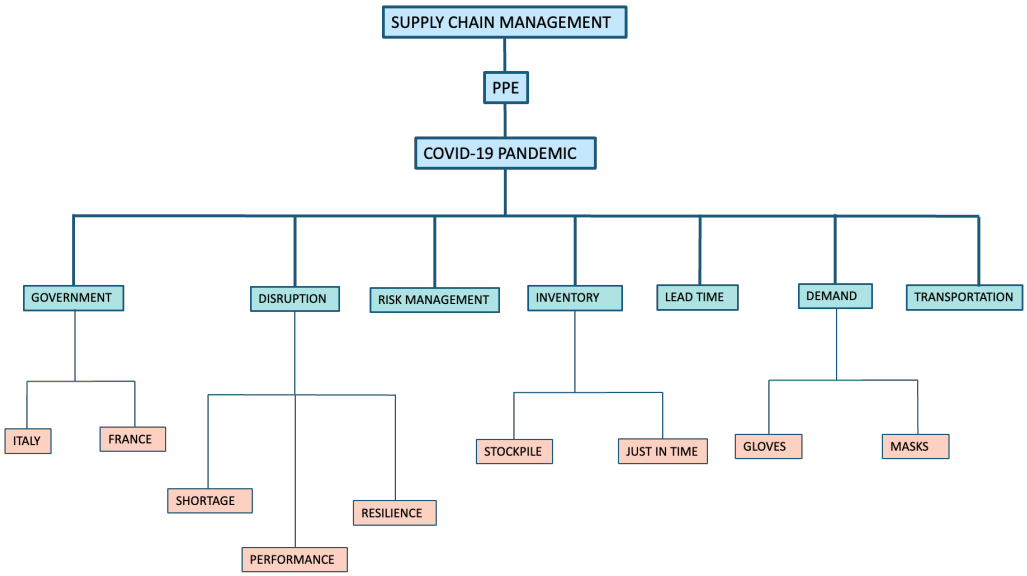

Figure 4: Keywords' tree

In Table 2, the main strings used in the research are presented. The first column indicates all the articles found with the related string; during the analysis, some of them were selected (second column) and others discarded (third column), as explained in the section 2.4. Finally, some articles were not accessible for free reading (fourth column).

Keyword research	Findings	Articles taken	Articles discarded	Not access
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic”	53	17	28	8
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “demand”	21	16	1	4
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “inventory” AND “just” AND “in” AND “time”	18	11	1	6
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “risk” AND “management”	18	9	8	1
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “government”	16	8	4	4
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “disruption” AND “shortage”	15	10	3	2
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “inventory”	9	5	2	2
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “inventory” AND “stockpile”	8	3	3	2
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “transportation”	5	1	4	0
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “lead” AND “time”	5	5	0	0
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “demand” AND “masks”	4	3	1	0
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “government” AND “Italy”	3	2	1	0
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “disruption” AND “resilience”	3	2	1	0
“Supply” AND “chain” AND “management” AND “PPE” AND “Covid” AND “pandemic” AND “disruption” AND “performance”	2	1	1	0

Table 2: Keywords' research

The following words cloud, shown in Figure 5, identifies the keywords that appear most often in the research; the dimension of the words, linked to the number of occurrences, underlines the fact that the most common words are also the most general ("Supply chain", "PPE", "Covid", "pandemic", etc.), while the detail of the word increases as its dimension decreases:

Figure 5: Keywords cloud

After the selection of the most relevant keywords, the search was performed. This phase was crucial to identify the papers and to recognize the main key factors affected by the pandemic and the strategies to face it; it will be discussed in detail in the section 2.6.

2.4. Papers' selection

The literature investigation was conducted using a reputable database, Scopus. The Scopus examination was performed using "*Article Title*", "*Abstract*", "*Keywords*" in the string of research. Then, the emerged articles were sorted by relevance. The next step was to open the abstract and read it: if, in the first reading, it seemed to be in line with the research, the article was saved and added in an Excel table summarizing the literature review; after the selection of all the articles, they were read in detail and, if not considered relevant, eliminated from the list. This method allowed to find 94 papers. 50 papers were selected as relevant, while the others discarded. The list is not exhaustive of the whole literature: in the first place, only one database was deployed in the study (Scopus); secondly 21 articles were not accessible and consequently not included in the research. However, the literature presented can be deem sufficiently detailed since it covers all the topic's important points.

Some of the publications were discarded because they focus on the Covid disruption on the global supply chain and not on the PPE's one; nevertheless, they were considered in some part of this work for its contextualization. In the same way, several papers focus on the PPE supply chain structure without mentioning the Covid period: they were selected to identify the most important stages to consider in the survey, presented in the first chapter of this thesis.

2.5. Snowballing approach

After the constructing of the main corpus, it has been employed the Snowballing approach in order to complete the systematic literature review.

This approach is a non-probability sampling technique whereby current individuals refer new subjects to fill out the sample sizes needed for a research project. The snowball method implies the identification of an initial set of respondents which will provide for new potential subjects to be included in the SLR [16]. The process continues until the moment the researcher decides the sample is large enough to satisfy the purpose of the study or the papers start providing the same papers already analyzed.

The utilization of this technique enabled to add other 14 papers at the corpus selection. Two types of Snowballing technique were adopted: the backward selection and the forward selection. The first is conducted scrolling the bibliography of the papers already selected in the corpus: the procedure was the same of the previous assortment (reading the abstract, adding in the table, reading the entire article, deciding if relevant or not). The forward research is conducted directly on Scopus: each paper was searched on the database and the articles citing it were analyzed.

After having finished the Snowballing research, the corpus was completed with a total of 64 papers selected.

2.6. Corpus description

Before analyzing the content of the papers, a descriptive analysis was conducted. Regarding the distribution of articles over time, they were all organically published between 2020 and 2022, with a peak in 2021, when 50% of the total number of articles were released.

The rise can be understood by taking into account the time lapse between the pandemic outbreak and the development of scientific understanding of the phenomenon, which caused the release of the initial articles to be delayed.

In addition, the decrease of the number of articles in the 2022 compared to the previous year, can be explained by considering that the investigation was conducted from September to November 2022 and probably more articles were published after this period.

Furthermore, in 2021, when the pandemic was at its worst, the world began to look for alternative approaches and strategies to deal with the Covid disruption.

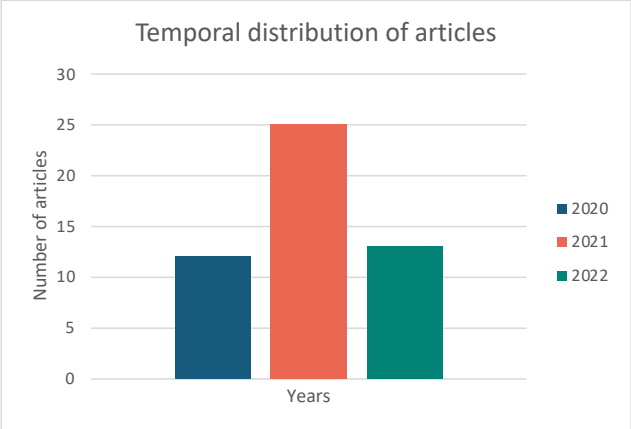

Figure 6: Year of article publication - main corpus

On the contrary, the articles found by using the Snowballing approach referred on the 2020 for the backward analysis and on the 2022 on the forward. The explanation is evident: the backward articles are found by going on the bibliography of the papers in the corpus (so they must have been published before them) while the forward by looking at the articles that cited them (published after the articles in the corpus).

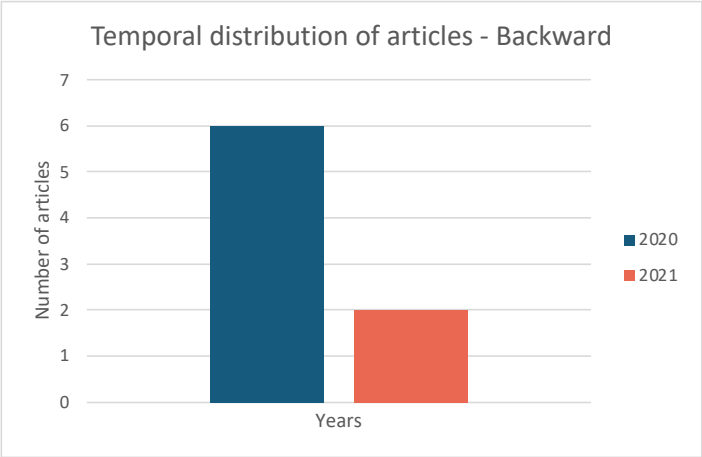

Figure 7: Year of article publication - backward Snowballing articles

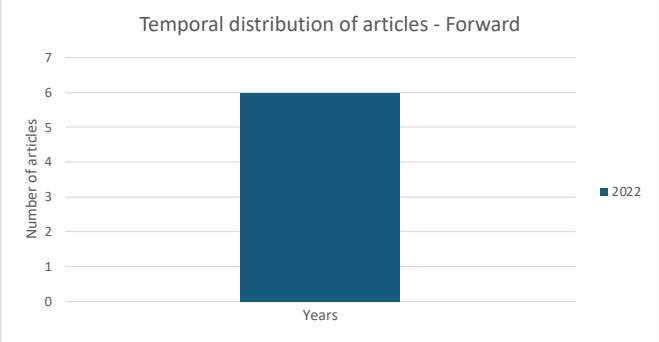

Figure 8: Year of article publication - forward Snowballing articles

Concerning the main journals where the studies were published, the Figure 9 presents the three most important journals considered; the "International Journal of Production Research (IJPR)" with 4 publications, followed by the "American Journal of Infection Control (AJIC)"[2] and "Science of the Total Environment" with 2 publications each. The first journal, the IJPR, is a leading journal in the areas of manufacturing, industrial engineering, operations research and management science[3]. The overall rank of the IJPR is 680. According to

[2] https://www.ajicjournal.org/

[3]https://www.scimagojr.com/journalsearch.php?q=27656&tip=sid

https://www.tandfonline.com/action/journalInformation?show=aimsScope&journalCode=tprs20

SCImago Journal Rank (SJR)[4], the ranking of the journal is calculated basing on an indicator which measures the scientific influence of journals considering the number of citations received and the importance of the journals from where these citations come.

AJIC is the foremost resource on infection control, epidemiology, infectious diseases, quality management, occupational health, and disease prevention. Finally, Science of the Total Environment is an international multi-disciplinary natural science journal for publication of novel, hypothesis-driven and high-impact research on the total environment.

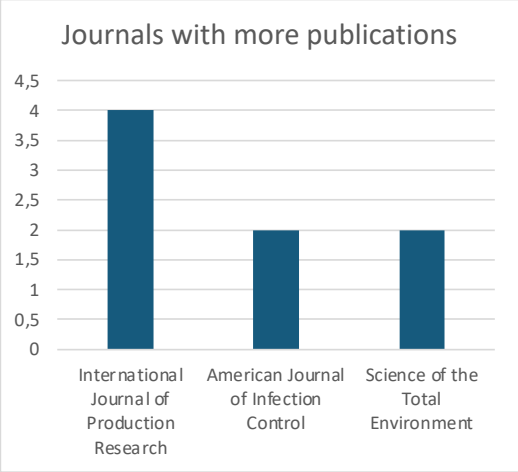

Figure 9: Journals with more publications

The most used research method in the articles is the qualitative: it represents the 69% of the total. The aim of the qualitative approach is to understand the event and its consequences on the supply chain without using quantitative data, as, on the opposite side, were used in the quantitative research's articles. One of the most common ways to conduct qualitative research was using the systematic review, which represents the 30% of total selection. It is followed by the case study (27%). The first quantitative method used is the mathematical optimization model that represents only the 14% of the total articles presented in the corpus selection. A small part of the publications used the mix type qualitative and

[4] https://www.scimagojr.com/SCImagoJournalRank.pdf

quantitative. This means that some articles used different approaches to perform their study. An example is the "Mitigating personal protective equipment (PPE) supply chain disruptions in pandemics – a system dynamics approach" [17]: in the first place, it was analyzed the literature on supply chain disruption and mitigation strategies in health emergencies; then, the authors conducted interviews with experts of PPE supply chains to validate and better understand the findings from the literature; finally they developed a conceptual System Dynamics (SD) model that captures the identified mismatches between PPE supply and demand.

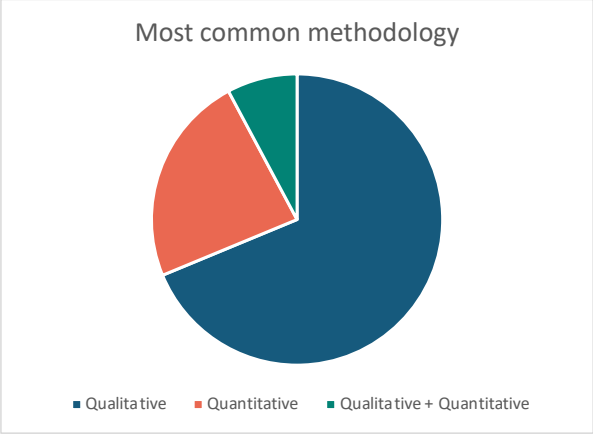

Figure 10: Most common method in the corpus selection between quantitative, qualitative and the mix type

In Figure 11, the methodology distribution is presented in detail:

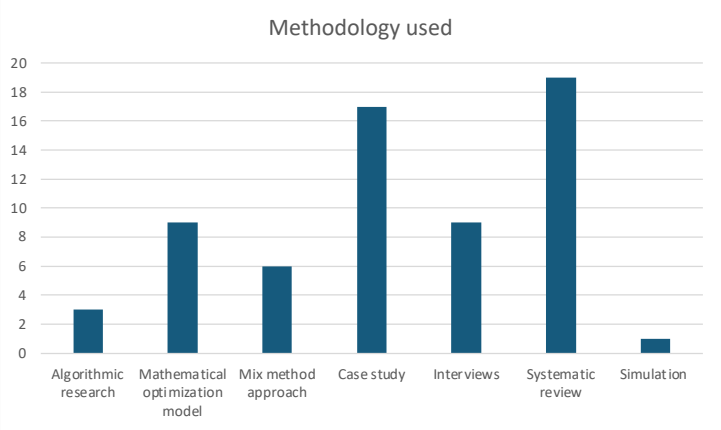

Figure 11: Methodology most used in the studies

To conclude, the analyze on the geographical scope underlines that the country with the highest number of studies is US (31%), followed by Canada and UK (5%). In general, many articles do not cite a particular country, but they describe the situation on the PPE supply chain during the pandemic in all the world (31% of the total).

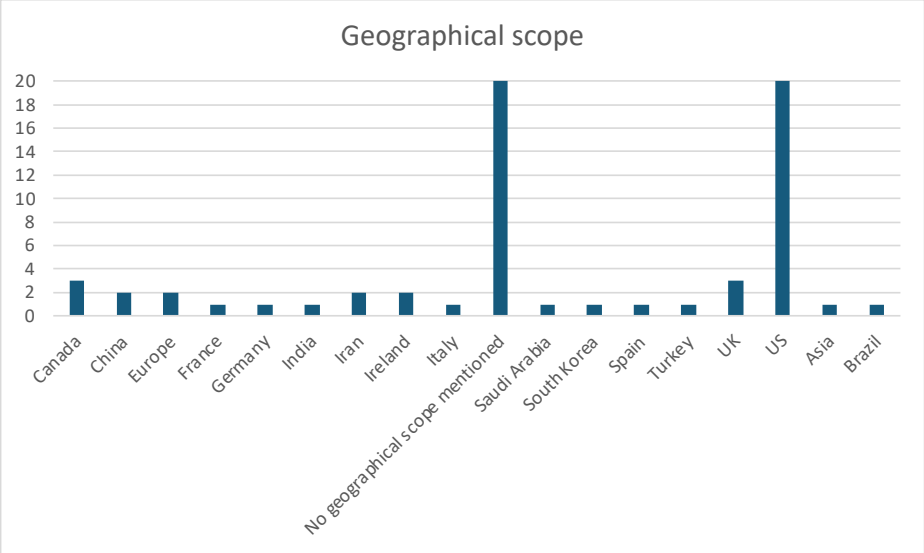

Figure 12: Geographical scope of the corpus

2.7. Main research trends

The main conclusions of the literature review are covered in this section.

