Optimizing EcoCenter's Annual Purchases

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July 2025

Bachelor Thesis

Bsc Industrial Engineering & Management

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Dear reader,

You are about to read my thesis *Optimizing EcoCenter's Annual Purchases*. This research was conducted as the final project for the bachelor's program in Industrial Engineering and Management at the University of Twente, in collaboration with the public company EcoCenter in Bolzano, Italy. The main goal of this thesis is to support the improvement of purchasing decisions and inventory management, with a focus on reducing the number of orders and minimizing costs.

I would like to express my gratitude to everyone who guided and supported me during the development of this thesis. First, I want to thank my first supervisor DR. Stephan Meisel for the guidance, ideas, and helpful feedback you have provided me throughout the work.I want to thank my second supervisor DR. B. Alves Beirigo for valuable feedback and perspectives. A special thank you also to my supervisors at EcoCenter, Marco Palmitano, Roberta De Santi and Monica Zamboni, for your professional guidance, support, and insightful advice throughout the process. I would also like to thank all of my friends for motivation and good company throughout the process. Last, I would like to warmly thank my brother Jacopo and my parents for the support and love shown throughout these 3 years.

I hope you enjoy!

Gaia Eloisa Fattor
July 2025

Executive Summary

Context

EcoCenter is a public company from South Tyrol (Italy) in the environmental sector that oversees 27 environmental facilities. This includes 5 waste treatment plants and 22 wastewater treatment plants. Until early 2024, its standard practice was to issue a purchase order any time a need arose: "what's needed, when it's needed, how much is needed." New bureaucratic rules introduced in January 2024 have lengthened approval times, so EcoCenter managers began consolidating multiple small orders into fewer, larger ones. This cut annual orders from over 2000 annual purchase in 2023 to a little over 1000 annual purchases in 2024 without a formal study. EcoCenter now aims to reduce its total number of purchase orders to approximately 900 per year, while guaranteeing that critical materials never run out and to minimize the costs of the process.

EcoCenter provided four Excel files: (1) a list of all purchase orders made in 2024, including how much was ordered, the price, and any extra shipping costs; (2) a list of all invoices linked to those orders; (3) transport documents (called DDTs) that confirm when goods or services were delivered; and (4) more detailed information about each purchase order, like product descriptions and amounts.

Methods & Models applied

First, we followed the CRISP-DM framework to build a simple inventory management model tailored to EcoCenter's needs. It is a process model used to guide data mining projects. It breaks down the data mining process into six phases: Business Understanding, Data Understanding, Data Preparation, Modeling, Evaluation, and Deployment. This methodology was essential to understand and analyze all the data provided by EcoCenter. Following the steps of the CRISP-DM methodology, we address the following research question: *Which optimization technique and model can be applied to reduce the number of orders while ensuring stock availability for essential items*?

We conducted literature review to identify inventory management models that suit Ecocenter's data and are the most suitable to tackle the request of reducing annual purchase orders. We reviewed five inventory models: dynamic lot-sizing (Wagner-Whitin), stochastic continuous review, periodic review (R,S), machine-learning methods, and the classic Economic Order Quantity (EOQ) with ABC classification. We find that one of the variations of the Economic Order Quantity Model, the joint ordering policy with ABC Classification, is the best fit for the company's problem. The objective of the model is find the best order quantity that minimizes both ordering costs and holding costs. The EOQ extension that we applied is useful when managing multiple products, which fits EcoCenter's case.

EcoCenter's suppliers were ranked using ABC Analysis, which shows that a small share of suppliers (5–20%) drive most of the spend (55–65%, Type A), a mid-level group (20–30%) accounts for 20–40% of spend (Type B), and the rest (50–75%) make up only 5–25% of spend (Type C). This analysis was essential for the research, since the joint ordering policy was applied to all Type A and the most important Type B suppliers.The ABC analysis is important because it helps EcoCenter focus on the most important suppliers that have the biggest impact on spending.

Findings & Results

We began by applying ABC analysis to three years of EcoCenter's purchasing data (2022–2024), which revealed 27 Type A suppliers, 161 Type B suppliers, and 1,190 Type C suppliers.

For each Type A supplier and for the 14 most important and from the company suggested Type B suppliers, we put their demand, unit costs, and holding costs into the joint-replenishment EOQ formula. The model calculated that instead of 73 separate orders, which the company issued in 2024, EcoCenter need to place 57 consolidated orders in 2025. That's a 22% reduction, equivalent to 16 fewer purchase orders. Extending the same logic to all 1378 suppliers suggests a system-wide reduction of about 14%, roughly 140 fewer orders each year. This confirms that EcoCenter can reach its goal of 900 total purchase orders per year.

A Sensitivity Analysis was condcuted in order to validate the results and it showed that this result holds whether we assume a fixed order cost of €500, €750, or €1000, and whether we use holding-cost rates from 15 to 25 percent. These ranges were chosen as reasonable industry benchmarks and to reflect uncertainty in the absence of exact cost figures.

Conclusions and Reccomendations

Through answering each of the sub-research questions, we can conclude that we are able to decrease annual purchase orders by 14% thanks to the extension of the EOQ model the joint-ordering policy. Currently, the model closely reflects the observations of 2024 and we can expect the accuracy to improve when more representative data is available.

Although EcoCenter successfully cut purchase orders by about 1000 in 2024, the total number of DDTs and invoices did not change. This suggests that while orders were consolidated into larger batches, the underlying volume and frequency of deliveries remained unchanged. To improve accuracy of the model, we reccomend EcoCenter to record the actual fixed cost of each order (staff time, fees, etc.) and the true annual holding cost for inventory. Using these real figures in the joint-EOQ formula will improve accuracy and highlight further savings.

Contents

1 Introduction

In the first chapter we introduce the company and the problems they are facing. We identify the core problem we want to focus on based on a problem cluster. We define the methodological approach to solve the problem based on the CRISP-DM methodology. Following the steps of CRISP-DM we define the sub-research questions that help us structurally approach the thesis.

1.1 Company overview

EcoCenter is a public company based in Bolzano, in South Tyrol. The company is fully owned by 97 local municipalities, 7 district communities of South Tyrol, and the Autonomous Province of Bolzano. EcoCenter works in the environmental sector, managing waste treatment and water services across the region. Any profits made by the company are not kept but reinvested to improve the performance of their plants and services, to benefit the environment.
EcoCenter runs 27 environmental facilities in total. This includes 5 waste treatment plants and 22 wastewater treatment plants. Every year, EcoCenter processes around 180,000 tons of waste and treats over 40 million cubic meters of dirty water. From this, they recover more than 230,000 MWh of energy, including about 129,000 MWh of heat energy, which helps power the district heating system in the city of Bolzano. EcoCenter also manages over 250 kilometers of sewer pipes and carries out more than 9,500 laboratory tests each year to make sure everything runs safely and efficiently.
The company also has its own modern laboratory, which checks the quality of the treatment processes and provides environmental testing services to other clients as well. EcoCenter is certified with ISO 9001 and ISO 14001, meaning they follow high standards for quality and environmental protection. They are also very focused on sustainability and reuse treated water in some plants for industrial purposes, like cleaning and heating, which helps to save groundwater. EcoCenter recovers over 19 million kWh of energy from waste materials to power their own plants, making them more energy efficient. All treatment phases are continuously checked by the company's analytical laboratory, which can detect any disturbance in the delicate biological balance of the wastewater-treatment plants. Smaller facilities are monitored in real time through a remote control system, and the operator provides 24-hour emergency response on both weekdays and holidays. At the treatment plants in Bolzano, Merano, Bronzolo, Termeno, Lana, and Passiria, the operator also processes liquid waste.
EcoCenter also operates an environmental laboratory. A team of 22 biologists, chemists, and laboratory technicians supports the company's treatment plants by performing a wide range of environmental checks and overseeing industrial dis-

charges within the Optimal Territorial Area 2 (ATO2). The laboratory assists South Tyrolean municipalities in monitoring drinking-water quality, handling both sampling and chemical–bacteriological analyses. The facility also offers services to external clients, including food analyses for micro-contaminants. It validated the European standard EN 1948-4 for sampling and analyzing PCBs in emissions (through a European tender) and participates in the Utilitalia–ENEA working group that is developing a standardized method for micro-plastic analysis. The laboratory is consistently involved in EcoCenter's environmental research projects in collaboration with universities, public agencies, and private companies.