The authors of each study focus on a different effect of the pandemic and offer potential solutions to use in the supply chain to lessen the disruption but, more significantly, to recover, restructure, and create a more adaptable system.

The Covid-19 epidemic has produced significant disorders with the key logistic components of the PPE supply chain, revealing some structural weaknesses and vulnerabilities to disruptions of the supply chain: it is evident how the pandemic has brought about a number of serious issues, which have all negatively affected the continuity of service delivery [18].

For instance, the demand was one of the most impacted factors; the monthly average demand exceeded up to 43% greater than the monthly demand under normal condition [19]. The dramatic surge in demand for goggles, face masks, gowns, and gloves have depleted the stockpiles, prompting significant price rise (by more than 1,000% in some cases [20], surgical masks' prices increased six-fold, N95 respirator prices tripled, and gown prices doubled [21]) and leading to a production backlog of 4–6 months in fulfilling the orders [22, 23]. The surge in the demand was also exacerbated by panic buying, excessive stockpiling and their related bullwhip effect: because of this phenomenon, the distortion propagated in an amplified form which cause the supply chain disruption to be more intense [24, 25, 26].

Supply chains that are resilient and adaptable can quickly absorb demand shocks, but this was not the case for the PPE supply chain, which was negatively impacted by the rise in demand and took a while to recover and achieve equilibrium.

Supply chain resilience has been defined as "the ability to proactively plan and design the supply chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a post-event robust state of

operations, if possible, more favorable than the one prior to the event, thus gaining competitive advantage" [27].

Preparation, robustness, recovery, and adaptation are the four resilience skills that the PPE supply chain has to acquire. With these four capabilities, the SC is able to prevent disruption, withstand it, and then bounce back stronger than before.

Not only the demand, Covid-19 had also a huge impact on stock management. The use of the Just In Time approach was one of the reasons. This technique is a management strategy that aligns raw materials orders from suppliers with production schedules. This means that companies order only when they receive requests from their clients and their stocks are kept at a low level. As a result, many firms were unable to meet the spike in demand, which caused delivery times to double.

In addition, inventory replenishment policies during the pandemic outbreak were scarce [28]. To better handle the unexpected spread of demand, a mitigation strategy may be to size and set up a system of storage and permanent conservation of safety stock [29], which were not in place at the beginning of the pandemic.

Furthermore, it is crucial to identify strategic stock locations at the national level and to monitor the stock rotation to avoid products to expire [30, 31]. For instance, [32] shows how a resource-sharing policy among different regions or countries can enhance essential-resource stock resilience. This approach may provide a more feasible way to effectively suppress future pandemics. The tool proposed by [33] allows to control and keep the stock at safety levels to the demand, mitigating the risk of stock-out.

Another aspect affected by the pandemic is that most of the PPE used in Europe is produced offshore. China is the largest exporter of masks [34] and other protective equipment in the world, owning the 50% of the global production [35], while other countries, for example the US [36], base most of their production on imports: they could not rely on their domestic manufacturers to

satisfy the healthcare PPE demand. With the spread of the pandemic all over the world, most countries applied lockdown restrictions and ban to the exportations, with the obligation to serve exclusively the domestic market. This was the case of China, but also of European countries as France, Italy, UK, etc.

The closing borders forced nations with poor PPE manufacturing to develop rapidly a stronger system; many of them disposed subsidies to convert their business in the PPE production, to build up additional capacity [37] and to enlarge the market with the creation of new start-up. Since not always government financial helps were successful, [38] suggests an optimal strategy to efficiently allocate subsidies to manufacturers to achieve a social equilibrium coverage.

The analysis of the literature revealed that the poor data tracking and inventory management tracking capabilities [30, 40] affected healthcare supply chains as well. The lack of visibility of material in the PPE supply chain contributed to the significant lack of PPE during the Covid epidemic. Due to the shortage of mask supply, smart consumption is required along with collaboration with public and private sectors, as well as global organizations [41, 42].

Consequently, developing an agile supply chain is fundamental [43]. Supply chain agility refers to the ability of a firm and its supply chain partners to respond rapidly to uncertainties due either to the risk of changes in demand or to the risk of supply chain disruptions [44]; achieving this agility requires several capabilities: flexibility – through the employment of advanced PPE planning [45], strategic sourcing plans – traceability and transparency – through the use of inventory visibility systems [46, 47], barcode and QR code tracking of materials, blockchains solutions [48, 49], app that uses backend database to save all information about the PPE stock [50] – persistency and responsiveness, and finally global independence. On the one hand, to reduce inefficiencies and costs, supply chains must be constantly prepared and informed of risks and opportunities through solid market intelligence. On the other hand, independence ensures that national enterprises may survive without relying

solely on outsourcing. The goal is not to simply eliminate international suppliers, which is impossible and may also increment the overall supply chain risk, but to maintain domestic sources in order to support national stockpile, and to build a global network of trusted suppliers. [51]

Reading the publications in the literature enabled the analysis of the impacts and strategies above-mentioned. A list of them was created for each publication based on the keywords chosen and the major topics covered in the papers.

In order to identify all the most discussed topics, a Pareto analysis was conducted. The Pareto analysis is based on the fact that the majority of results are often derived from a minority of inputs [52]. In this case the aim was to identify the number of factors most affected by the pandemic using the papers selected in the literature review as a base: in doing so, the most discussed impacts were selected as the most relevant for the ongoing research. After constructing the list of impacts with the related occurrences, it was applied the 80/20 rule – the top 20% of impacts were discussed in the 80% of publications. In this case, this rule is not exactly respected but it can be used as a good reference; the 80% of papers discuss the 34% of the impacts. This analysis was very helpful to find the criticalities that constitute the base of the survey conducted in the second part of the study.

In the same way, the analysis of the main strategies applied to face the pandemic was conducted. As before, it was applied the 80/20 rule, but as for the impacts, the 35% of strategies were discussed in the 80% of articles.

In Table 3, it has been reported the list of the above-mentioned impacts and in the Table 4 the strategies, followed by the number of occurrences and the cumulative percentage that they represent.

Impacts	Count of Impacts	%	Cumulative
Inventory	31	20,00%	20%
Demand	23	14,84%	35%
Number of outsourcing partners	15	9,68%	45%
Production capacity	15	9,68%	54%
Prices	8	5,16%	59%
Delivery times	7	4,52%	64%
PPE final product availability	7	4,52%	68%
Exports	5	3,23%	72%
Imports	5	3,23%	75%
Just in time practice	5	3,23%	78%
Manpower	5	3,23%	81%
Transportation costs	4	2,58%	84%
Lead time	3	1,94%	86%
Production quality	3	1,94%	88%
ELT service Level	2	1,29%	89%
National stockpile	2	1,29%	90%
PPE raw material availability	2	1,29%	92%
Transportation capacity	2	1,29%	93%
Customer service	1	0,65%	94%
Facilities allocation	1	0,65%	94%
Information system	1	0,65%	95%
Manufacturing flexibility	1	0,65%	95%
Materials' costs	1	0,65%	96%
Ordering costs	1	0,65%	97%
PPE allocation	1	0,65%	97%
PPE raw materials availability	1	0,65%	98%
Production rate	1	0,65%	99%
Transportation availability	1	0,65%	99%
Well-being of customers	1	0,65%	100%

Table 3: List of impacts and number of occurrences

In the Figures 13 and 14 it is presented the Pareto diagram that underlines how few impacts/strategies were the most claimants in the papers: they are so assumed to be the main factors affected by the Covid disruption, and the main strategies adopted by the companies along the supply chain stages.

As said before, the Pareto analysis was the first step to identify these factors. Nevertheless, not all the impacts/strategies included in the cumulative 80% have been retained. The selection regarded the most interesting to study; moreover,

some of them were hard to use; for example, prices in the impacts' list would be difficult to study since companies are not always willing to share financial data. When the set has been skimmed, the final list was the following: the impacts selected were inventory, customer demand, production capacity, customer delivery times, exports, imports, just in time practice, supplier demand, supplier delivery times, production rate. Concerning the strategies, they were the coordination improvement among the SC stages, inventory visibility systems, resilience, diversification of sources, subsidies.

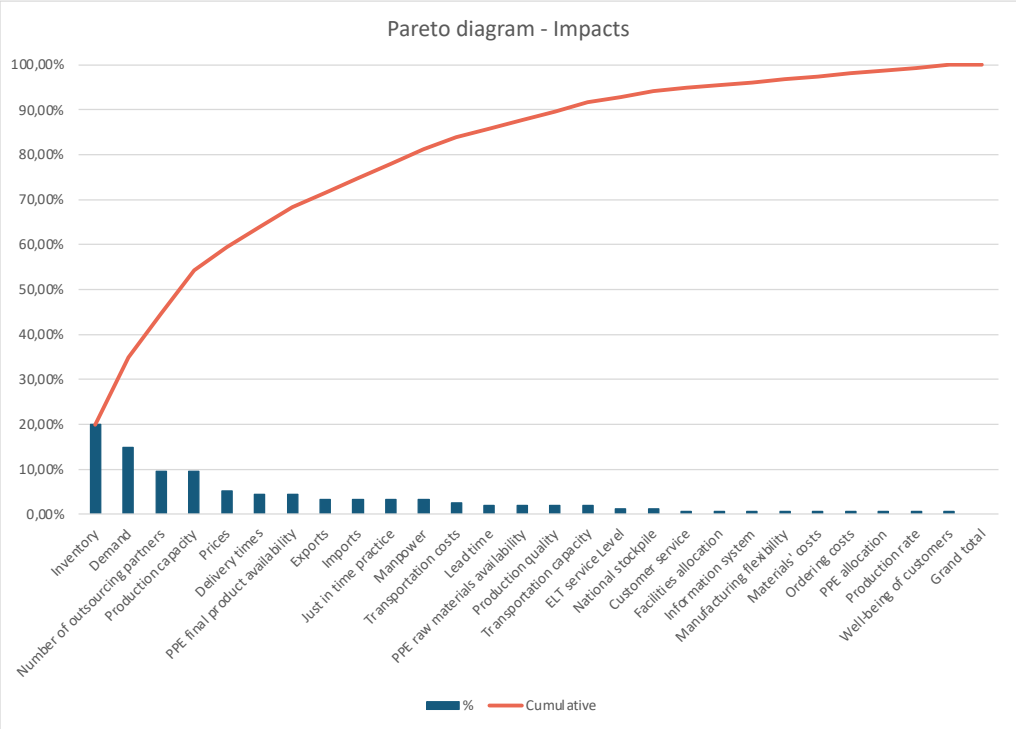

Figure 13: Impacts' Pareto diagram

Strategies	Count of Strategies	%	Cumulative
Private-public collaboration	14	10,37%	10%
Capacity expansion	12	8,89%	19%
Coordination improvement among SC s	12	8,89%	28%
Inventory visibility systems	12	8,89%	37%
Resilience	12	8,89%	46%
Diversify sources	11	8,15%	54%
Additive manufacturing	10	7,41%	61%
PPE reuse	6	4,44%	66%
Safety stock	6	4,44%	70%
PPE regulations	4	2,96%	73%
Subsidies	4	2,96%	76%
Blockchain technology	3	2,22%	79%
Limit stock levels	2	1,48%	80%
Proactive budgeting strategy	2	1,48%	81%
Production changeover	2	1,48%	83%
Re-purpose production lines	2	1,48%	84%
Stress testing on production capacity	2	1,48%	86%
Alternative PPE production	1	0,74%	87%
Backup facilities location	1	0,74%	87%
Chase strategy	1	0,74%	88%
Demand forecast improvement	1	0,74%	89%
Demand postponement	1	0,74%	90%
Efficient demand forecast	1	0,74%	90%
Facilities allocation improvement	1	0,74%	91%
Improve governement ability to coordir	1	0,74%	92%
Increase responsiveness	1	0,74%	93%
Increase social media utilisation	1	0,74%	93%
International trade policy cooperation	1	0,74%	94%
Monitore PPE distribution	1	0,74%	95%
Monitoring PPE consumption	1	0,74%	96%
Partnership with technology companies	1	0,74%	96%
PPE allocation model	1	0,74%	97%
PPE disinfection	1	0,74%	98%
PPE Mobile Phone App	1	0,74%	99%
Replenishment policy	1	0,74%	99%
Rotating inventory	1	0,74%	100%

Table 4: List of strategies and number of occurrences

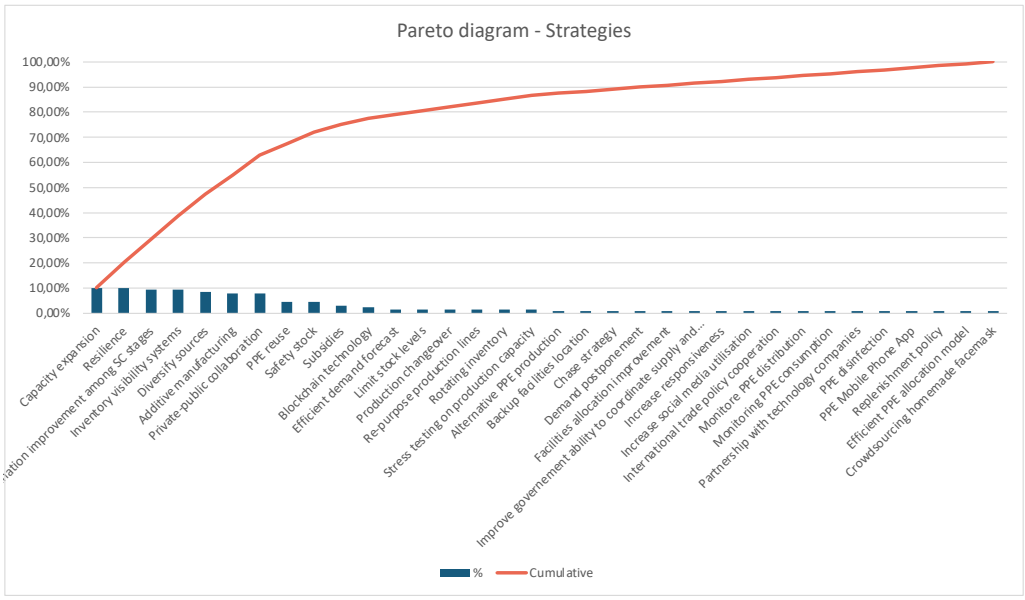

Figure 14: Strategies' Pareto diagram

Table 5 shows partially the Pivot Table used to connect the impacts with the strategies adopted by the companies to face the pandemic. In fact, several solutions were actively applied to assist the supply chain's recovery, with a focus on a specific aspect harmed by the pandemic.

As it is evident in the table, most strategies were implemented to manage the demand uncertainty: the surge in the demand obliged the firms to think different and to find alternatives to the classical production; a temporary solution adopted by several companies is the re-use of PPEs: this is a potential option to meet the critical shortage in the supply chain [53, 54] which, nevertheless, encounter difficulties in the application in the long term; in fact the reusing puts the life of frontline healthcare workers at risk of catching Covid-19 and spreading it to patients and the public [55].

On the other hand, an example of efficient long-term solution is the employment of the additive manufacturing as a valued substituted of the original products. In fact, given the shortage of materials, masks produced recurring to the 3D printing, capable of producing face shield useful as personal protective equipment [56], becomes a supplementary manufacturing process to meet the explosive demands and to ease the health disaster worldwide [57, 58], in the

crisis caused by COVID-19, it ensured the continuity of healthcare provision [59]. However, the standardization and certification appear to represent the main challenges for adopting the AM in healthcare against COVID-19 [60]. The pandemic brought forward a culture of novel collaboration and willingness to explore innovation with non-traditional partners [61]. Novel design and manufacture of reusable mask respirators presented by [62] represented one output of this collaboration.