1.2 Problem identification

In this section we will introduce the different problems EcoCenter is facing regarding purchasing strategies and develop a problem cluster to visualize the cause-effect relationships of the issues. Based on the problem cluster the candidate core problems will be identified, the problems that will be tackled, and the costs and benefits of them will be analyzed, in order to choose one to solve that would bring the most benefit for the company.

1.2.1 Current situation and company's objective

EcoCenter's purchasing stratgey was to order whenever something was missing (standard orders). A standard purchase order provides clear purchase information, such as identifying the item or service needed, the delivery date, the quantity, and payment terms. In other words, what's needed, when it's needed, and how much is needed. Due to recent changes in purchasing procedures, which have become more bureaucratic, the company aims to reduce the number of purchases by 10%. Usually, the company would order what they need, the moment they notice that they need something. For instance, if one wastewater treatment plan gets damaged, they order what they need on the spot. Since the beginning of 2024, bureaucratic changes in the purchasing process have created challenges for the company, as completing a purchase now takes more time. They provided me with Excel sheets detailing their annual purchases for 2022, 2023, and 2024. A significant difference is noticed between 2023 and 2024. The company explained that, as a natural consequence of these new bureaucratic changes, they have already managed to reduce annual purchases without conducting any formal study, simply by consolidating orders. The company objective is to decrease even more their annual orders. Their hope is that an effective statistical model can be established, that enables them to maintain essential items in stock, rather than making frequent purchases whenever something is missing and to minimize costs.

1.2.2 Problem cluster

From first conversations with company representatives, it became clear that there are several points of improvement regarding the purchasing strategy at EcoCenter. The problem cluster in Figure 2 is made based on the cause-effect relationships the problems have to see how they link together [1]. In addition, it shows that problems are not isolated but usually affect one another. Developing the problem cluster is essential to understand what issue to focus on. The core problem and the action problem are marked with orange and purple, respectively, on the cluster in Figure 2.

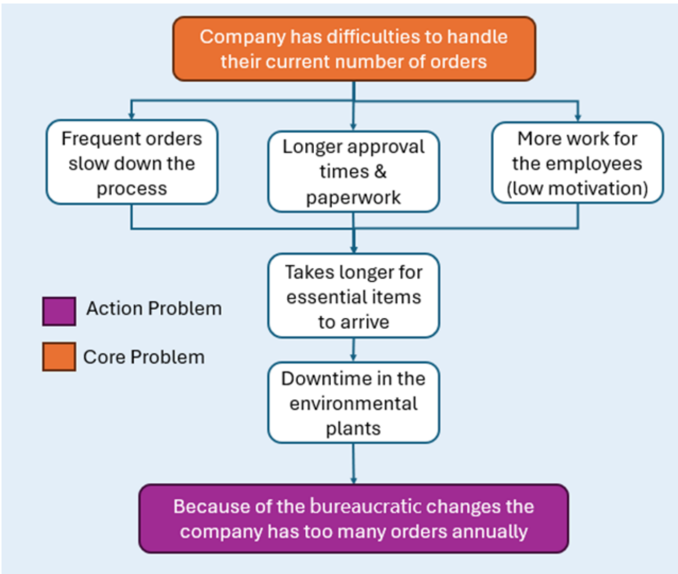

Figure 1: Problem Cluster

This cluster helps to see which problems are causing others. The core problem(the root causes) is shown in orange, and the more visible action problem is in purple. Problems the company cannot influence, such as damaged goods during delivery, are not included. The cluster shows that too many purchase orders lead to slower processes, more paperwork, and more work for employees. This causes delays in getting important items, leading to downtime in the plants. This shows that the main issue is the high number of purchase orders, since the process of purchasing takes a long time, because of the bureaucratic changes. Solving this could reduce delays, ease workload, and improve how the company operates. That's why choosing the right problem to focus on is important for the rest of the project.

1.2.3 Action and Core Problem

EcoCenter is currently facing challenges in handling its purchasing process. After recent changes in the law, the company now needs to follow more complicated and bureaucratic steps for each purchase order. These bureaucratic changes were introduced because, starting in 2024, every publicly owned company in Italy must follow a new anti-corruption compliance procedure. Chapter 2 outlines how the purchasing process worked before the new changes and how it works now, after the bureaucratic changes. If we look at the problem cluster, we see several related issues. The action problem is clear: EcoCenter currently places too many orders each year. To find the core problem, we need to look deeper. The reason for the high number of orders is the lack of an inventory management and ordering strategy. Right now, EcoCenter does not have a proper system to manage stock levels or to consolidate orders. After looking at the options, we conclude that this is the most important issue to solve because it will bring the biggest improvements in efficiency, cost savings, and process flow. A core problem is a cause, instead of a consequence, of other problems [1]. For this reason, the core problem is defined as: EcoCenter does not have an optimized ordering and inventory management strategy.

1.3 Research Design

In this section the scope and the limitations regarding the research will be defined, as well as what we hope to accomplish with it. The CRISP-DM methodology will be introduced, which will be used throughout the research for a more structured approach. The main research questions will be defined, and the sub-questions that need to be answered in order to complete the research. Lastly, the KPIs, that help us measure the ability to solve the core problem, will also be defined.

1.3.1 Scope & Limitations

EcoCenter wants to reduce their number of orders. Their goal is to minimize orders per year while still keeping important items in stock and to decrease cost. The scope of this thesis is to build a simple and useful inventory model that will help EcoCenter plan better. The model will help them group orders together, so they don't have to place so many separate orders. The model will be made in Excel, so EcoCenter can implement it in their daily work.

However, there are some limitations in this research. The biggest challenge is the data. EcoCenter provided data about their annual purchases from 2022, 2023, and 2024. Majority of inventory models work best when there is regular demand for the same items; it is possible to predict how much is needed for each item, there

are enough information about lead times and how much stock is available.
However, EcoCenter's data looks different, since they have very diverse orders. Some orders consists in repairs, some are insurances, some are maintenance, some are spare parts. A few purchases are urgent orders; for instance, repairs when something breaks. Delivery dates are not always urgent, but the data provided does not give clear usage patterns. This means, the main limitation for the research is that there is no inventory model that will fully fit EcoCenter's situation right away, since most classic models assume a steady flow of purchases and regular inventory turnover. EcoCenter's situation is more maintenance and service focused, where purchases are based on incidents or scheduled maintenance. The solution to this problem will be to adapt an existing inventory model to EcoCenter's situation.