Count of Impacts		Strategies				
Impacts	Title	Additive manufacturing	Diversify sources	Resilience	Coordination improvement among SC stages	Grand Total
⊟Customer service	57					1
Customer service Total						**1**
⊟Delivery times	2			1		1
	3				1	1
	7					1
	33					1
	35		1			1
	37					1
	49					1
Delivery times Total			**1**	**1**	**1**	**7**
⊟Demand	3		1			1
	5					1
	6					1
	7					1
	8					1
	12					1
	13					1
	17	1				1
	18					1
	21					1
	24					1
	25					1
	26					1

Table 5: Impacts and Strategies' Pivot Table

2.8. Literature gaps

Some possible gaps were detected after reviewing the literature and the content of the articles selected for the analysis. To begin with, no article compares different countries' responses to the Covid-19 disruption.

Existing research on the effects of the pandemic on the PPE supply chain examine the situation country by country, globally, or by continent. Few studies concentrate on the Italian and French situation and any of them compared the two countries. Comparing the responses of two different European nations to the supply chain disruptions caused by the epidemic and the methods they used to recover from them can be intriguing. In fact, the two nations are very similar historically and geographically. The goal is to investigate this similarity also at the organizational level of their PPE supply chains.

Second, in terms of the available literature, the research focuses on the early stages of the pandemic, particularly 2020 and 2021, which, in the rest of the research, it will be referred to as first wave and second wave. This could be due to the time lag between writing and publication, but as far as we know, there is a lack of contribution on the most recent phase of the pandemic, 2022, which constitutes the second key conclusion of the literature review. In the rest of the research such a phase will be called third wave.

Starting from these two findings, the comparison between two European countries and the third phase of the Covid-19 pandemic, the present research proposes to cover such lack accordingly. First, a questionnaire is designed and administered to a sample of potential respondents with the aim of collecting information about the main logistics factors affected by Covid-19, as identified in the SLR. Second, some statistical methods are applied to analyze the survey results, interpret them and explain the behavior of the PPE supply chain when disrupted by the pandemic.

In the following chapter, the survey construction is explained in detail.

3. Survey design

3.1. Design approach

In this section it will be discussed the survey's construction and the selection of the potential respondents.

The last two observations in the previous section serve as the starting point for the questionnaire's goal. In fact, it became clear from examining the literature review that there was not a single publication focused on the third wave and making a comparison between two distinct countries. These two conclusions made it possible to carry out the survey, in order to highlight possible changes of the PPE supply chain in 2022 regarding Italy and France, two of the most impacted countries in Europe and in the world.

The choice of the type of questionnaire to be administered was the first issue that needed to be addressed. The choice fell on the closed-ended item questionnaire (Jessica L. O'Leary and Glenn D. Israel, Constructing closed-ended items for a questionnaire, Savvy Survey Series, 2021). In fact, since it has a suitable set of response options, such a form of survey may be more challenging to write. However, the questions are quick and simple for participants to complete. In addition, they are also easy to analyze because the answers can be converted into numbers and entered in a spreadsheet, in order to do some evaluation.

It is employed a Likert scale to grade the answers. The Likert scale is a psychometric scale that allows respondents to select from a variety of categories to express their opinions, attitudes, or feelings regarding a specific topic [63].

The usual Likert scale is a five-, seven-, or nine-point scale of agreement. This method has the benefits of being simple to use for its ease of comprehension and reply, simple to report, using statistical techniques, and accurate in its facts. In this survey it was used the five points scale of agreement because it offers different answer options distinct enough for the respondents without throwing them into confusion (Babakus, E., & Mangold, G., Adapting the SERVQUAL

Scale to Hospital Services: An Empirical Investigation. Health Service Research, 26, 767-780, 1992).

3.2. Questionnaire design

Determining who would be responding to the survey and which supply chain stages would be chosen for interviews was a crucial phase in its development.

The choice fell on these stages: manufacturers, wholesalers, and distributors. As far as manufacturers are concerned, because many producers are Chinese and may be challenging to contact, they were not taken into consideration. In the same way, retailers – the pharmacies - and the final clients – people and hospital workforce – were also excluded. They would actually open up to a population that is too large to be easily reached.

The questions were partially generic and applicable to the entire group of respondents, and partially directly tailored to a particular target. For example, some questions related to the production rate and the production capacity were directed to manufacturers.

According to section 2.7, the questions were chosen based on the impacts and strategies selected at the conclusion of the literature research. Each question focuses on one of these and asks how they evolved in 2022 compared to the years 2020–2021. As a result, the Likert scale employed is of five points going from much decreased, to moderately decreased, unchanged, moderately increased, and much increased. A yes/no response was given to three questions about:

- The use of the Just in Time practices to Stock Management in the three periods, before 2020, during 2020/2021, after 2021.
- The use of ICT solutions by the company in the 2022 compared to the previous periods.
- The allowance of subsidies by the government during the pandemic.

These three questions were important to understand some behavior of the respondents to face the pandemic. The first of the three was also used in the Kruskall-Wallis tests to characterize the categories taken as populations for the test.

All questions, apart from those that were primarily relevant to manufacturers, were mandatory, and there was only one viable response.

The 20 total questions were broken up into two sections, the first of which focuses on the effects of COVID-19 and the second on the strategies used.

The survey was administered through email: it was anticipated by a brief presentation of the aim of the research and of the persons involved in the study. The text of the email was written in Italian, for Italian respondents, and in French, for the French companies. The reason behind this was that using English might discourage them from responding, whereas using their native language would encourage them.

It was administered starting from the 25th of January 2023 and it was closed on the 31st of march.

The first 4 questions are about the general information of the companies, in order to categorize them, based on their supply chain' stage, geographical position, type of customers, type of PPE mostly produced. These questions were fundamentals for the following step of the research that is the statistical analysis and the Kruskall-Wallis tests because they allowed the identification of the categories among which making the comparison.

The following section of the questionnaire contains the questions regarding the logistic factors that were, according to the respondents, the most impacted in their businesses by the Covid-19 explosion. The effect is measured as a comparison with the first and second wave because, as already explained, the third wave was the focus of the research.

These were the logistic factors considered:

- Inventory level: stock located in warehouses, logistics centers, and physical stores. It is an important indicator to know how much companies are still stocking, if they are relying on safety stock or producing only what is needed.
- Customer demand: type and quantity of products and services that people will buy or would buy if they were available. It reflects the need for a

product for the clients, in this case, for PPE and how is changing compared to the outbreak of the pandemic.

- Production capacity: maximum possible output of a manufacturing business. It is an important indicator because it states how prudential are the companies nowadays.
- Customer delivery times: the period between when an order is placed and when that order is delivered to the customer. In the beginning of the pandemic, they were very large since the companies could not provide in time the products, due to the shortages. It is interesting to study how this value is changing now.
- Exports: number of units goods produced in one country and sold to buyers in another. This indicator, with also the importations, is useful to understand if the market is domestic or global.
- Imports: number of units goods bought from a company in another country.
- Supplier demand: type and quantity of products and services that the supplier will buy or would buy if they were available. This indicator, as for the customer demand, reflects the pandemic trend that is decreasing.
- Supplier delivery times: the period between when an order is placed and when that order is delivered to the supplier. This indicator, as for the customer delivery times, measures how long the suppliers have to wait to have the products delivered.
- Production rate: units actually produced per year. It is fundamental to distinguish between the production capacity and the production rate because if the first is unchanged, the latter not necessarily is following the same trend.
- Just in time stock management: lean production method that aligns raw-material orders from suppliers directly with production schedules: produce only when required. This policy was largely used in the PPE

supply chain and this behavior caused a severe disruption and shortages because the stocks were empty and the surge in demand unprevented.

The last section of the survey regards the strategies adopted by the companies in order to face the disruption.

- ICT solutions: RFID technology, barcode system, Warehouse management system, Light Fidelity (LiFi) Technology. These systems are technologies born to gain more visibility of the inventory, thanks to the tracking of the material across its flow.
- Inventory visibility: full real-time visualization of every asset, tool and material across the entire facility.
- Resilience level: the ability to recover quickly from a crisis and to bounce back better.
- Diversification level: the number of sources across the globe, very important to not rely on only one big supplier – as China was for most of the market.
- Subsidies: financial helps given by the government- to help the companies to restart their businesses or to open new ones.

3.3. Potential respondents selection

The respondents were selected using different approaches for the French and the Italian companies.

The ATECO codes were used for the Italian companies. ATECO is the classification of economic activities adopted by Istat, the National Statistical Institute, for statistical purposes, that is, for the production and dissemination of official statistical data[5]. Companies' available databases are typically based on these codes, making it simple to select a list of potential responses after they have been identified.

Determining the codes was thus the initial step. Three primary codes were identified:

- 32.50.12: production of surgical masks and/or personal protective equipment.
- 32.99.19: Manufacture of other protective clothing and equipment.
- 46.46.30: import and/or wholesale placing on the market of masks and other devices – including coats, helmets, etc. – for medical use.

Finding the appropriate databases to use came in the second phase. Two were picked: AIDA and ISS (National Sanity Institute). AIDA is the database, created and distributed by Bureau van Dijk S.p.A., containing financial statements and trade data of all active Italian capital companies and bankrupt (excluding banks, insurance not available for free consultation)[6], the research was conducted through the Politecnico's credentials. The selected ATECO codes were then entered in the string of research on AIDA which subsequently produced a list of companies registered under those codes. The list was afterwards exported to an Excel file.

[5] https://www.istat.it/

[6] Aida | Italian Company Data | Bureau van Dijk (bvdinfo.com), https://www.bvdinfo.com/en-gb/

The research on ISS was easier: in fact, it is available on the website a free access file with all the companies authorized to produce medical masks in Italy.
Following the completion of the investigation on the two databases, the resulting lists were combined after the duplicates were removed.
The initial set of companies contained 900 rows: after the examination and the elimination of the ones unreachable, the number decreases to 481.
During the administration of the survey, most of the companies contained in this set resulted definitely closed or not concerned about the topic; they were eliminated from the database. The final number of reachable companies was 175.
The French companies were slightly more difficult to find. The reference code used is the NAF[7]. When a company is registered in France, the Insee (The National Institute of Statistics and Economic Studies) gives an APE code, sometimes also called the NAF code. This code serves to identify which sector the activity is in and it can be considered the correspondent ATECO code in Italy. The codes selected are:

- 3250A: Manufacture of medical-surgical and dental equipment.
- 4646Z: Wholesale of pharmaceutical products.

The problem of these two codes is that they are too general to identify only the personal protective equipment: they returned also all the companies that produce medical devices, not useful for this research.
Furthermore, the selection of the databases was complicated; Companiesdata.cloud[8] and Silex[9] were the only one of free access found on internet. The first is a useful website where anyone can find valuable business contact information in one place – a comprehensive, premium database with over half-a-million entries and regular updates. The free version of the database

[7] https://www.companow.com/the-ape-code-the-naf-code-what-is-it/

[8] https://companiesdata.cloud/ode

[9] https://silex-app.com/a-propos-de-silex/

contains only the name of the companies filtered by economic activities, but not the contact emails or phone numbers. Silex is the leading French supplier sourcing and management solution.

The two databases were completed by the use of the international database Orbis. Orbis is a powerful database which has information on close to 450 million companies and entities across the globe – 45 millions of these have detailed financial information. The codes used to search companies in this database are the NACE codes[10].

The acronym NACE, Nomenclature of Economic Activities, designates the integrated classification system for products and economic activities.

It designates the various statistical nomenclatures of economic activities developed since 1970 in the European Union. The NACE codes used were:

- 32.50: Manufacture of medical and dental instruments and supplies.
- 32.99: other manufacturers industries.
- 46.41: Wholesale of textiles.

The set of the three databases provided a long list of enterprises which were not all concerned by the research. The second step was thus to analyze the firms one by one, selecting only the appropriate ones and eliminating the others. The initial size was of 732 companies; after the skimming, the number became 398.

During the examination of these 398 firms, most of them were unreachable: some were closed, others did not have a website, a public email or number to be contacted. This analysis led to an additional skimming of the database which became of 145 companies.

[10] https://connects.world/nace-codes/

In the following Figures 15 and 16 it is shown the two processes of selection of the companies with the main steps:

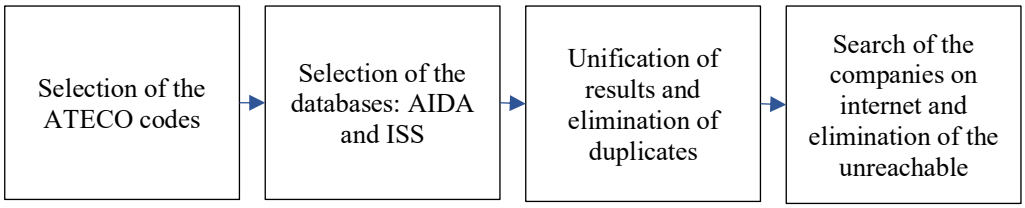

Figure 15: Italian companies' search process

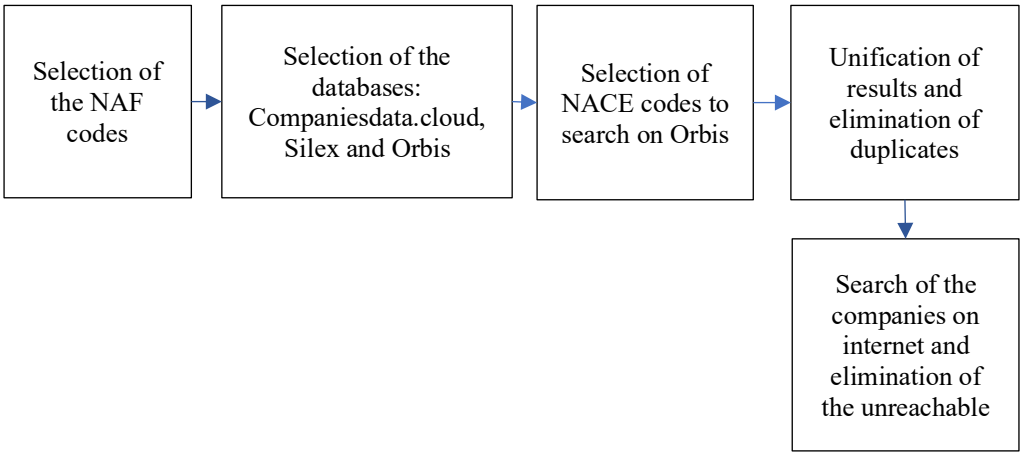

Figure 16: French companies' search process

4. Analysis of results

The goal of this chapter is to present the results provided by the questionnaire administration and the interpretation given to them.

The chapter is organized as follow: section 4.1 explains how the data were collected and the methods used to analyze them, namely descriptive statistics and the Kruskall-Wallis tests. Then, section 4.2 presents the results obtained by using these methods. Finally, the last section summarizes the main findings of the research.

4.1. Analysis Methodology

The questionnaire was administered by a Google form which provided a first draft of the descriptive statistics, that measured the frequency distribution. This analysis provided the base on which structuring the first hypothesis and was useful to see if the data contain some errors.

After understanding the basic characteristics of the results obtained by the descriptive statistics, the Kruskall-Wallis tests were conducted using the software Minitab-18[11] provided by the INSA laboratories to go deeper in the analysis.

The Kruskal Wallis test [64] is the non-parametric alternative to the One Way ANOVA. The term "non-parametric" refers to a test that makes no assumptions about the distribution of the data.

The test determines whether there is a difference between the medians of two or more groups. The H statistic is the test statistic applied in this test. The test's hypotheses are as follows:

[11]https://support.minitab.com/en-us/minitab/21/help-and-how-to/statistics/nonparametrics/how-to/kruskal-wallis-test/interpret-the-results/all-statistics/#mean-rank

- H_0: population medians are equal.
- H_1: population medians are not equal.