1.3.2 Research Goal

The research aim is to address the core problem of the overall issues EcoCenter is facing. As visualized by the problem cluster in Figure 2, EcoCenter is currently facing problems caused by the high number of orders and new bureaucratic procedures.
Overall, we aim to develop a functional inventory model used in order for the company to apply it in the future and that minimizes the total cost of ordering and holding stock. Instead of trying to manage every single item, we will prioritize the materials and parts that are frequently ordered or important for EcoCenter's operations, like spare parts for their environmental plants. One goal is to find patterns in EcoCenter's past orders to understand which items are bought regularly and which ones are only ordered occasionally. Combining similar orders to reduce the total number of purchases, even if demand is not always steady, and stating the cost parameters used so that managers can adjust them later if prices change, will also be important steps.
The main deliverable will be an adapted inventory optimization model to EcoCenter's data. A transparent explanation of how the chosen inventory model works and how it was modeled will be given. We will also explain how each variable was obtained. This will ensure that the company can use the inventory model clearly. Thus, a simple user manual of the adapted inventory model will be added as a deliverable.

1.3.3 Research Methodology

After some research the best methodology for processing the provided data is the CRISP-DM, which stands for Cross-Industry Standard Process for Data Mining. To choose the method, two different methodologies for conducting research were compared, the Managerial Problem Solving Method (MPSM) and CRISP-DM.

The MPSM is more theory oriented and does not specify the use of data, whereas CRISP-DM is data-oriented. CRISP-DM is a process model that serves as the base for a data science process and it has six sequential phases:

1) Business Understanding (What does the business need?): The Business Understanding phase focuses on understanding the objectives and requirements of the project.

2) Data Understanding (What data do we have / need?): It drives the focus to identify, collect, and analyze the data sets that can help accomplish the project goals. Examine the data and document its surface properties like data format, number of records, or field identities and identify relationships among the data.

3)Data Preparation (How do we organize the data for modeling?): This phase prepares the final data set(s) for modeling. It is important to clear the unnecessary data, derive new attributes that will be helpful and create new data sets by combining data from multiple sources.

4)Modeling (What modeling techniques should we apply?): In this phase is it necessary to build and assess various models based on several different modeling techniques.

5)Evaluation (Which model best meets the business objectives?): This phase looks more broadly at which model best meets the business and what to do next.

6)Deployment (How do stakeholders access the results?): In the last phase it is important to develop and document a plan for deploying the model and to conduct a project retrospective about what went well, what could have been better, and how to improve in the future.

For this project I will especially focus on the Data Understanding phase, the Data Preparation phase and the Modelling phase, since as a first step is essential to group and understand the provided data. The design of the research is visualized in Figure 1.3, showing the steps needed to solve the problem based on the CRISP-DM methodology.

Figure 2: CRISP-DM Methodology

1.3.4 Research Question

The company needs to optimize its purchasing process to minimize delays and ensure essential items remain available. This leads to the central research question: **Which optimization technique and model can be applied to reduce the number of orders while ensuring stock availability for essential items?**

1.3.5 Sub research questions

In this section, the sub-research questions are defined and the method of approaching each question is explained. Further details on each sub-question can be found in the table of research design in Appendix 3.1 . The sub-research questions show the steps needed to take in order to complete the research as a whole, and structures the order of the tasks.

1) How does the current purchasing system operate at EcoCenter?
As the aim of the research is to develop an inventory model, it is important to first be familiar with the current methods. We obtain the knowledge by conversations with the supply chain manager of the company in charge of the current decision making.

2) How is the data structured, and what insights can be drawn from an initial analysis?
We identify the available data that can be used for the inventory model. Data

analysis is carried out to get a better understanding of the data. We especially address the trends and seasonality that the data contains, and find ways to better prepare the data for applying it to inventory models. Purchase records from 2022, 2023, and 2024 as well as inventory reports will be used to collect data.

3) How should the data be cleaned and structured for effective analysis?
The collected data is cleaned and organized. This include correcting mistakes and eliminating unneeded data. The data will also be grouped by material type and supplier so that it is easier to analyze and model in the next phase.

4) Which models are best suited to minimize annual purchases?
We conduct systematic literature review with the aim of gaining insights on the inventory models that can be applied to the case. There are models that take into account different factors related to demand and thus, can return different results. The findings are presented under the Theoretical Framework section.

5)What are the most suitable inventory models based on the available data and objectives and how can they be applied to the case of Ecocenter?
Different KPIs defined in Section 1.3.6 help assessing the accuracy and determine the most suitable model. This allows us to provide EcoCenter with recommendations on which models they should use now and in the future.

6)In what ways can the developed invenotry model be used for the benefit of the company and how can it be integrated into EcoCenter's operations?
In the final two phases of the CRISP-DM, we will check how well the chosen model works. This includes looking at key performance indicators (KPIs). By analyzing the results of the inventory model, we identify the ways the model can be improved. This includes what data the company should gather for better accuracy of the model in the future. Conclusions of the findings are also presented as well as a step-by-step guide for applying the inventory model in the future.

1.3.6 Chosen KPIs

We want to evaluate the developed forecast by several Key Performance Indicators. Measuring the performance of the inventory model is of high importance for determining to what extent the model can be relied on for decision making.

Common KPIs used in inventory and purchasing optimization include the total number of orders per year, stockout frequency, average order size, and order consolidation rate. These will help to understand if we are really reducing the number of orders while still keeping enough stock of important items.

The first and most important KPI is the total number of orders. Since EcoCenter wants to lower the number of annual purchases, this will show if we reach the target of minimzing orders per year while minimzing costs.

The second KPI is stockouts, which shows how often EcoCenter runs out of important items. We need to make sure that by ordering less, we do not risk delays or problems in operations.

Another important KPI is inventory turnover rate. This shows how fast inventory is used and replaced. If this number is too low, it means we are holding too much inventory, which increases costs.

The last KPI will be the order cycle time, which measures how long it takes from placing an order until delivery. With the new bureaucracy, this is especially important to track.

KPI Name	**Description**	**Target/Goal**	**Importance**
Total Number of Orders	Measures the total purchase orders placed annually.	Around 900 orders per year	Directly measures if EcoCenter is reaching its main goal of reducing the number of orders.
Stockouts	Tracks how often EcoCenter runs out of essential items.	As low as possible	Ensures that reducing orders does not lead to supply shortages or operational problems.
Inventory Turnover Rate	Shows how quickly inventory is used and replenished.	Balanced turnover to avoid excess inventory	Helps monitor if inventory is moving efficiently, avoiding high storage costs.
Order Cycle Time	Measures the time from placing an order to receiving it.	Reduced time, despite bureaucratic delays	Important to track how long the purchasing process takes under new rules.

1.3.7 Key Concepts

EcoCenter faced recent changes in public purchasing procedures, which lead to the fact, that making a single purchase has become more complex and time-consuming. A more optimized ordering system would allow them to reduce workload and avoid urgent last-minute orders. These four key concepts accurately sum up EcoCenter's situation. Inventory management was chosen because it covers every decision about what, when, and how much to buy and because it is the central term of the research. On the other hand, Order Optimization is the practical lever for cutting paperwork without risking shortages. Stock Levels refer to the quantity of a specific product that a business has in stock at a given time. Order Reduction is EcoCenter's ultimate goal: fewer annual purchases, less administrative work, and minimize costs.

Concept	**Description**	**Role / Goal**	**Importance**
Inventory Management	All decisions about what to buy, when to buy, and how much to buy, since this is a clear inventory management problem.	Provides the overall framework for planning and controlling stock.	Central to the research: ensures EcoCenter orders the right items in the right quantities.
Order Optimization	Practical methods (e.g. EOQ, joint replenishment) to group and time orders.	Cuts paperwork and processing time by consolidating purchases.	Reduces staff workload and avoids urgent, last-minute orders.
Stock Levels	The quantity of each product held on hand at any moment.	Serves as the metric around which reorder points and safety stock are set.	Keeps essential items available while preventing both shortages and overstock.
Order Reduction	EcoCenter's target of fewer annual purchase orders.	Measures success of consolidation and optimization efforts.	Lowers administrative costs and minimizes total purchasing expense.

1.4 Assessment of validity and reliability of measurement

In the book Business Research Methods reliability is defined as something that has to do with the accuracy and precision of a measurement procedure [2]. We will try to check the reliability by comparing data from different years and looking for items that are ordered often. Results must be consistent to be considered reliable, which reduces random errors.We reconcile purchase orders, DDT transactions,

and invoices line-by-line, flagging any inconsistencies in supplier codes, dates, or cost centers. On the other hand, validity is defined as the extent to which a measurement instrument accurately measures what it is designed to measure [2]. Validity is concerned with measuring what should be measured [1]. In this case, the goal is to reduce the number of orders at EcoCenter and make sure essential items are always available, while minimizng costs. Even though the data is not perfectly suited for inventory models, it still gives a good picture of how often EcoCenter buys items.
To improve the validity, we will also discuss my findings and assumptions with EcoCenter employees, because they know the system best. We aim to mitigate possible biases that may occur in applying inventory models by taking several precautions. First, the nature of the data can cause bias on the outcomes of the invenotry model. The data is analyzed to be consistently tracked promoting reliability Data availability is explored further in Section 2.2.1 and data reliability in Section 2.2.2. In Chapter 3we go thrpugh various inventory models and choose the modt suitable one for EcoCenter's case.To assess the validity of the ordering policy, we conduct a simple sensitivity analysis by applying different parameters on the chosen inventory model to determine if the outcomes significantly alter. The overall design of the research is developed based on a careful literature search to define the theoretical framework. This ensures the methods are well thought out and validated in literature by numerous other studies.

1.5 Ethical Considerations

To make sure that everything in this research is done properly and respectfully, clear rules for confidentiality will be followed. Before the thesis will be submitted, EcoCenter will review it to check if there is any sensitive information that should be removed or hidden. Even though EcoCenter is a public company and majority of their data is already published, it is important to have their approval before publishing the thesis. In addition, the university's ethics committee will assess ethical considerations to ensure that the study follows institutional research integrity guidelines. Finally, the researcher and the company signed a formal agreement outlining the terms for confidentiality, data protection, and the handling of sensitive information throughout the research process.

2 Current Method and Data Overview

In this chapter, we explain the current purchasing method of EcoCenter. We analyze the available data, its limitations and reliability, and inspect whether it contains trends.

2.1 Purchasing system before the bureaucratic changes

Before the new 2024 rules, to buy something EcoCenter followed a simple, seven-step path that one officer controlled from start to finish. The project officer, called the RUP, first asked several suppliers for quick e-mail price quotes and, at the same time, applied for the official CIG code that every public purchase in Italy needs. If the expected cost was ten-thousand euro or more, the officer had to gather at least three written offers; for smaller amounts, three offers were only suggested, not required. After comparing the quotes, the officer filled out an internal form that named the winning supplier and added a short note when the choice was not the cheapest. All papers (the quote request, the offers, the supplier's compliance form, the CIG code, and the purchase request) were then saved in EcoCenter's D3 archive. Finally, each week the officer sent signed delivery notes or invoices to the Purchasing office as proof that the goods had arrived. Because almost every task rested with one person and the paperwork was light, the whole process was quick and flexible; much faster than the anti-corruption procedure introduced in 2024.