The variables should have:

- One independent variable with two or more levels (independent groups).
- Ordinal scale, Ratio Scale or Interval scale dependent variables.
- The observations should be independent. In other words, there should be no relationship between the members in each group or between groups.
- All groups should have the same shape distributions.

The Kruskall-Wallis test was then permitted by using the Likert scale in the questionnaire responses. In fact, converting the answers - Much decreased, Moderately decreased, Unchanged, Moderately Increased, Much Increased - into the equivalent numbers - 1,2,3,4,5 - enabled this analysis to be carried out in this manner.

4.2. Data analysis – Italian results

Firstly, in this section, it is presented the descriptive statistics of the Italian results. The Italian companies belong mostly to these categories, as shown in Figure 17:

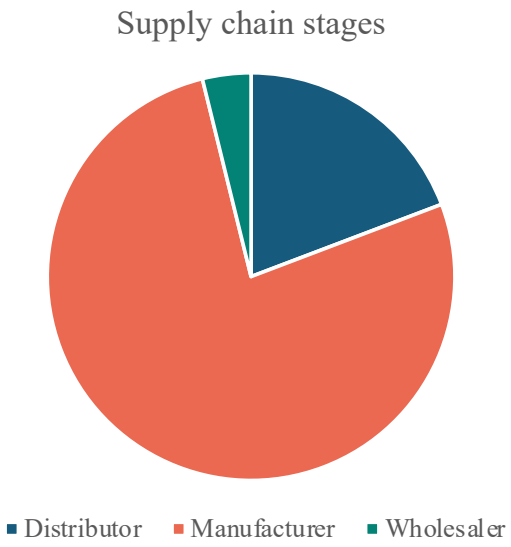

Figure 17: Supply chain stages - Italy

Most of the respondents were manufacturers (77%), while only 19% and 4% were respectively distributors and wholesalers.

The figure 18 illustrates the type of clients of these companies in Italy. As it is clearly observable, the majority belongs to the category of national clients, with only the 4% of European clients. This highlights that the PPE supply chain in Italy is pretty much local and domestic.

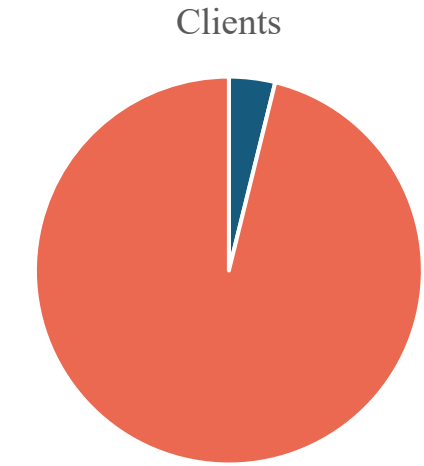

Figure 18: Type of clients - Italy

The following question was critical in determining which kind of PPE were most commonly produced in Italy. As seen in the Figure 19, the 73% produce surgical masks, the 15% gloves, the 8% gowns and the 4% goggles.

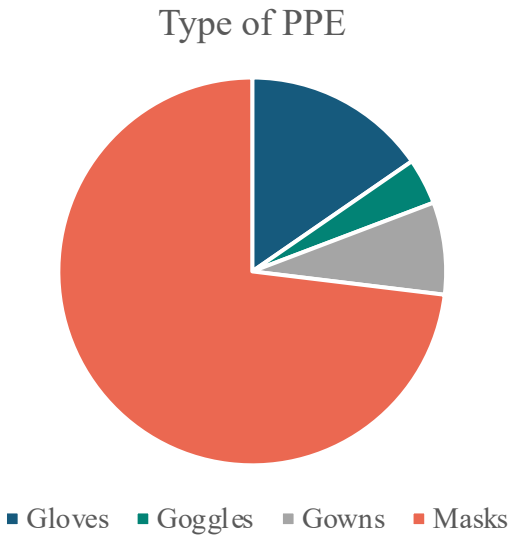

Figure 19: Type of PPE - Italy

This is understandable since masks were the PPE most commonly used by the general public during the pandemic, whereas the other categories were mostly used in healthcare facilities.

The following pie charts are related to the questions in the first section of the questionnaire, about the logistics factors most affected by the Covid-19 pandemic, in the 2022 compared to the 2020-2021.

In Figure 20, it is presented the changing in the clients demand according to the respondents: the 58% affirmed that the demand has extremely decreased following the first waves of Covid-19, followed by the 27% that announce a moderately decrease.

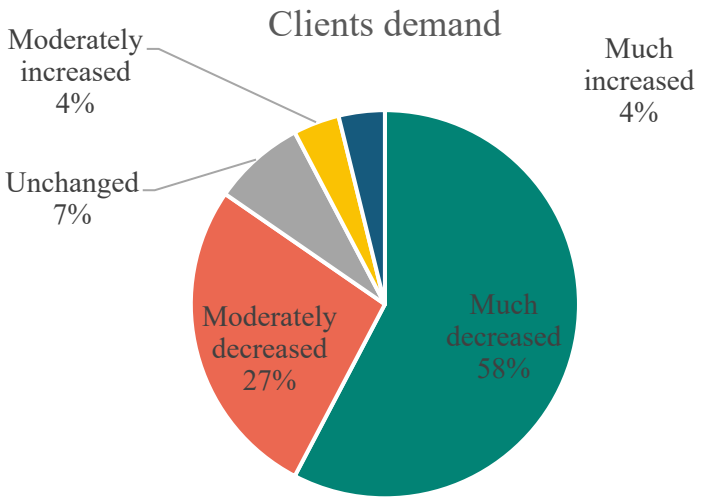

Figure 20: Change in the clients' demand - Italy

In the same way, also the stock level receives quite the same answers: a large part of respondents believe that the inventory level has decreased in this period – as the companies are not stocking a large amount of PPE that are no more mandatory in almost all the environments, excluding the healthcare buildings. Surprisingly, there is a 19% of them that affirm an high increase of stock; this can be explained by maybe a safety stock policy, used to prevent a possible new wave and new shortages.

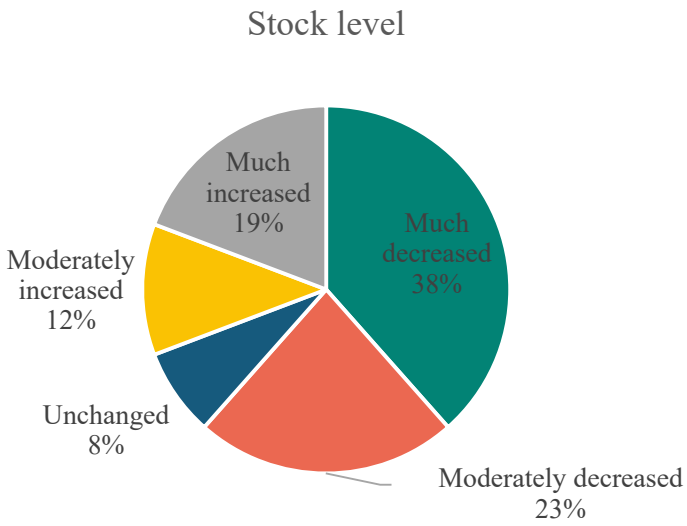

Figure 21: Change in the stock level - Italy

An interesting result can be observed in the following Figure 22, regarding the production capacity. In fact, the 36% of respondents answered that is unchanged compared to the first and the second waves. This could be an indication of caution on the part of companies that continue manufacturing large quantities of PPE, even though the pandemic is now under control.

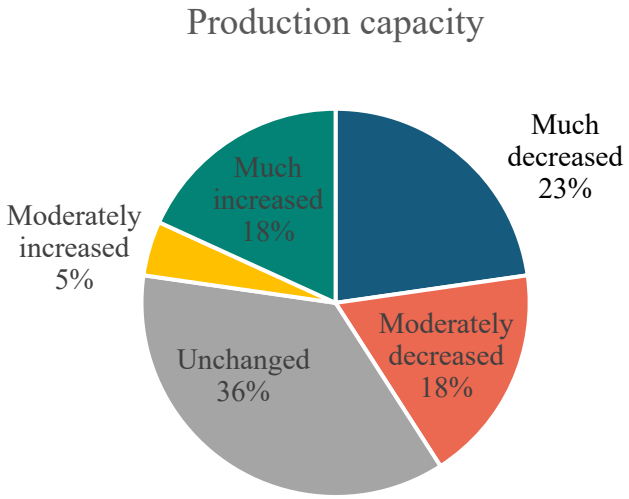

Figure 22: Change in the production capacity - Italy

The clients' delivery times remains unchanged for the 54% of respondents, while the 46% believes that they are decreasing compared to the previous periods. As

before, this can also be explained because, since the demand is decreasing, the stock is higher, resulting in faster delivery times to the customer.

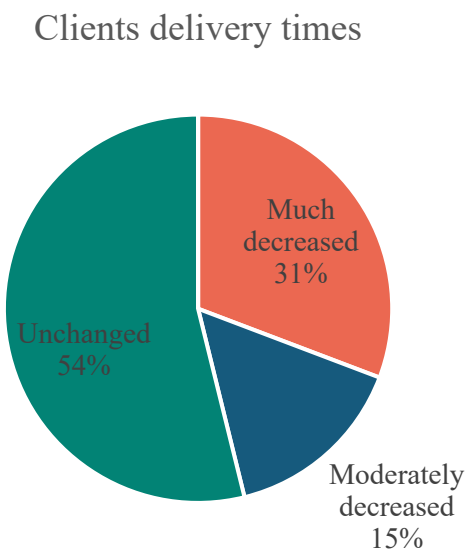

Figure 23: Change in the clients' delivery times - Italy

Since the PPE supply chain in Italy seems to be mostly domestic, it is not surprising that the exportations remain unchanged – 61% - because most of the customers are in Italy, where the government regulations maintained the obligation of wearing a mask in public longer than in other countries. To do a comparison with France, in Italy it was suppressed in late September 2022 while in France in March 2022.

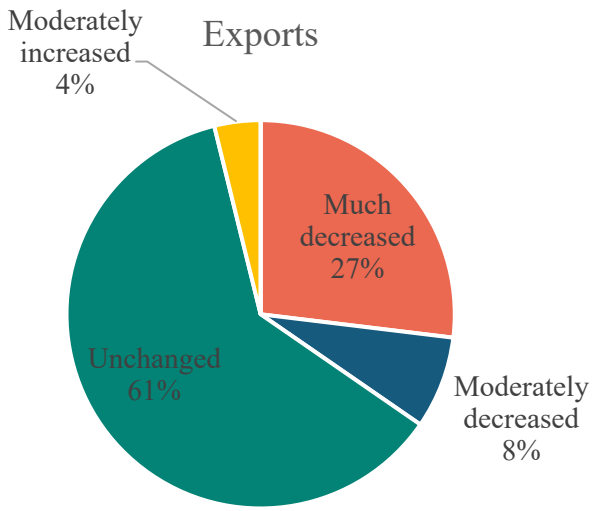

Figure 24: Change in exports - Italy

The same comment applies also for importations: the domestic market of Italy and the Italian government regulations of wearing a mask still in place in late 2022 makes the importations level to remain the same as the first and second wave.

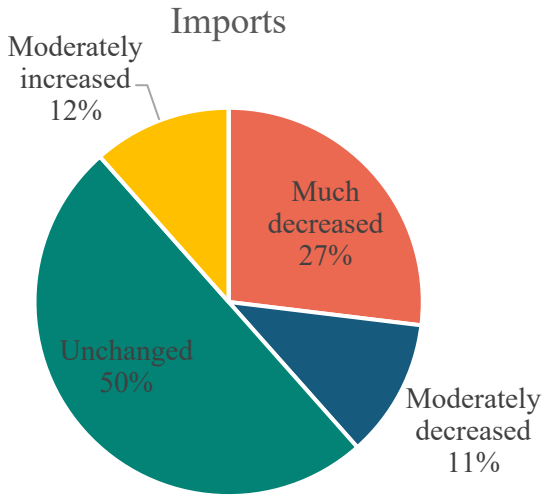

Figure 25: Change in imports - Italy

The answers about the use of the Just in Time during 2020-2021 and after this period are surprising. According to the findings of the systematic literature

review, the use of the Just in Time practices should decrease with the explosion of the pandemic. In fact, these policies caused the shortage of PPE and the fact that the companies were not able to meet the surge in demand because their inventories were empty. The first question regards the pre-Covid period; Figure 27 shows that the 54% of companies' respondents used, not surprisingly, these practices.

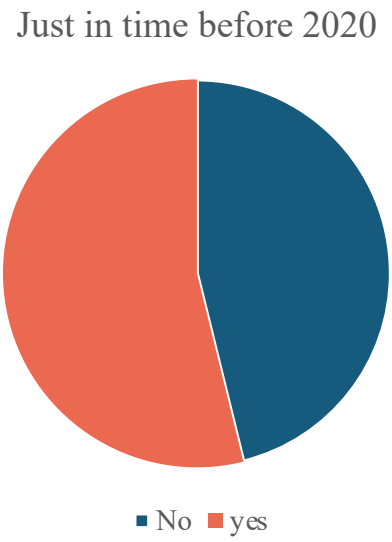

Figure 26: Use of Just in Time before 2020 - Italy

According to the answers received, this percentage of firms using the JIT increased during the pandemic instead of decreasing, with a total of 67% answering « Yes » to the question. Even more for the last question about the period after the 2021: the 73% uses the JIT. These results can be explained by a misunderstand of the respondents about the questions. It cannot be proved the technical background of the person responding the questionnaire, so maybe they were no familiar with this terminology. In addition, JIT was applied as the companies faced a huge demand and were not able to stock up PPE: all the production was immediately absorbed by customer orders and the stock level was always at zero, as JIT requires.

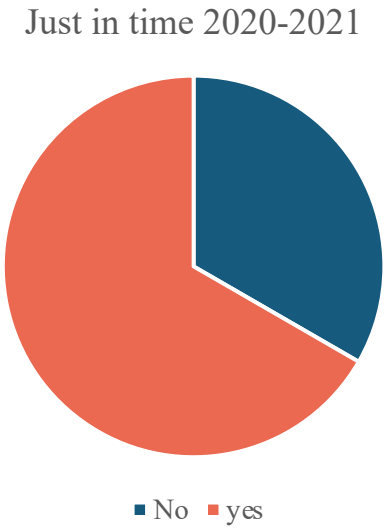

Figure 27: Use of Just in Time 2020-2021 - Italy

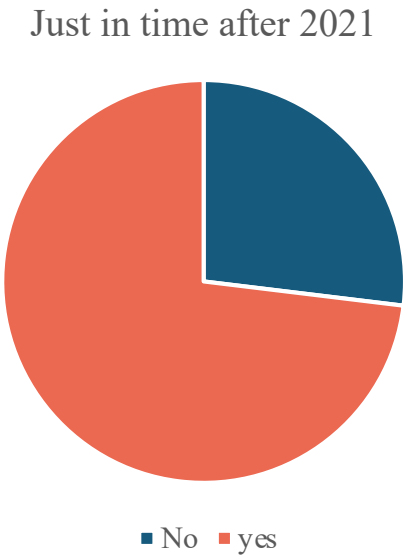

Figure 28: Use of Just in Time after 2021 - Italy

The following question is about the supplier demand. As for the clients' demand, this is decreasing for the 84% of respondents.

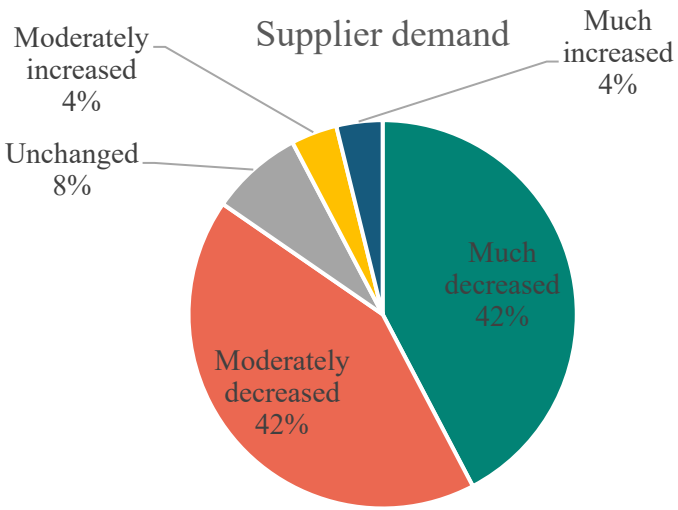

Figure 29: Change in the supplier demand - Italy

Same comment also for the supplier delivery times, that remain unchanged for the 46% and decrease for the 42%.

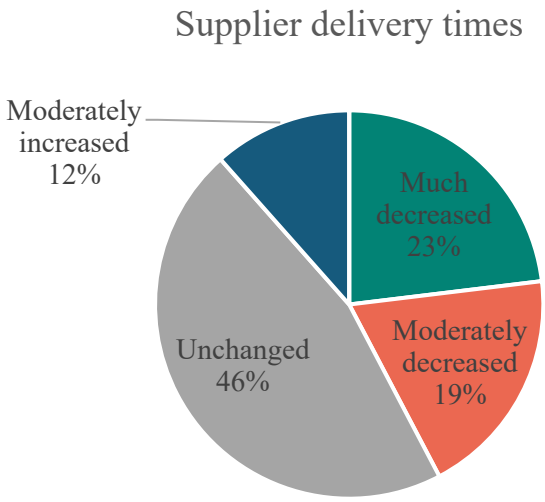

Figure 30: Change in the supplier delivery times - Italy

The production rate is decreasing – 45% of much decreased – differently from the question about the production capacity. This means that companies are effectively decreasing their production, but they are conservating some capacity in case of another pandemic or the sudden surge of infection cases.

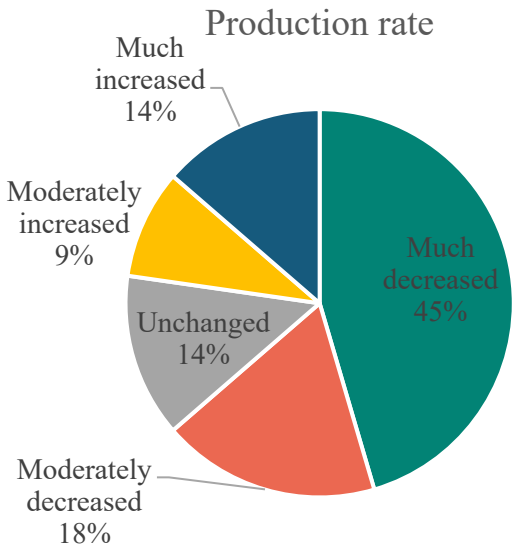

Figure 31: Change in the production rate - Italy

The second part of the questionnaire regards the strategies employed by the Italian companies in the third wave compared to the ones used in the first two waves. The first question, shown in the Figure 32, is about the employment of ICT technologies – such as RFID technology, barcode system, Warehouse Management System, Light Fidelity (LiFi) Technology – used to increase the coordination with the supply chain partners. The 62% answered « No », they did not adopt new ICT technologies, which make the Italian companies not so technological advanced.

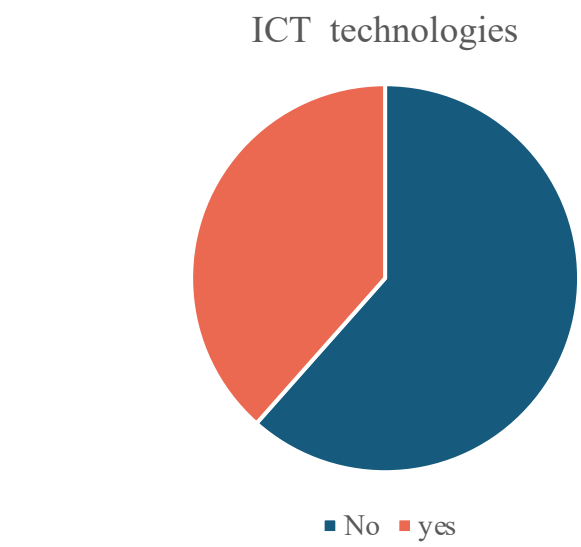

Figure 32: Change in the use of ICT technologies - Italy

The stock visibility has experienced a huge increase: the 44% affirm the rise in the use of this strategy to face the pandemic, which was essential to recover from the disruption and face some of the supply chain vulnerabilities unraveled from the Covid-19 pandemic.

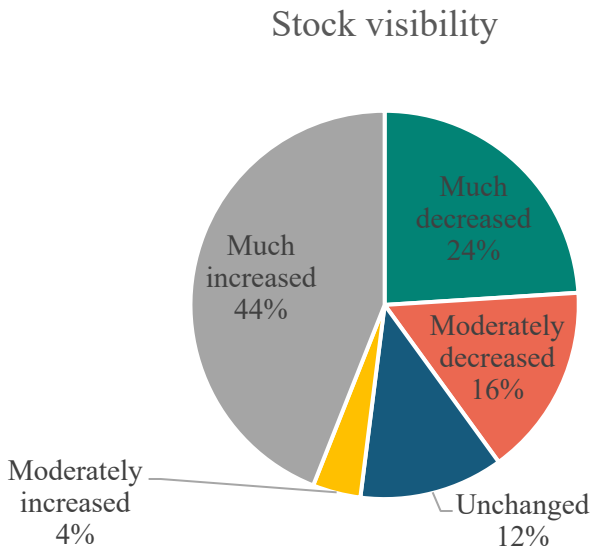

Figure 33: Change in the stock visibility - Italy

The following question is controversial: the 60% of respondents affirm the decreasing resilience level, that was a fundamental strategy during the pandemic, with only the 28% that claim an increasing level. This can be explained by the reestablishing of the old practices pre-covid, such as the Just in Time, or the non-appliance of new ICT technologies, that leave the Italian companies exposed to new dangers and vulnerabilities of the supply chains.

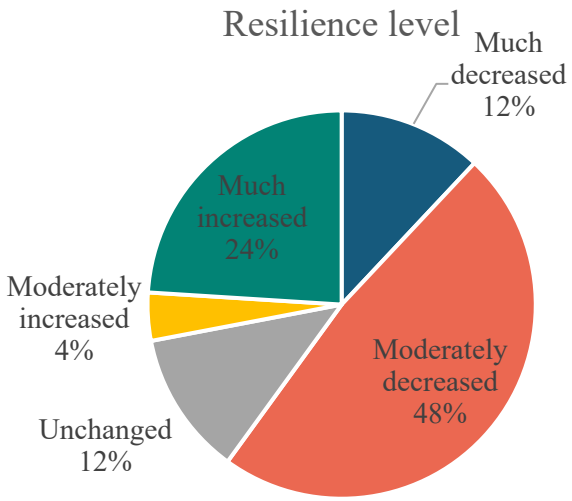

Figure 34: Change in the resilience level - Italy

Concerning the diversification of sources, another strategy considered essential to the recover from the disruption, the respondents are not unanimous in the answer: the 28% affirms its increase, while the 60% claims its decrease. Apparently, some companies continue to diversify their sources, while others are returning to the pre-covid levels where they only relied on few sources. In case of another pandemic starting in China, the main producer of PPE in the world, this leaves the firms exposed to, again, supply shortages.

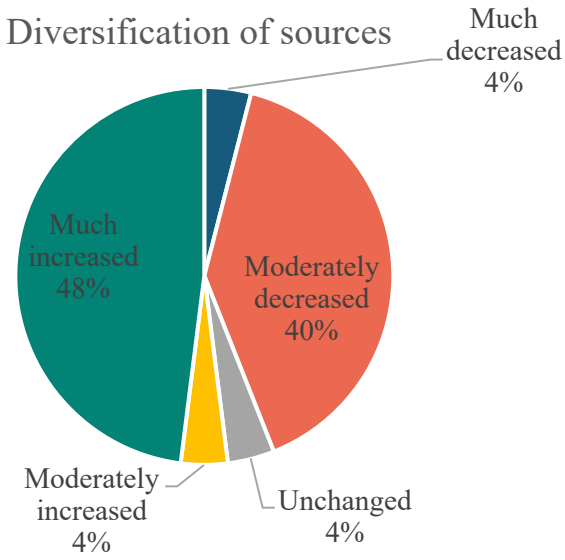

Figure 35: Change in the diversification of sources - Italy

The last question was about the subsidies received by the companies. Only the 20% of the respondents received subsidies by the government, especially in the first semester of 2020 (20%) and in the second semester of 2020 (80%),

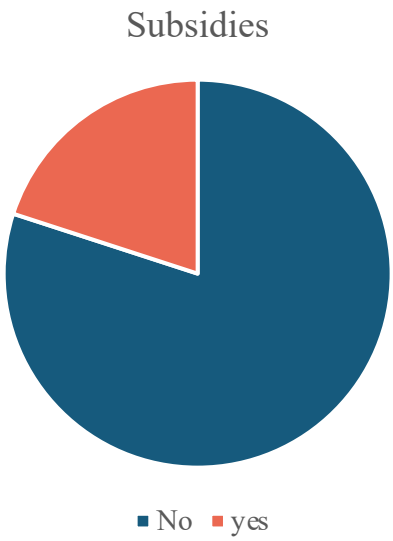

Figure 36: Allowance of national subsidies - Italy

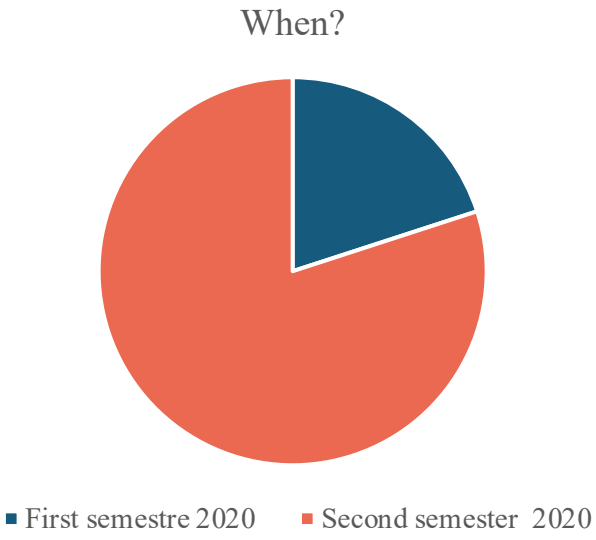

Figure 37: Period of subsidies accordance

4.3. Data analysis – French results

The same approach is applied also for the F rench respondents. In this case, the supply chain stages among the respondents are more balanced than the Italians: in fact, the 41% are distributors, the 35% manufacturer and the 24% are wholesaler. This is an advantage later on in the work for the Kruskall-Wallis tests' preparation.

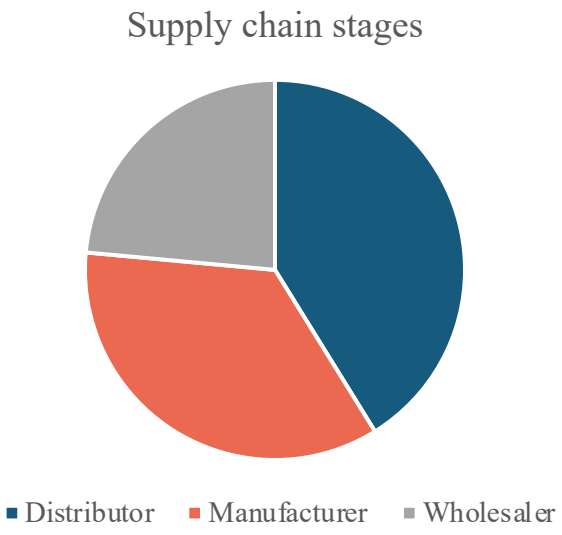

Figure 38: Supply chain stages respondents - France

As for the Italian companies, the market is above all domestic, with the 94% of respondents answering national clients to the question about what customers account for most of the yearly revenues.

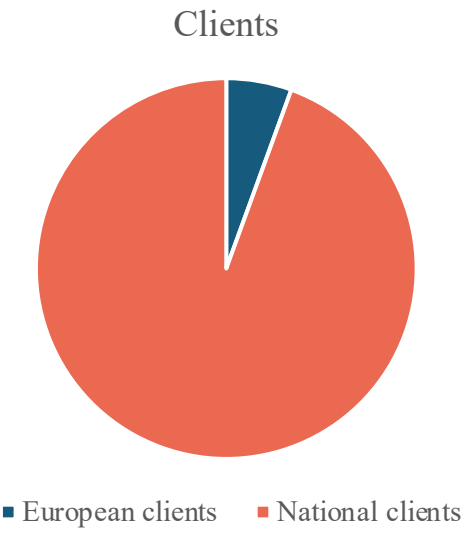

Figure 39: Type of clients' respondents - France

Not surprisingly, the type of PPE most produced were the masks and the gloves with 47% respectively while only the 6% produces gowns.

Figure 40: Type of PPE produced by the respondents - France

The following questions regard again the first section of the survey, about the key factors most impacted by the pandemic. The first question, shown in the Figure 42 is about the change in the stock level: the opinion is divided in two

almost equal part, with the 35% affirming its decrease and the 30% claiming its increase, while the remaining part, the 35% believes that it is not changed.
This difference in the answers can be explain by the different categories of PPE produced by the respondents. Apparently, the ones affirming a rise in the stock produce primarily masks, while the supporters of the decline of it produce gloves. Since the masks were the ones most used in every environment, not only of healthcare facilities, but also, and especially, in the public, their inventory's level has been maintained higher, considering the probable risk of another wave of pandemic.

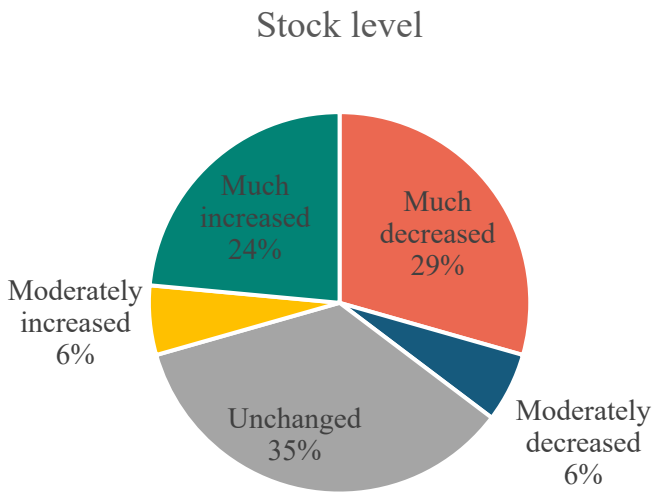

Figure 41: Change in the respondents' stock level – France

Concerning the variation of the customer demand, the respondents are quite unanimous – 76% of the total – answering that is decreasing comparing to the 2020-2021.

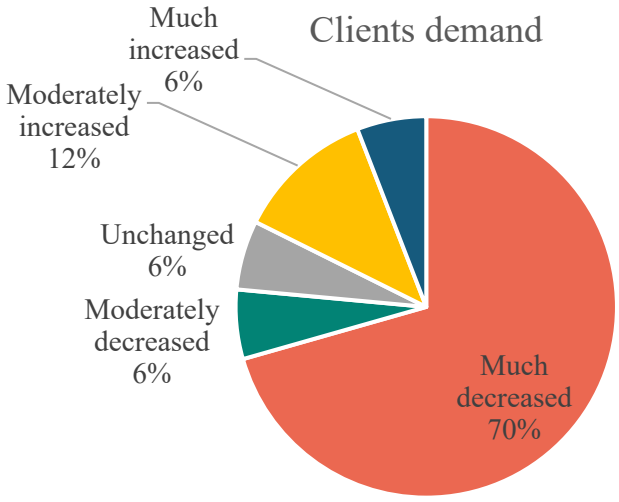

Figure 42: Change in the respondents' clients demand - France

The following pie chart, Figure 43, shows the results of the changing in the production capacity. The 46% affirms that it is decreasing, while the 36% believes is unchanged and the remaining 18% that is increasing. The result seems in line with the Italians answers: companies are generally decreasing their production capacity due to the drop in the demand.