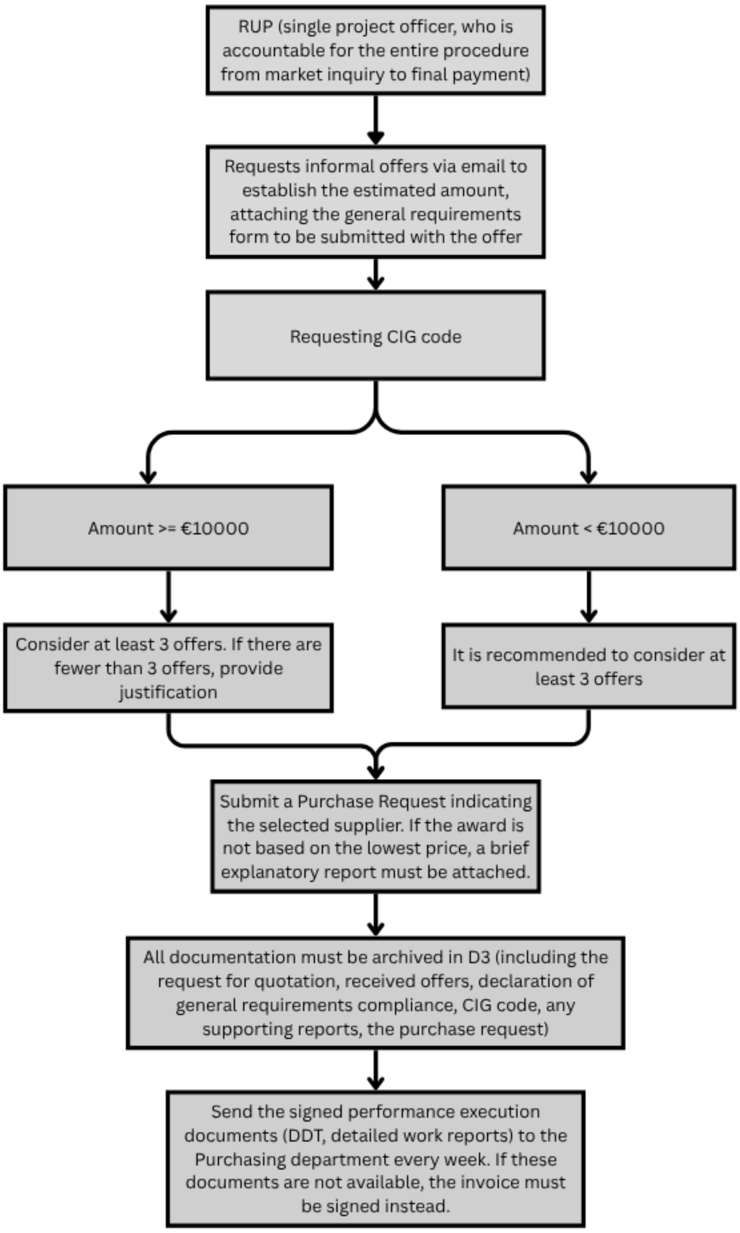

Figure 3: Flowchart of the previous purchasing system before 2024

2.2 Current purchasing system

In this section, we want to answer the first sub-research question defined in Section 1.3.5: How does the current purchasing system operate at EcoCenter?
Eco Center's direct-award purchasing flow is designed to satisfy Italian public-procurement law while meeting the firm's own quality and transparency standards. The process starts when one of the 27 environmental facilities (or another internal client) recognizes a need for a material, service, or minor works contract. That need is channeled to the RUP, the single project officer, who is accountable for the entire procedure from market inquiry to final payment. Where workload or technical complexity is required, the RUP may appoint a formally nominated assistant drawn from the technical staff or (for non-technical goods) from the Purchasing/Warehouse office. The Technical Director or the General Director validates this appointment, depending on the area involved.
The first step of the process is the Market inquiry / quotation request (RDO: Richiesta di Offerta): The RUP first checks whether the requirement can be covered by an existing benchmark price list. If no reference exists, the RUP launches a market survey inside the Radix ERP and issues an electronic RDO (Market inquiry) to qualified suppliers. This document must be created in Radix so that it can later be published on the Transparency Portal.
Next EcoCenter has to carry out a bid comparison and compliance checks. When quotes arrive, the RUP or the formally nominated assistant drawn from the technical staff evaluates price, delivery, and vendor compliance with legal and fiscal rules. The preferred bidder is recorded in a formal award decision required by the Article of the Italian Constitution nr. 17,2 of Legislative Decree 36/2023.
After the bidder has been chosen, the next step is the publication and CIG acquisition. The award summary is uploaded to the SICP platform for transparency, and a CIG (unique tender identifier) is generated. The CIG is a code attributed to each purchase order.
The RUP now sends an Internal purchase requisition to the central Purchasing Office. This requisition summarises scope, supplier, price, budget code, and CIG.
A Purchasing-Office Clerk converts the internal purchase requisition into an purchase-order issue in Radix. The Head of the Purchasing Department, acting on delegation from the General Director, releases the order. The signed Purchase-order issue , while contractually binding if no separate contract exists, is dispatched to the supplier by certified mail.
In the next step the supplier ships. Receiving personnel inspect the goods or certify the service, sign the transport document (DDT) and upload it to Radix; once all lines are received the system closes the order.
Eventually, the supplier's invoice is matched with the Purchase-order issue and the respective DDT in Radix by the Purchasing clerk. When quantities, prices,

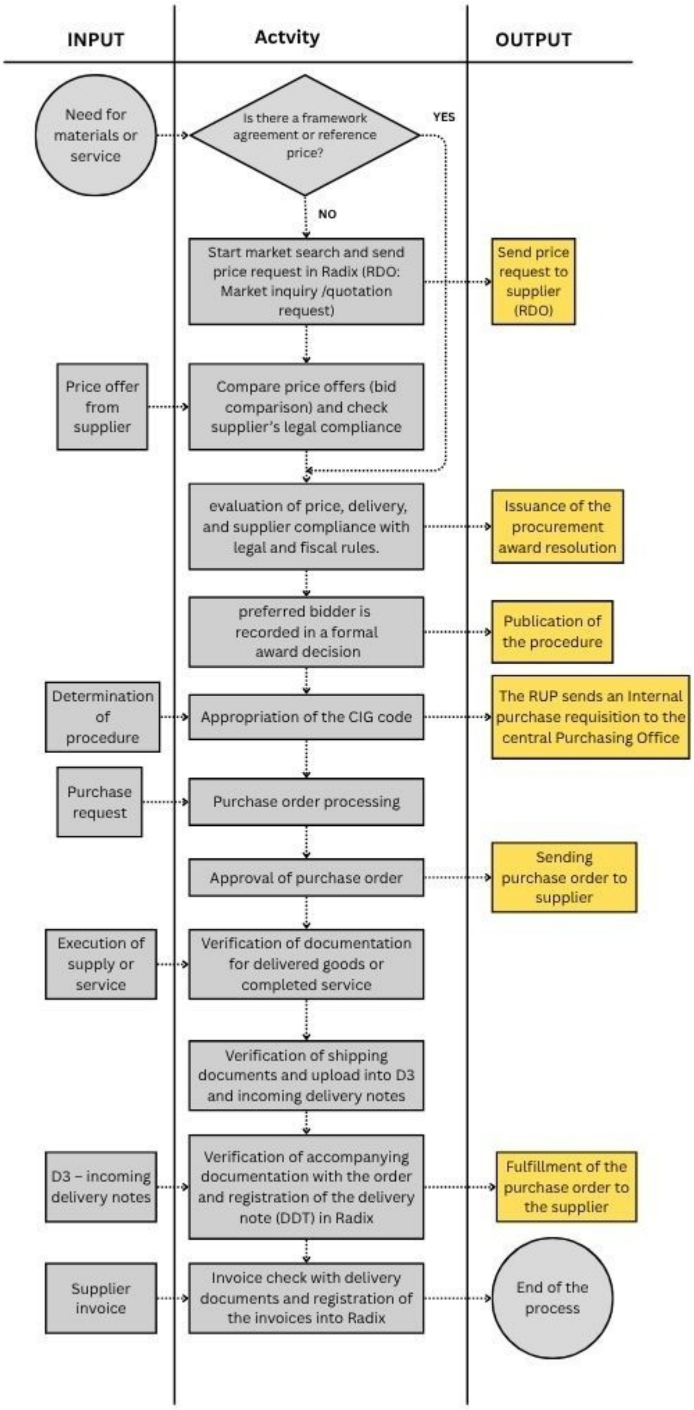

Figure 4: Flowchart of the current purchasing system

and CIG align, Accounts Payable posts the record and the payment is scheduled. With this the procedure is formally closed.
Throughout these stages the file moves through at least six roles (RUP, the formally nominated assistant drawn from the technical staff, Purchasing Clerk, Head of Purchasing, Receiver, Accounts Payable) and seventeen separate control gates.

2.3 Data Overview

As the focus is on improving the purchasing method, understanding the data provided by the company is an essential step of the process. This section is related to the second step of the CRISP-DM methodology called Data Understanding. We address the second and the third sub-research question:
How is the data structured, and what insights can be drawn from an initial analysis?
How should the data be cleaned and structured for effective analysis?

2.3.1 Data Availability and Limitations

Before we can choose the right inventory management model for EcoCenter we must look carefully at the data the company already has and at the limits of those data. EcoCenter supplied four primary Excel workbooks, hereafter listed for better understanding:

1. Purchase Orders 2024: This Excel spreadsheet contains every Purchase Order raised in 2024, with header fields for CIG code, supplier, material code, quantity and price.

2. Invoices 2024: It illustrates all the matching invoice for each CIG-code, hence Purchase Order.

3. DDT 2024: This Excel spreadsheet contains all transport documents (DDT) booked against every PO line. The DDT is the processing in the management system of any document that certifies the execution of the supply (goods), the execution of a service or a work (certificate of regular performance of service or employment relationship).

4. Details of every PO issued in 2024: This Excel spreadsheet illustrates the quantities of each material ordered in each purchase order in 2024. It also contains extra shipping cost that some purchase orders charge and it contains a more detailed order description.

We also have files from 2022 and 2023 that we used for background knowledge and not for our calculations, since many aspects have changed and developed from

the introduction of the bureaucratic changes. The mix of suppliers, the average order size and the timing of orders have all shifted. Thus, after discussing with EcoCenter's supply chain manager, we can conclude that data from 2022 and 2023 is not fully representative of the current situation. Hence for the model the data of 2024 will be used.
Eco Center has authorized full disclosure of the figures used in this study; therefore the tables and graphs in the report present the actual euro values and quantities without scaling or concealment.