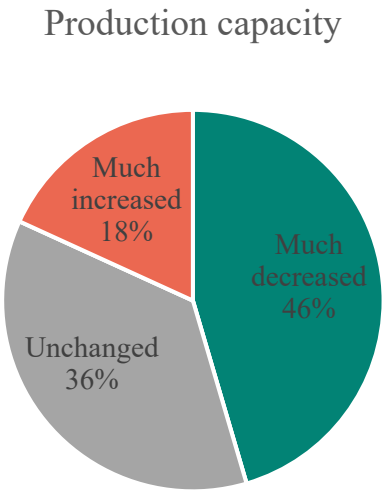

Figure 43: Change in the respondents' production capacity - France

The Figure 44 illustrates the percentages for the question about the variation in the customers' delivery times. They are diminishing, due to their higher stocks, as for the Italian side.

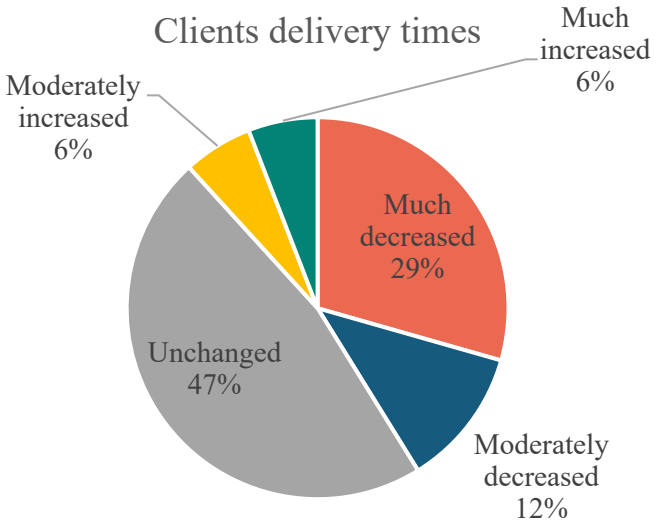

Figure 44: Change in the respondents' clients' delivery times - France

The exportations are rapidly falling – 35% - or maintaining their levels– 53% claims that are unchanged – and the importations follow the same behavior with similar percentages, as shown in Figure 45 and 46.

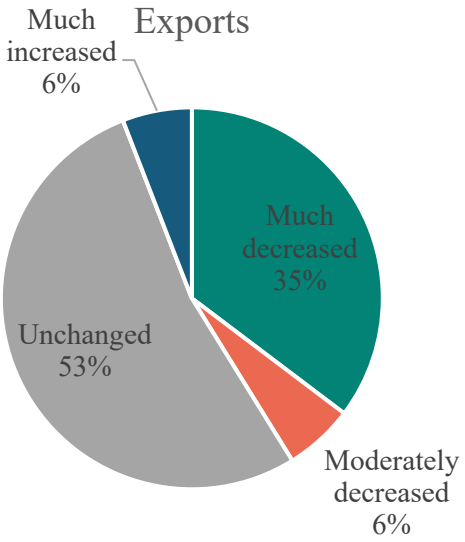

Figure 45: Change in the respondents' exports – France

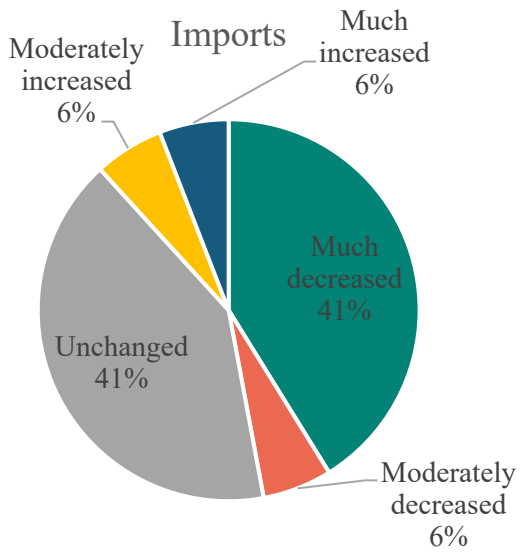

Figure 46: Change in the respondents' imports - France

The French answers regarding the use of the Just in Time practices, before, during and after the pandemic are controversial as the corresponding Italians. There is, indeed, an increasing of its use, shown by the following three Figure 48, 49 and 50. Before the pandemic, only the 29% of the companies interviewed used to apply the JIT to their business; during the pandemic the percentage rises to the 39%, finishing with a 47% after the 2021. This is not coherent with how is supposed to be structure the PPE supply chain. As mentioned before, the JIT practices are among the causes of the serious disruption in the SC and the shortages of personal protective equipment. Also in this case, we can consider a misunderstand of the respondents in the questions, that should have been more detailed in order to be completely understood.

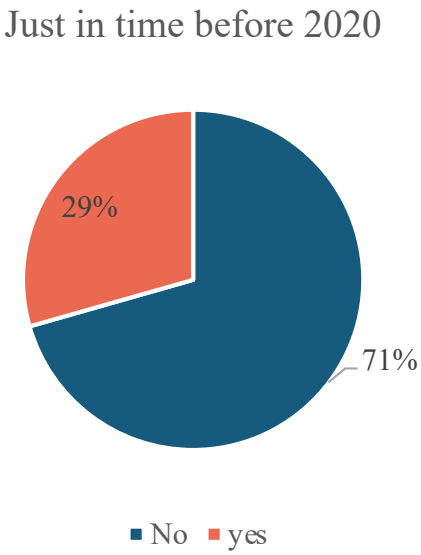

Figure 47: Use of Just in Time before 2020 - France

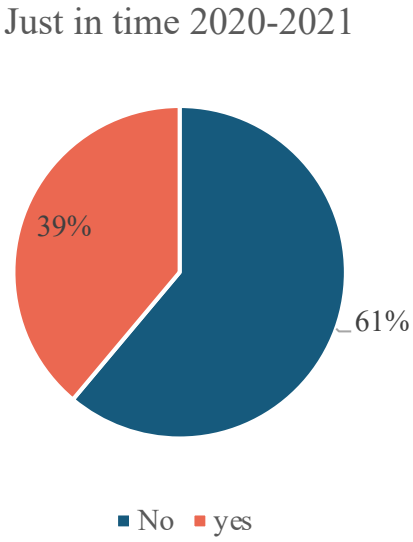

Figure 48: Use of Just in Time 2020-2021 - France

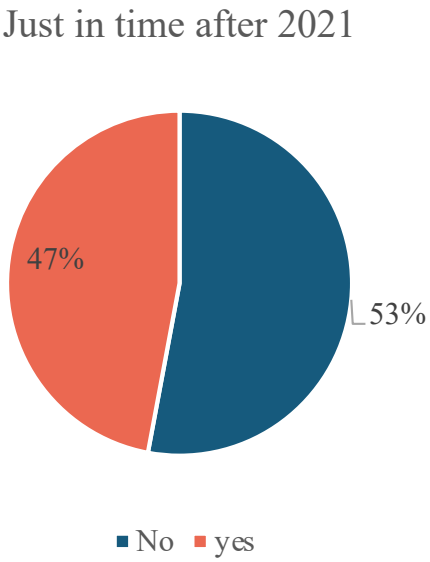

Figure 49: Use of Just in Time after 2021 - France

Compared to the first and second waves, the supplier demand has diminished in the third one, as it is shown in the Figure 50, with the 71% affirming its decrease.

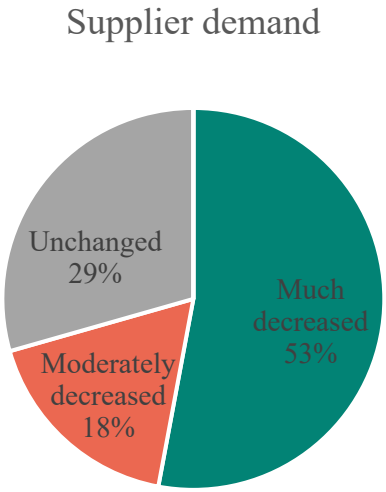

Figure 50: Change in the respondents' supplier demand - France

As for the customers' delivery times, also the supplier delivery times have suffered a decline, since the decreasing necessity to deliver the products and the saturation of the market.

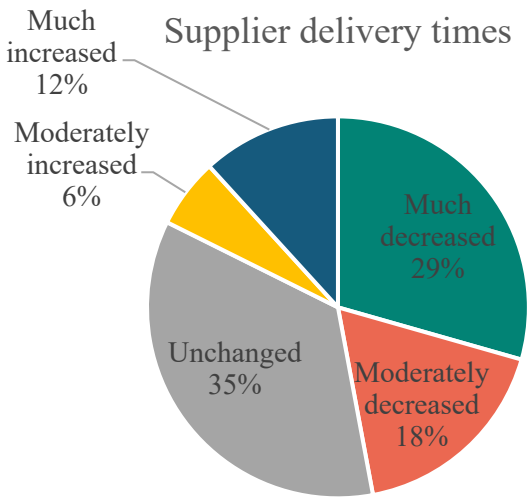

Figure 51: Change in the respondents' supplier delivery times - France

According to the question about the production capacity, the production rate is declining for the 80% of the respondents. While the Italians conservative behavior, the French one seems to be more adaptative to the dynamics of the market.

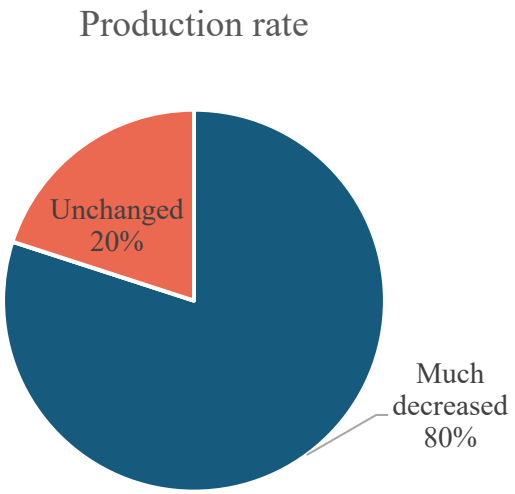

Figure 52: Change in the respondents' production rate - France

The following section regards the strategies most used by the French companies in 2022, compared to the previous periods.

As for the Italian companies, the French firms did not increment the use of ICT technologies, even though the well-established usefulness of them.

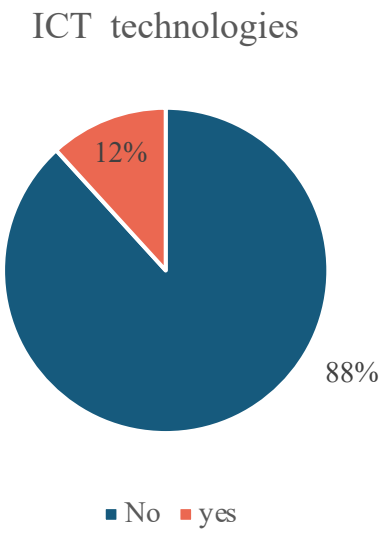

Figure 53: Use of ICT technologies - France

The following results about the last questions of the survey are quite controversial. In fact, the answers show a decreasing in the use of the main strategies applied by the PPE supply chain during the pandemic, instead of claiming their increasing. This can be explained considering that, now that we live in a less uncertain period, the firms consider too much expensive – not only monetarily but also in the sense of time, effort, and resource expense – maintaining these strategies and they consider more convenient slowly abandoning them. This can be a risky behavior and it does not provide any improvements for the supply chain, in case of another pandemic or natural disaster.

The stock visibility is unchanged for the 53% of respondents and increasing for the 35%, while for the 12% is heavily decreasing. These results show that this strategy is now not more employed than the past periods, but companies are simply maintaining constant its level.

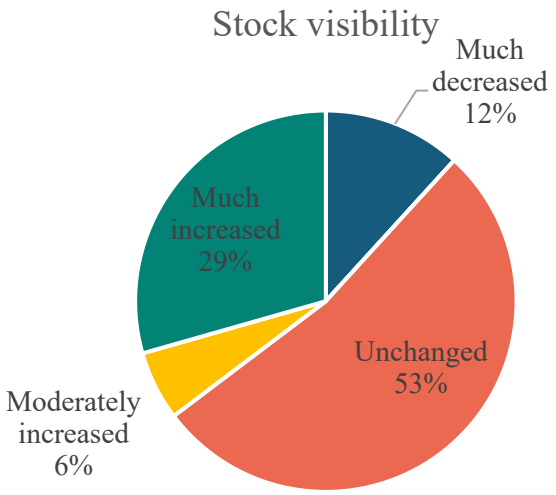

Figure 54: Change in the respondents' stock visibility - France

The resilience level is also experiencing a fall – 56% of moderately decreasing – and in the following position the 22% is unchanged.

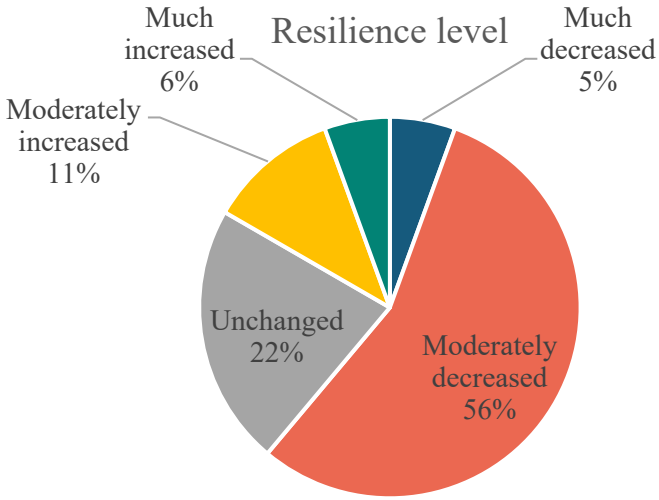

Figure 55: Change in the respondents' resilience level - France

Differently, the diversification of sources is still an increasing strategy with the 47% believing in its rise and only the 6% of decline, the rest believes that is unchanged. French companies rely on more suppliers than the Italians.

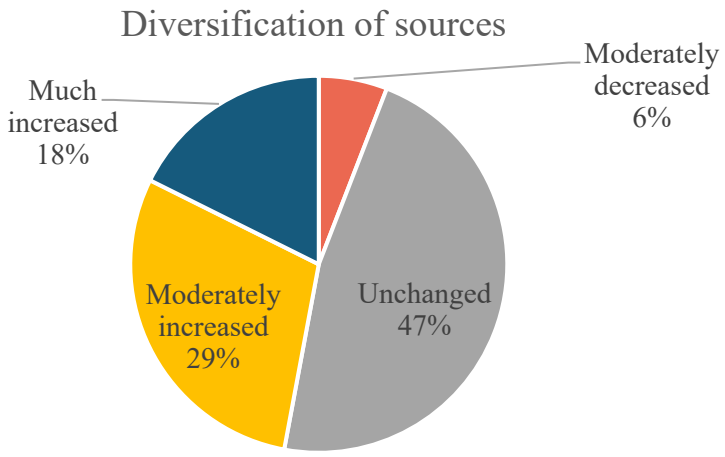

Figure 56: Change in the respondents' diversification of sources - France

Concerning the receiving of subsidies from the government, only the 12% received some financial help, and they were half in the first semester of 2020 and the other half in the 2021.

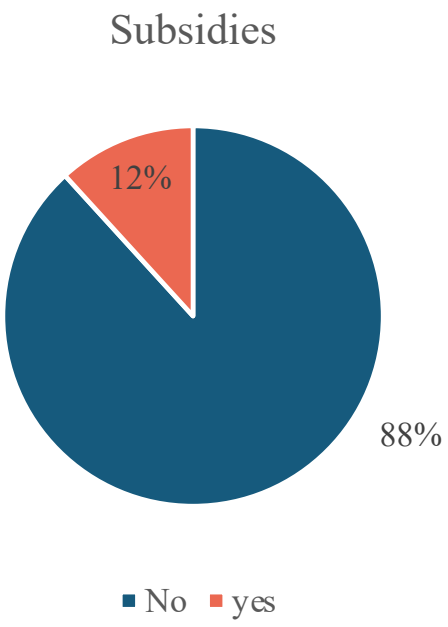

Figure 57: Allowance of subsidies - France

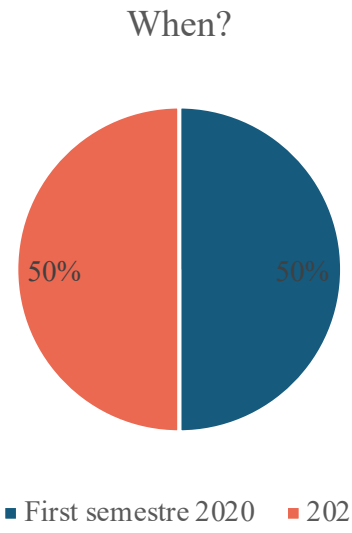

Figure 58: Period of subsidies accordance – France

4.4. Summary of the main findings

The descriptive analysis was helpful to understand some behaviors of the companies but did not allow a deep comparison between Italy and France. In fact, some differences, as the inventory visibility or the imports level, were not highlighted by this method, for this reason the Kruskal-Wallis test is applied.

This test can be used when the populations do not follow a normal distribution, but data follow a natural order.

This section displays the results of these tests, which were performed by means of Minitab-18.

The first stage in developing the tests is to select the categories to be compared. The categories chosen for the first set of KW tests are countries, specifically Italy and France, because the amount of responses was adequate to generate good findings.

The next step was to convert the Likert scale responses to numbers: "much decrease" became "1", "moderately decrease" became "2", and so on until "much increase" became "5". In fact, the KW test only works with numbers, not text. As a result, the Yes/No questions were omitted from the analysis.

The results of the single tests are displayed by Minitab, as shown in the Figure 59: in the rows, the results are separated by country; in the columns it is indicated N, the numerosity of the category, the median of the responses, the mean ranking, and the Z-value.

Kruskal-Wallis test : stock level depending on country

Descriptive analysis

Country	N	Median	Mean ranking	Z-value
France	17	3	23,9	0,81
Italy	26	2	20,8	-0,81
Overall	43		22	

Test

Null hypothesis	H_0 : all medians are equal
Alternative hypothesis	H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	1	0,65	0,419
Ajusted for ties	1	0,7	0,404

Figure 59: Kruskall-Wallis test - Stock level

The mean ranking is the average of the ranks for all observations within each sample. Minitab uses the mean rank to calculate the H-value, which is the test statistic for the Kruskal-Wallis test. The Z-value displays how each group's average rank compares to the average rank of all observations.

The greater the absolute value, the greater the distance between a group's average rank and the overall average rank.

A negative z-value shows that the average rank of a group is lower than the overall average rank.

A positive z-value shows that the average rank of a group is higher than the overall average rank.

After this data comes the real test. The null hypothesis and the alternative hypothesis are mutually exclusive statements about a population. The null hypothesis states that the populations' medians are equals, while the alternative hypothesis states that at least one is different. There are just two populations in this case: Italy and France.

The DF indicates the number of degrees of freedom, so the number of groups in the dataset minus 1. In this case it is equal to one.

H is the test statistic for the Kruskal-Wallis test. Under the null hypothesis, the chi-square distribution approximates the distribution of H. When no group contains fewer than five observations, the approximation is reasonably accurate. Minitab uses the test statistic to calculate the p-value, which you use to make a decision about the statistical significance of the terms and the model. The p-value is a probability that indicates how likely it is that the data occur under the null hypothesis. Lower probabilities provide stronger evidence against the null hypothesis.

A sufficiently high-test statistic indicates that at least one difference between the medians is statistically significant.

The null hypothesis states that the population medians are all equal. Usually, a significance level (denoted as α or alpha) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that a difference exists when there is no actual difference.

- P-value ≤ α: The differences between some of the medians are statistically significant:

  If the p-value is less than or equal to the significance level, the null hypothesis can be rejected and not all the population medians are equal.
- P-value > α: The differences between the medians are not statistically significant:

  If the p-value is greater than the significance level, there is not enough evidence to reject the null hypothesis that the population medians are all equal.

Minitab displays a p-value that is adjusted for ties and a p-value that is not adjusted for ties. A tie occurs when the same value is in more than one sample. The adjusted p-value is usually more accurate than the unadjusted p-value. However, because the unadjusted p-value is always greater than the adjusted p-value, it is considered the more conservative estimate.

Figure 59 shows the KW test for the changing of the level of stock in 2022 for the two countries. The p-value adjusted for ties is 0,404, so higher than 0,05: we cannot reject the null hypothesis.

In the table 6, it is reported all the results obtained by the KW tests. The second column shows the question concerned, the third and the fourth contain the mean of the answers for respectively the Italian and the French companies. The last column indicates the p-value adjusted for ties for each question, which correspond to a single KW test.

These results show that the behavior of the companies in the two different countries are quite the same. In fact, the p-values calculated do not allow the rejection of the null hypothesis, so the median values are considered as equals.

		Average		
N°	**Question**	**Italian companies**	**French companies**	**p-value**
1	Inventory levels	2,50	2,90	0,404
2	Customer demand	1,70	1,80	0,666
3	Production capacity	2,80	2,50	0,511
4	Customer delivery times	2,20	2,50	0,532
5	Exports	2,40	2,40	0,714
6	Imports	2,50	2,20	0,31
7	Supplier demand	1,80	1,80	0,851
8	Supplier delivery times	2,50	2,50	0,958
9	Production rate	2,30	1,40	0,079
10	Inventory visibility	3,20	3,40	0,055
11	Resilience	3,40	3,60	0,715
12	Diversification of sources	2,50	2,90	0,618

Table 6: Kruskall-Wallis tests - Recap table

In only two cases – shown in Figure 60 and 61 – the p-value is fewer and is on the edge of the acceptance – for the production rate and the inventory visibility but still does not permit the rejection of the null hypothesis.

This is understandable given that the descriptive analysis revealed some variations for these factors. Italian firms have proven to be more conservative in the implementation of their strategies than French firms. The Italians' production

rate remains high, implying that they continue to produce a considerable number of PPE even though the situation post-pandemic is under control.

Kruskal-Wallis test : Production rate depending on Country

Descriptive analysis

Country	N	Median	Mean ranking	Z-value
France	10	1	12,6	-1,59
Italy	22	2	18,3	1,59
Overall	32		16,5	

Test

Null hypothesis	H_0 : all medians are equal
Alternative hypothesis	H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	1	2,51	0,113
Ajusted for ties	1	3,08	0,079

Figure 60: Kruskall-Wallis test - Production rate test

Furthermore, we must consider that in Italy the use of mask was mandatory until September, implying that manufacturing was still high in order to meet all client demand from the general population. France, on the other hand, repealed the obligation in March, and the need for masks and other PPE has drastically declined since then.

The French have better inventory visibility. Italian answers are more heterogeneous, since 44% think it has increased and the 40% that it has decreased. On the French side, only the 12% think it has decreased, while for the others it has increased or remained unchanged.

Nonetheless, the majority of French respondents answered "unchanged," although the percentage of "much increase" or "moderately increase" is not as large as in Italy. This can be explained by the difference in timing between the two countries: companies in France were more agile in implementing new methods to combat the pandemic, whilst Italians reacted slowly. As a result, they are still enhancing their visibility, whereas French enterprises have reached an equilibrium point and their visibility is no more increasing.

Kruskal-Wallis test : Inventory visibility depending on Country

Descriptive analysis

Country	N	Median	Mean ranking	Z-value
France	17	3	26,3	1,81
Italy	26	3	19,2	-1,81
Overall	43		22	

Test

Null hypothesis	H_0 : all medians are equal
Alternative hypothesis	H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	1	3,29	0,07
Ajusted for ties	1	3,69	0,055

Figure 61: Kruskall-Wallis test - Inventory visibility test

After running the first set of Kruskall-Wallis tests, other three sets were prepared because it is also interesting to do a comparison between the supply chain stages – producers, wholesalers, and distributors – between the PPE categories – masks, gloves, gowns – and finally between the user of the Just in Time and the not users.

The purpose of the second set of Kruskall-Wallis tests is to understand the different reactions of the supply chain at various stages in both Italy and France. The results of the KW testing for these categories are shown in the tables below. Table 7 provides the Italian results, whereas Table 8 gives the French results.

Starting from the Italian side, only distributors and manufacturers were selected for this series of tests. Indeed, the wholesalers' responses were insufficient to provide an appropriate analysis. The tests show not statistically significant differences between distributor and manufacturers that applied almost the same behaviors for all the different logistics factors and implemented strategies.

MEAN SCORES				
N°	Question	Distributor	Manufacturers	p-value
1	Inventory level	2,30	2,50	0,943
2	Customer demand	1,80	1,60	0,351
3	Customer delivery times	3,00	2,20	0,16
4	Exports	2,80	2,30	0,371
5	Imports	2,30	2,40	0,715
6	Supplier demand	2,00	1,70	0,131
7	Supplier delivery times	2,80	2,50	0,513
8	Inventory visibility	3,30	2,60	0,39
9	Resilience level	3,30	3,10	0,566
10	Diversification level	3,30	3,40	0,823

Table 7: Kruskall-Wallis tests - Italian SC stages

On the French side, respondents are more evenly distributed among the three categories, thus distributors, producers, and wholesalers are all represented. In this case, too, the tests show no statistically significant difference between the categories.

In conclusion, both countries' supply chain stages had the same attitude throughout the third wave, with no significant variations.

MEAN SCORES					
N°	Question	Distributor	Manufacturers	Wholesaler	p-value
1	Inventory level	2,60	3,00	3,20	0,795
2	Customer demand	2,40	1,80	1,00	0,106
3	Customer delivery times	2,40	2,30	2,70	0,783
4	Exports	2,40	2,50	2,20	0,887
5	Imports	2,10	2,50	2,00	0,942
6	Supplier demand	1,70	2,00	1,70	0,747
7	Supplier delivery times	2,90	2,30	2,30	0,822
8	Inventory visibility	3,70	3,50	3,00	0,516
9	Resilience level	3,30	3,50	3,50	0,838
10	Diversification level	4,10	3,00	3,30	0,096

Table 8: Kruskall-Wallis tests - French SC stages

The PPE types are used as categories in the next round of testing. Gloves, masks, and gowns were included for the Italians, but just masks and gloves were included for the French due to a lack of data on gowns.

		MEAN SCORES			
N°	**Question**	**Gloves**	**Masks**	**Gowns**	**P-value**
1	Inventory level	3,20	2,30	2,00	0,231
2	Customer demand	2,30	1,50	2,50	0,222
3	Production capacity	-	2,7	2,5	0,896
4	Customer delivery times	2,00	2,30	2,50	0,478
5	Exports	2,80	2,40	2,00	0,132
6	Imports	3,30	2,20	3,50	0,046
7	Supplier demand	2,70	1,60	2,00	0,018
8	Supplier delivery times	1,70	2,70	1,50	0,086
9	Production rate	-	2,10	2,50	0,787
10	Inventory visibility	2,80	2,60	3,50	0,433
11	Resilience level	3,70	2,90	3,00	0,171
12	Diversification level	3,70	3,30	4,00	0,646

Table 9: Kruskall-Wallis tests - Italian PPE categories

Analyzing the Italian data, shown in Table 9, the computed p-values were less than 0.05 in two cases: imports and supplier demand.

In particular, the p-value for imports was 0.0466. This can be explained by the market's differing demand for each form of PPE. While imports of gloves and gowns have increased, imports of masks have gradually dropped. In fact, as stated in section 4.2, masks will no longer be required to be worn in public,

beginning in 2022. As a result, their market is shrinking faster than that of other PPE.

Kruskal-Wallis test : imports depending on PPE Type

Descriptive analysis

PPE Type	N	Median	Mean ranking	Z-value
Gloves	4	3,5	18,4	1,59
Gowns	2	3,5	20,3	1,45
Masks	19	3	11,1	-2,29
Overall	25		13	

Test

Null hypothesis	H_0 : all medians are equal
Alternative hypothesis	H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	2	5,33	0,069
Ajusted for ties	2	6,16	0,046

Figure 62: Kruskall-Wallis test – Imports

Concerning supplier demand, masks' one is probably dropping for the same reason, compared to gloves and gowns, which are still significantly used in

hospitals and healthcare institutes. Masks are losing a significant portion of their customers : ordinary people.

Kruskal-Wallis test : Supplier demand depending on PPE Type

Descriptive analysis

PPE Type	N	Median	Mean ranking	Z-value
Gloves	4	3	21,3	2,45
Gowns	2	2	16	0,6
Masks	19	1	10,9	-2,48
Overall	25		13	

Test

Null hypothesis	H_0 : all medians are equal
Alternative hypothesis	H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	2	6,84	0,033
Ajusted for ties	2	8,03	0,018

Figure 63: Kruskall-Wallis test - Supplier demand

In Table 10, the p-value for the French results is less than 5% at the level of customer delivery times.

Masks' customers delivery times are decreasing more than the gloves' ones: in France in 2022, it was still vital to supply products to clients quickly for the mask industry, compared to the gloves business.

		MEAN SCORES		
N°	**Question**	**Gloves**	**Masks**	**P-value**
1	Inventory level	2,40	3,60	0,09
2	Customer demand	1,90	1,80	0,701
3	Production capacity	3	2,4	0,626
4	Customer delivery times	2,00	3,10	0,042
5	Exports	2,50	2,40	0,906
6	Imports	2,10	2,40	0,463
7	Supplier demand	1,90	1,80	0,689
8	Supplier delivery times	2,00	2,80	0,249
9	Production rate	1,70	1,30	0,513
10	Inventory visibility	3,90	3,30	0,289
11	Resilience level	3,60	3,10	0,396
12	Diversification level	3,90	3,30	0,14

Table 10: Kruskall-Wallis tests - French PPE categories

Kruskal-Wallis test: Customer delivery times depending on PPE Type

Descriptive analysis

PPE Type	N	Median	Mean ranking	Z-value
Gloves	8	2	6,3	-1,89
Masks	8	3	10,8	1,89
Overall	16		8,5	

Test

Null hypothesis H_0 : all medians are equal

Alternative hypothesis H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	1	3,57	0,059
Ajusted for ties	1	4,15	0,042

Figure 64: Kruskall-Wallis test - Customer delivery times

The six tables that follow include the findings of KW tests conducted on the use of Just in Time practices before 2020, throughout 2020/2021, and after 2021 for both Italian and French enterprises.

Table 11 shows the results based on Italian responses for the use of the Just in Time system prior to the pandemic.

Because the p-values are all greater than 0,05, we can conclude that the two populations - JIT users and non-users - have the same median.

This finding indicates that the logistics factors most impacted during the epidemic, as well as the tactics used to deal with it, did not differ significantly between those that used JIT prior to the Covid-19 outbreak and those who did not. This may appear quite surprising, as JIT users were generally more vulnerable to disruptions, but it can be assumed that the pandemic's crisis was so severe that it had a significant impact on all the companies.