2.3.2 Data Reliability

The primary feature of reliability is consistency in the data, which helps to prevent mistakes in interpretation and in converting the data into a consistent format. Over the years, EcoCenter has collected the data consistently, since they are a public company and are forced to public majority of their purchases. Every purchase order of EcoCenter has a CIG, which is a code attributed to each purchase order. Thanks to the CIG it is possible to navigate through the 4 Excel spreadsheets and know exactly how many DDTs, invoices, price and the precise quantity linked to each purchase order. Thanks to the CIG it is simple to navigate through the data provided and we lower the possibility of misinterpretations.
For the data to be reliable, it should also be complete. The data is complete in a sense that for each purchase order we have the amount of DDTs, invoices, the price, the quantity, the material, the shipping cost. This means there are no gaps in tracking demand.
We base our analysis on the complete 2024 data set because it fully reflects EcoCenter's new order way of purchasing. However, the data is not complete in the sense of having information of enough seasonal cycles to be able to accurately estimate the patterns, as we use one year of observations, as the years 2022 and 2023 are more for background knowledge, since they do not reflect the current purchasing strategy fully. By focusing on the 2024 records we assume that next year will show a similar seasonal shape unless other major changes occur. Additional years of data will let us improve the model later, but the current set is reliable enough to draw practical conclusions for today's planning.

2.3.3 Order Patterns

In this subsection we look at the data to check whether it contains trend and/or seasonality. A trend is the presence of a long-term increase or decrease in the sequence. Seasonality is a variation that occurs at specific regular intervals, for example, annually or quarterly.
Figure 4 plots EcoCenter's total purchase orders per ISO calendar week for the

last three years, with each line representing one year (blue = 2022, green = 2023, red = 2024). The x-axis shows ISO calendar weeks 1 to 52 and the y-axis counts how many purchase orders EcoCenter placed in each week. The number of orders goes up and down each week. We can notice that the three lines follow roughly the same pattern. Calm weeks rarely drop below 10 to 15 orders, while busy weeks generally never exceed 60 to 65 orders. EcoCenter's demand appears to be basically constant since the three lines are evenly distributed and do not tilt either upward or downward. Seasonality is also not straightforward but we can identify peaks and declines in the same weeks of different years. A late-summer rush or pre-holiday restocking are examples of small increases that seem to be event-driven, but they are temporary and do not result in a long-term pattern.

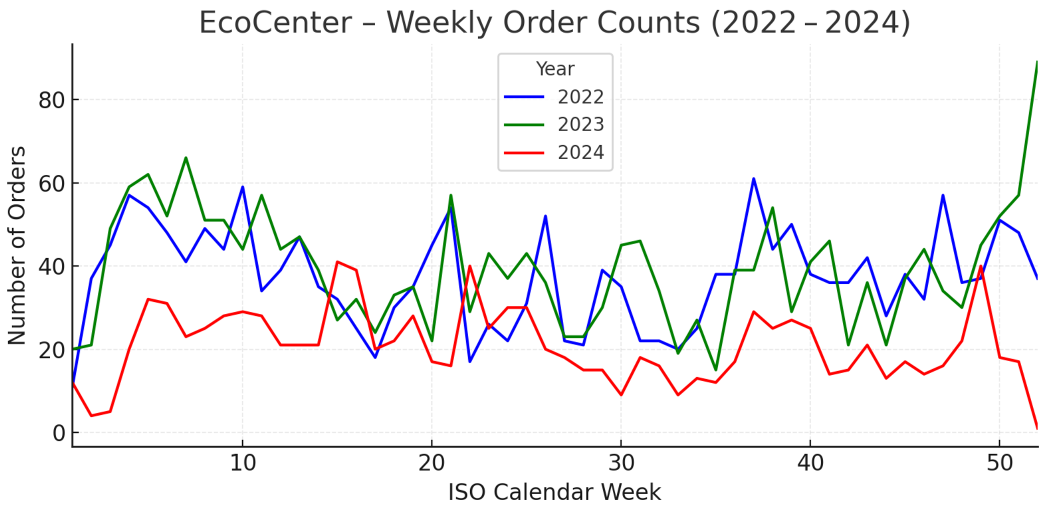

Figure 5: Weekly demand of EcoCenter per each year of the data set

We drew the week-by-week chart in Figure 4 to see if EcoCenter's demand stays steady or changes a lot over time. The three lines for 2022, 2023, and 2024 all sit in the same band: slow weeks usually stay above about 10 orders, and the busiest weeks stay below about 65. In other words, there is no lasting growth or decline. The few sharp spikes (for example in late summer and just before Christmas) re-appear in the same calendar weeks each year; they are linked to one-off events rather than to a fixed seasonal cycle. This shows that demand is regular over the years.

3 Theoretical Framework

In this chapter we conduct systematic literature review to explore the importance of inventory management and issues it contributes to solve. To determine which inventory model is best, we look at the several that are available. We introduce several inventory models for minimizing annual purchases. In this section, we answer the sub-research question: Which models are best suited to minimize annual purchases?

3.1 Importance of Inventory Management

To meet demand on time, companies often keep on hand stock that is awaiting sale. The purpose of inventory theory is to determine rules that management can use to minimize the costs associated with maintaining inventory and meeting customer demand. A critical part of the managing process refers to inventory control, i.e. defining whether and when an order should be placed for a particular item, as well as how many units such an order should involve [3]. Inventory Control refers to in-operation management, logistics and supply chain management, the technological system and the programmed software necessary for managing the inventory. The objective of inventory control is to establish levels of inventory which will serve to minimize the company's cost and maximize its revenues [4]. Inventory models answer the following questions.

- When should an order be placed for a product?
- How large should each order be? [5]

Inventory management is the process of making sure that the right products are in stock at the right time. Good inventory management helps not only with avoiding shortages, but also with reducing administrative work and focusing on the most important materials. A company with appropriate inventory management is able to maintain a smooth and efficient production flow and can ensure deliveries of its products against delays [4]. It allows the firm to have a better utilization of man power and machinery and to increase its output. Inventory management basically serves two main goals [6]. The first goal is the availability of goods. It is essential for all the operations in process that the required materials or goods are present in the right quantities, quality and at the right time in order to deliver the required service level. The second goal is to achieve the aforementioned service level against optimal costs. This leads to the inevitable challenge, that is, to find the suitable equilibrium between keeping sufficient inventory with the optimal costs with respect to the desired service level that one has to deliver. In that sense, not all items can be held in stock against every cost and therefore choices have to be

made.
Because of this, the research goal is to build a model that is easy to use and fits EcoCenter's data and goals. To understand which model fits best, several academic sources were studied. One useful book was Inventory Control: Models and Methods by Bartmann and Bach [7]. This book explains many inventory models, including EOQ (Economic Order Quantity), ABC analysis, various stochastic models, the Wagner-Whitin algorithm for dynamic lot-sizing and the Wilson model with Poisson Demand. Another useful source was the book Operations Research APPLICATIONS AND ALGORITHMS (fourth edition) by Wayne L. Winston [5], in which the importance of inventory management is explained and other models like Deterministic EOQ Inventory Models, Probabilistic Inventory Models, Dynamic Programming, Queuing Theory and Markov Chains are introduced.