		MEAN SCORES		
N°	**Question**	**Yes**	**No**	**P-value**
1	Inventory level	2,90	2,00	0,148
2	Customer demand	1,90	1,50	1
3	Production capacity	2,7	2,9	0,707
4	Customer delivery times	2,30	2,20	0,732
5	Exports	2,30	2,60	0,475
6	Imports	2,40	2,50	0,867
7	Supplier demand	1,90	1,80	0,78
8	Supplier delivery times	2,40	2,60	0,565
9	Production rate	2,50	2,00	0,465
10	Inventory visibility	2,60	2,80	0,893
11	Resilience level	3,40	2,90	0,229
12	Diversification level	3,40	3,30	0,713

Table 11: Kruskall-Wallis tests - JIT before 2020 - Italy

The same outcome can be found in the KW tests for France: no statistically significant results.

		MEAN SCORES		
N°	**Question**	**Yes**	**No**	**P-value**
1	Inventory level	2,60	3,00	0,621
2	Customer demand	1,40	1,90	0,513
3	Production capacity	2,5	2,4	0,819
4	Customer delivery times	2,20	2,60	0,498
5	Exports	3,00	2,10	0,178
6	Imports	2,20	2,20	0,82
7	Supplier demand	1,60	1,80	0,642
8	Supplier delivery times	2,20	2,70	0,584
9	Production rate	1,50	1,30	0,759
10	Inventory visibility	2,80	3,70	0,224
11	Resilience level	2,80	3,70	0,172
12	Diversification level	3,20	3,80	0,213

Table 12: Kruskall-Wallis tests - JIT before 2020 – France

Tables 13 and 14 summarize the results of the Kruskall-Wallis tests for JIT users versus non-users during the epidemic.

For Italian users, the analysis finds that there is no statistical difference in the median of the two populations for the logistics aspects evaluated.

MEAN SCORES				
N°	**Question**	**Yes**	**No**	**P-value**
1	Inventory level	2,50	2,50	0,977
2	Customer demand	1,70	1,80	0,574
3	Production capacity	2,7	3	0,597
4	Customer delivery times	2,40	1,90	0,139
5	Exports	2,30	2,60	0,386
6	Imports	2,40	2,60	0,548
7	Supplier demand	1,70	2,10	0,335
8	Supplier delivery times	2,70	2,00	0,139
9	Production rate	2,20	2,40	0,804
10	Inventory visibility	2,80	2,50	0,54
11	Resilience level	2,90	3,60	0,14
12	Diversification level	3,30	3,60	0,285

Table 13: Kruskall Wallis tests - JIT during 2020/2021 – Italy

MEAN SCORES				
N°	**Question**	**Yes**	**No**	**P-value**
1	Inventory level	2,40	3,20	0,309
2	Customer demand	1,30	2,10	0,225
3	Production capacity	2,3	2,6	1
4	Customer delivery times	2,10	2,70	0,321
5	Exports	2,70	2,10	0,329
6	Imports	2,10	2,20	0,916
7	Supplier demand	1,70	1,80	0,83
8	Supplier delivery times	2,40	2,60	0,723
9	Production rate	1,40	1,40	1
10	Inventory visibility	2,60	4,00	0,032
11	Resilience level	3,10	3,60	0,7
12	Diversification level	3,40	3,70	0,6

Table 14: Kruskall-Wallis tests - JIT during 2020/2021 – France

For French users - Table 14 - the study reveals an interesting result: the change in inventory visibility is not the same for those who expanded their use of JIT

and those who did not. When compared to users, the non-users have experienced a greater gain in inventory visibility. This is an interesting result: as indicated in the systematic literature review, the usage of Just in Time constitutes an obstacle and exacerbates the disruptive impacts of the epidemic. As a result, it is natural that those who were not growing its use increased its stock visibility.

Kruskal-Wallis test : Inventory visibility depending on JIT during 20-21

Descriptive analysis

JIT during 20-21	N	Median	Mean ranking	Z-value
No	10	4	11	1,95
yes	7	3	6,1	-1,95
Overall	17		9	

Test

Null hypothesis H_0 : all medians are equal

Alternative hypothesis H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	1	3,81	0,051
Ajusted for ties	1	4,61	0,032

Figure 65: Kruskall-Wallis test - Inventory visibility

The following two tables, 15 and 16, illustrate the results of the Kruskall-Wallis tests performed on these two groups, the first that increased its use of JIT after 2021 and the other which did not.

		MEAN SCORES		
N°	**Question**	**Yes**	**No**	**P-value**
1	Inventory level	2,80	1,70	0,076
2	Customer demand	1,60	2,00	0,416
3	Production capacity	2,6	3,4	0,273
4	Customer delivery times	2,20	2,30	0,847
5	Exports	2,40	2,40	0,947
6	Imports	2,60	2,10	0,364
7	Supplier demand	1,60	2,40	0,221
8	Supplier delivery times	2,30	2,90	0,207
9	Production rate	2,20	2,60	0,649
10	Inventory visibility	2,60	3,00	0,43
11	Resilience level	3,10	3,30	0,69
12	Diversification level	3,40	3,40	0,34

Table 15: Kruskall-Wallis tests - JIT after 2021 – Italy

In the Italian results, the test for inventory level has a p-value of 0,076, which is still above 5% but close to the non-acceptance zone. A possible explanation is that who did not employ JIT experienced a larger decrease on their inventory than the JIT users, for which the inventory level was already low.

Kruskal-Wallis test : Inventory level depending on JIT after 2021

Descriptive analysis

JIT after 2021	N	Median	Mean ranking	Z-value
No	7	1	9,3	-1,71
yes	19	2	15,1	1,71
Overall	26		13,5	

Test

Null hypothesis H_0 : all medians are equal

Alternative hypothesis H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	1	2,91	0,088
Ajusted for ties	1	3,15	0,076

Figure 66: Kruskall-Wallis test - Inventory level

We can see a p-value of 0.02 for the inventory visibility change in the French results, in Table 16.

		MEAN SCORES		
N°	**Question**	**Yes**	**No**	**P-value**
1	Inventory level	2,60	3,10	0,547
2	Customer demand	1,30	2,20	0,135
3	Production capacity	2,4	2,5	1
4	Customer delivery times	2,00	2,90	0,11
5	Exports	2,80	2,00	0,2
6	Imports	2,30	2,10	0,604
7	Supplier demand	1,60	1,90	0,525
8	Supplier delivery times	2,50	2,60	0,92
9	Production rate	1,30	1,50	0,759
10	Inventory visibility	2,60	4,10	0,02
11	Resilience level	3,00	3,80	0,175
12	Diversification level	3,30	3,90	0,121

Table 16: Kruskall-Wallis tests - JIT after 2021 - France

This is a logical result for the same reason as before: inventory visibility is higher for those who did not use Just in Time versus those who did.

Kruskal-Wallis test : Inventory visibility depending on JIT after 2021

Descriptive analysis

JIT after 2021	N	Median	ean ranking	Z-value
No	9	5	11,4	2,12
yes	8	3	6,3	-2,12
Overall	17		9	

Test

Null hypothesis	H_0 : all medians are equal
Alternative hypothesis	H_1 : at least one median is different

Method	DF	H-value	P-value
Non adjusted for ties	1	4,48	0,034
Ajusted for ties	1	5,42	0,02

Figure 67: Kruskall-Wallis test - Inventory visibility

This outcome is also consistent with the literature review described in the second chapter.

Indeed, Just in Time techniques are incompatible with the PPE supply chain, especially given the threat of a pandemic. Companies that did not use it recovered quickly and easily from the Covid-19 pandemic, and they also had the opportunity to implement these new strategies - higher inventory visibility, resilience level, and source diversification - in their core businesses, rather than returning to the pre-covid situation, as most other companies did.

The Kruskall-Wallis tests results in this section of the thesis provided an interesting insight into the current situation in Italy and France. Some of the factors investigated are debatable and accessible to numerous interpretations. In general, Italian companies demonstrated prudential behavior in their enterprises that is absent - or only slightly present - in French organizations.

Of course, we must keep in mind that the responses received are for the 2022 period, when the situation can be considered back to pre-Covid levels. Companies, both Italian and French, are still dealing with pandemic-related challenges, but the consequences are less obvious than before. Indeed, there

are notable differences from the previous period, when the pandemic was at its worst: in general, firms are suffering a decrease in their operations, particularly those who produce PPE as their core business. Customer demand is decreasing, as is the requirement for PPE. Furthermore, companies that began making PPE during the epidemic and joined the market solely for this purpose are gradually leaving this segment due to declining profitability.

5. Conclusion

In this last chapter, it will be discussed the academic and practical implications brought by this thesis, the problems encountered, the limitations of the work and the possible future research that can take place starting from this project's conclusion.

5.1. Main findings

This work brought many findings to the literature that can represent possible topics to be discussed in the future.

First of all, the supply chain management absorbed several changes due to the Covid-19 pandemic, but also experience again new changes due to its decline. In fact, of course during the pandemic companies had to adapt their businesses to the new situation, changing their rules and methods, trying to satisfy a customer demand growing more and more. While at the beginning anyone could know how to face the situation and which were the mainly strategies to adopt, after two years of pandemic the situation was almost under control. The problem was: how to manage the present? What was the best option, maintaining the new management or going back to the past?

For most of the companies, maintaining the new strategies was probably too expensive or anyway not so convenient. As a result, they are slowly going back to the past. An example is the results found about the implementation of the ICT solutions: almost no one increased their use, even thought it was essential to have some solution to increase the stock visibility.

Also, the decreasing of the resilience level is a sign that they are letting their guard down.

The production is decreasing, both the production rate and the production capacity. Nevertheless, here we can observe some differences between the two countries interviewed. As already mentioned in the previous chapter, the Italian companies seems to be more conservative in their businesses compared to the French ones. They are of course changing again their supply chain management,

but more slowly. This is understandable if we also consider the way the two governments faced the situation and the timing during the different phases of the pandemic. In Italy, the restrictions were applied longer than in France, as well as the obligation of the masks in public.

This is a remarkable finding, since shows how a political behavior can also affect the economics of a country.

5.2. Academic and practical Implications

This thesis work brings new outcomes on the state of the art.

First of all, the research is the first to focus on the third wave of the Covid-19 pandemic, while the scientific literature concentrates on the outbreak and the first phases of the crisis around the world.

Secondly, it confirms some of the evidence of the literature on the main factors impacted by the pandemic, but also enlarges the discussion on some new behaviors of the companies. For example, it brings new considerations on the Just in Time practices and how companies are going back to the application of these methods, unlike what it is stated in the literature.

Then, the thesis provides also a comparison between two European countries for the first time, to see how they reacted and how they are changing their businesses after the crisis peak.

From a practical view, this work can help to better understand the events on the PPE supply chain after the first periods of the pandemic and to underline what are the main challenges that the SC is experiencing.

In addition, a better understanding of the dynamics of the PPE supply chain can enhance preparedness: organizations and government can better prepare for future pandemics or emergencies.

The research can help to understand the important role of technology in the PPE supply chain in this emergency situations: ICT technologies can enhance traceability, transparency, and efficiency, resulting in an optimization of the operations.

5.3. Thesis limitations

The thesis presents some limitations that can be overcome in next research. The main limit is of course the response rate to the questionnaire that is quite low: the 14,9% for the Italian respondents and the 13,28% for the French. This kind of questionnaire never reaches an high response rate, since it contains technical questions and the knowledge base of the respondents is unknown, making it difficult to adjust the level of the questions.

This can affect the results, since we do not have a sample very large of companies to be considered representative of the population. The sample dimension can be calculated taken into account the significance level that we chose, in this case the 10%. In this specific case, this number has not been calculated, since reaching out the companies was very complicated through a google form.

This limitation can be overcome by administering the questionnaire in other ways, for example by phone. In fact, in such a way questions can be explained to the respondents, in order to avoid misunderstand, but it requires a larger amount of time than a Google form. The survey phases took a few of months to complete, but a telephonic survey may take much longer, which was not feasible for this type of work.

Another limitation is the consideration of two countries that are very similar. It would be also interesting to do a comparison between some countries that are farer both geographically that culturally.

5.4. Future research

Based on these observations, future research can look into the effects of the Covid-19 pandemic on the PPE supply chain in additional countries and with a larger sample size.

In addition, the research was started in September 2022: all the accounts papers, conferences, etc. published in the rest of the year, are not taken into account. The study can be furthermore completed with new papers that could change some results of this work.

Future research can develop deeper the discussion about the ICT solutions and the Just in Time practices used in the PPE supply chain, explaining in detail which they are, how and in which echelon they were applied and how they are changing due to the Covid-19 disruption.

It would be also very interesting to examinate in terms of economic effort and resources required the strategies adopted by the companies to face the issues caused by the pandemic to identify which are suitable and affordable and understand why some of them were abandoned by the firms.

The investigation can also be broadened to include additional supply chain echelon, as the retailers, as well as a discussion about the customers and how their emotional behavior influences the PPE supply chain (for example, about the panic behavior generated by the virus that led the customers to buy enormous quantities of masks and, consequently, cause the demand to skyrocket).

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List of acronyms

AIDA	Analisi informatizzata delle aziende italiane
AJIC	American Journal of Infection Control
AM	Additive Manufacturing
ANOVA	Analysis of Variance
APE / NAF	Activité Principale Exercée / Nomenclature des Activités Française
ATECO	Attività Economiche
ICT	Information and Communication Technologies
IJPR	International Journal of Production Research
INSEE	Institut national de la statistique et des études économiques
ISS	Instituto superiore di Sanità
JIT	Just in Time
KW	Kruskall-Wallis
LiFi	Light Fidelity
NACE	Nomenclature of Economic Activities
RFID	Radio Frequency Identification
SCM	Supply Chain Management
SD	System Dynamics
SJR	Scimago Journal Rank
SRL	Systematic Literature Review
WHO	World Health Organization

Appendix

In this paragraph, all the questions are reported with the possible answers.

1. Which **supply chain echelon** does your company belong to?
    - Manufacturer
    - Wholesaler
    - Distributor
2. Where is **located** your company?
    - Italy
    - France
3. What are the **customers** that account for most of your yearly revenues (1 answer only)
    - National customers
    - European customers
    - American customers
    - Customers of the rest of the world
4. What kind of **PPEs** is responsible for the 50% of your company's revenues? (1 answer only)
    - Masks
    - Gloves
    - Goggles
    - Aprons
    - Gowns
5. How did the **inventory level** change in 2022 compared to 2020 and 2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased

6. How did the company's **customer demand** vary during 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased
7. How did your yearly **production capacity** (as maximum number of units you can produce) change? (Manufacturers only)
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased
8. How did the **customers delivery times** of final products change in 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased
9. How did the **exports** change (as number of units) in 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased
10. How did the **imports** change (as number of units) in 2022 compared to 2020-2021?

- Much decreased
- Moderately decreased
- Unchanged
- Moderately increased
- Much increased

11. Did you apply the **just in time stock management**?

	Yes	No
Before 2020	☐	☐
During 2020/2021	☐	☐
During 2022	☐	☐

12. How did the **supplier demand** (in number of orders) vary during the 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased
13. How did the **supplier delivery times** of products change in 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased
14. How did the company **production rate** (units actually produced per year) change in 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged

- Moderately increased
- Much increased

15. Following the covid pandemic, did the company adopt new **ICT solutions** (ex. RFID technology, barcode system, Warehouse management system, Light Fidelity (LiFi) Technology) to increase the coordination with your supply chain partners during 2022 compared to 2020-2021?
    - Yes
    - No
16. How do you think your company's **inventory visibility** have changed in 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased
17. How do you think the company's **resilience level** have changed in 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased
18. How do you think the **diversification level** of the company's sources have changed in 2022 compared to 2020-2021?
    - Much decreased
    - Moderately decreased
    - Unchanged
    - Moderately increased
    - Much increased

19. Did the company receive some **subsidies** from the government to help your company producing PPEs?
    - Yes
    - No
20. If yes, when?
    - First semester 2020
    - Second semester 2020
    - 2021
    - 2022