3.2 ABC Analysis

Before applying an inventory management model, it is essential to classify the materials based on their importance and contribution to overall spend. Most inventory management systems begin with such a classification to help prioritize decision-making. ABC classification was chosen because it is a simple and widely-used method that helps focus on the small number of items that have the largest impact on spending. This allows us to apply inventory models more effectively to the suppliers that matter most.
ABC analysis, also known as Pareto analysis, is an important tool for companies that want to optimize their inventory management strategies. The Pareto principle, also called the 80/20 rule, shows that about 80% of the effects come from 20% of the causes, emphasizing the importance of focusing on the most significant inventory items. The ABC classification, devised at General Electric during the 1950s, helps a company identify a small percentage of its items that account for a large percentage of the dollar value of annual sales. These items are called Type A items. Since most of the firm's inventory investment is in Type A items, concentrating effort on developing effective inventory control policies for these items should produce substantial savings. [5] Category B items are moderate in value and demand, requiring a balance of attention to maintain profitability. Category C items are low in value and demand, often making up the majority of inventory while contributing minimally to income [8]. EcoCenter can give special attention to the most important items, while managing less important ones with simpler methods.
Repeated studies have shown that in most companies, 5%–20% of all items stocked account for 55%–65% of sales; these are the Type A items. It has also been found that 20%–30% of all items account for 20%–40% of sales; these are called Type B items. Finally, it is often found that 50%–75% of all items account for only

5%–25% of sales; these are called Type C items. [5] For the purpose of goods management category A should receive maximum analysis because it is very high sales value and category B attention number two underneath. While the category C should be analyzed in a casual fashion by taking into account one tendency, for example what kind of goods tend to increase sales, or have the highest inventory level and so on. [9]

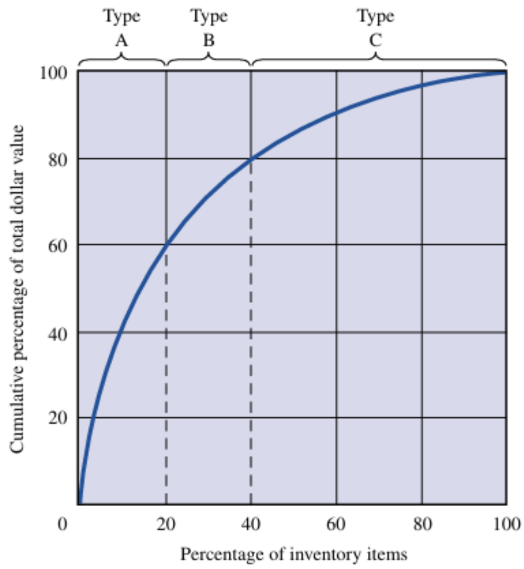

Figure 6: Example of ABC Classification of Inventory (Winston,2004) [5]

The insights from the ABC analysis will be used to support the choice of the most appropriate inventory management model for EcoCenter. Since Type A suppliers and the most important Type B suppliers contribute the most to the total value of purchases, the choosen model will focus primarily on these categories.

3.3 Overview of Inventory Models

In this subsection, we investigate several inventory models for minimizing annual purchases. We analyze their pros and cons and assess whether they would be suitable for EcoCenter's case, as I specifically focused on inventory management models that could be implemented within the 10-week timeframe and align with the company's goals.

3.3.1 Wagner-Whitin algorithm

First, the Wagner-Whitin algorithm was reviewed, which helps companies plan orders over time, especially if demand changes a lot. The core formula of the Wagner-Whitin model is [10]:

$$M_{jk} = A_j + C_j Q_j + \sum_{t=j}^{k} H_t \sum_{r=t+1}^{k} D_r$$

where:

- M_{jk} = Total cost of placing an order in period j to cover demand until period k.
- $Q_j = D_j + D_{j+1} + \ldots + D_k$ = Total demand from period j to k.

For EcoCenter, we interpret the variables of the Wagner-Whitin model as follows:

- D_t **(Demand in period t)**: Number of purchases needed from a supplier in a given month, based on EcoCenter's historical data.
- A_t **(Ordering cost in period t)**: Administrative cost per order (e.g., estimated at €40 per order).
- C_t **(Variable cost per unit)**: The cost for processing each line item (in EcoCenter's case, this could include handling invoices).
- H_t **(Holding cost per unit)**: The problem of delaying purchases or holding inventory; since EcoCenter does not hold physical stock, this is interpreted as bureaucratic/administrative work.

An optimal timing and quantity of orders per supplier over the year is obtained thanks to this model.

3.3.2 Stochastic model with continuous review and Poisson demand

In this model, the inventory level is continuously monitored, and when it drops to a certain reorder point, a new order is placed. Demand follows a Poisson distribution, meaning that it occurs randomly but at a predictable average rate. These models are useful when demand is very unpredictable [11]. For EcoCenter, we could interpret the model as follows:

- D **(Demand rate):** Number of orders per year for each supplier, based on historical data.

- S **(Maximum inventory level):** Target number of future purchases covered in advance.
- $S - s$ **(Reorder quantity):** When the accumulated purchases reach this point, a replenishment order is placed.
- L **(Lead time):** Time between placing an order and receiving confirmation or delivery.
- **Perishability:** EcoCenter does not have any perishable goods.
- λ **(Lambda):** Rate parameter of the Poisson process, $\lambda = \frac{Totalannualdemand}{Timeperiod}$.

The main process behavior:

- **Demand arrival:** $L(t) = L(t^-) - 1$
- **Replenishment arrival:** $L(t) = L(t^-) + (S - s)$
- **Perishability:** $L(t)$ decreases if orders become outdated.

The expected number of demands over time t is:

$$E[N(t)] = \lambda \cdot t$$

The probability of exactly n demands in time t is given by the Poisson distribution:

$$P(N(t) = n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!}$$

3.3.3 (R,S) Model

Next, we discuss the (R, S) inventory policy with periodic review and probabilistic demand. The policy works in a way that we check the on-hand inventory every R unit of time and make a replenishment order to raise the on-order inventory level up to S [5]. The (R,S) inventory policy is a way to manage stock levels by checking inventory at regular intervals and ordering more when needed. For EcoCenter, this means they would regularly check their stock of important items like chemicals, maintenance parts, and materials. If the stock level is low, they would place an order to bring it back up to the required level. However, this method can lead to higher costs for holding inventory, as it requires keeping more stock on hand to cover possible demand changes. The policy calculates the "order-up-to" level (S), which is based on forecasts of how much demand is expected, as well as the costs of holding inventory and losing sales when items run out. For EcoCenter, the main costs are the cost of keeping stock and the cost of losing sales if an item is out of

stock. We define:
L = Lead time for each order (constant)
R = Review period (time between inventory checks)
D = Yearly demand, with mean $E(D)$ and std. dev. σ_D
D_{L+R} = Demand during the protection window $L + R$
h = Annual holding cost per unit
c_{LS} = Cost per unit of a lost sale (stockout cost)
S = Order-up-to level
ss = Safety stock
CSL = Desired cycle-service level (prob. of no stockout in a cycle)
z = Standard-normal inverse for CSL
To determine the order up to level we use marginal analysis to calculate S such that it minimizes the sum of the expected holding and lost sales costs [5]. That value of S should satisfy:

$$\Pr(D_{L+R} \geq S) \;=\; \frac{Rh}{Rh + c_{LS}} \tag{1}$$

The model assumes demand is a continuous random variable that follows a normal distribution, and that lead times for deliveries are constant, meaning the time between placing an order and receiving it is predictable. We would use the NORM.INV function in Excel to compute the on-order inventory level. The function determines the inverse of the normal cumulative distribution for a determined probability. It requires inputs of the mean and standard deviation, as well as the mentioned probability, and returns the value at which the probability of the variable being less than or equal to this value equals the specified probability. The cycle service level CSL is the percentage of replenishment cycles where all customer demand is satisfied (the probability of no stockout in the review period) [12]. Since a stockout will occur if the demand during L+R exceeds S, the following must be true [12]:

$$P(E(D_{L+R}) \leq S) \;=\; CSL \tag{2}$$

$$S \;=\; E(D_{L+R}) + ss \tag{3}$$

One challenge with this method is that EcoCenter would need to regularly adjust the safety stock to account for changes in demand. The safety stock is calculated based on the desired service level, which is the likelihood of avoiding stockouts during the review period.

$$ss \;=\; z\,\sigma_{D_{L+R}}, \qquad z = F_s^{-1}(CSL) = NORMS.INV(CSL) \tag{4}$$

3.3.4 EOQ model

The standard Economic Order Quantity (EOQ) model is a cornerstone of inventory management [13].It helps find the best order quantity that minimizes both ordering costs and holding costs. It is one of the oldest and highly recognized models in business and operations research and it has been developed by Harris [10]. He based the dependency of different costs of inventory, namely holding costs and ordering costs, on the lot size produced per set-up (or the quantity ordered per order) on the assumption that the item under consideration has a continuous and constant demand rate [4]. According to this model, with an increase in the quantity of orders, the ordering costs decline, whereas the holding costs increase, and thus the curve of the total variable inventory cost has a minimum point. That is the point where the total inventory cost is minimized and the order quantity is most economical. First, some assumptions need to be clarified for the basic EOQ model to hold [5]:

- Demand is deterministic and occurs at a constant rate.
- If an order of any size (say, q units) is placed, an ordering and setup cost K is incurred.
- The lead time for each order is zero.
- No shortages are allowed.
- The per-unit holding cost of inventory is h per period of time.

Given these assumptions, the total cost function is defined as:

$$TC(Q) = \frac{D}{Q} \cdot S + \frac{Q}{2} \cdot H$$

Where:

- $\frac{D}{Q} \cdot S$ represents the annual ordering cost.
- $\frac{Q}{2} \cdot H$ represents the annual holding cost.

By minimizing this cost, we get the EOQ formula [9]:

$$Q = \sqrt{\frac{2DS}{H}}$$

Where (adapted to EcoCenter's needs):

- Q = Optimal order quantity (EOQ)

- D = Annual demand (in this case, the number of orders per supplier per year)
- S = Cost per order (administrative cost for processing each order)
- H = Holding cost per unit (adapted to the cost for handling delivery notes (bubbles) or invoices)

With this formula, it is possible to analyze suppliers with the highest number of orders, delivery notes, and invoices. After calculating EOQ for each supplier, we will sum up the total costs (orders, delivery notes, and invoices) and identify the most critical suppliers (those with the biggest impact on total administrative costs).

3.3.5 Joint-ordering Policy (Extension of the EOQ Model)

The joint ordering policy, when we are managing multiple products, is an extension of the basic EOQ model. This case occurs when a company replenishes several items with a single order from one supplier. In such systems, the company orders a group of products simultaneously, instead ordering them individually. The objective is to optimize the total cost of products by minimizing the inventory ordering and holding costs. By using joint ordering policy, thereby the fixed setup cost is shared between the products and reducing the total cost is achieved. [14] Additionally, because it uses the same vehicles for shipping and/or the same supplier, joint ordering is useful in the actual world. As a result, a joint ordering policy is less expensive than a simple distinct order. When acquiring big quantities of many products, it is possible to obtain discounts from the supplier. Enough items are jointly ordered under this policy.
To decide how many joint replenishments EcoCenter should schedule each year we first apply the "order-all-together" version of the Joint Replenishment Model (JRM). The model aggregates the annual demand, holding cost and unit value of every item that will share the same purchase order and balances those carrying costs against the one-time costs of raising an order. Thanks to the formula below we obtain n^*, which is the optimal joint-order frequency; how many times per year EcoCenter should place a consolidated order that contains all k items.

$$n^* = \sqrt{\frac{\sum_{i=1}^{k} D_i \, h \, C_i}{2\left(S + \sum_{i=1}^{k} s_i\right)}}$$

n^* optimal number of joint orders per year (order frequency)

D_i annual demand of product i (units, kg, L, tons ...)

h annual holding-cost rate (% per year)

C_i unit purchase cost of item i

S fixed order cost per joint replenishment

s_i item-specific ordering/handling cost of item i

k number of distinct items

In the joint ordering policy the total cost function consists in total ordering costs added to the total holding costs

$$TotalCost = n^* \left(S + \sum_{i=1}^{k} s_i \right) + \sum_{i=1}^{k} \frac{h\, C_i\, Q_i}{2}$$

3.4 Selection of Approach

EcoCenter buys many different chemical products each year, mostly for their treatment plants and laboratory. The most frequently ordered chemicals are polyelectrolytes, sodium bicarbonate, ferric chloride, mixed iron and aluminum defosfating agents, ammonia, and activated carbon. Each of these products has its own separate purchase order. These chemicals are essential for processes such as water purification, sludge treatment, and laboratory testing. By grouping these products into joint orders from the same supplier, EcoCenter could reduce the total number of orders and save time on administration.

In this research, we explored different inventory management and purchasing optimization models to find out which ones would be the most helpful for EcoCenter. EcoCenter's main goal is to reduce the number of annual orders while still making sure that essential items are always in stock. This is important because their purchasing process has become longer and more bureaucratic due to new anti-corruption compliance requirements, so they want to avoid delays and shortages without making too many orders. In selecting the most practical replenishment framework for EcoCenter, we compared several inventory management models: Wagner-Whitin algorithm, stochastic models with continuous review, (R,S) Model, EOQ Model and an extension of the EOQ Model, which is the joint-ordering policy.

We first looked at stochastic models with continuous review and with Poisson demand, which can be helpful because they monitor stock levels all the time and place orders whenever inventory drops below a certain point. Stochastic models

are useful when demand is uncertain and unpredictable. However, these models are more complex to apply in EcoCenter's situation because they require very detailed, real-time data and are usually used for fast-moving consumer goods or perishable items. EcoCenter's demand is more stable, and they do not order perishable goods.
We also considered the Wagner-Whitin algorithm, which is part of dynamic lot sizing. This method focuses on finding the best timing and quantity of orders across a specific time period, especially when demand changes. It is a very good method for handling fluctuating demand while keeping costs low. However, it is better suited for businesses with clear seasonal demand or fluctuating needs. EcoCenter's purchase patterns, as seen in their historical data, do not strongly follow such variations, and the complexity of this method might not fit.
The (R,S) Model assumes demand is a continuous random variable that follows a normal distribution, and that lead times for deliveries are constant. This model, which uses a periodic review policy with probabilistic demand, could be a possible option for EcoCenter. It is well-suited for environments with fluctuating demand and where stockouts carry significant cost. However, given the 10-week time constraint of this research and the aim to deliver a practical, easy-to-implement tool, the (R,S) model was judged to be too complex for the current scope. Simpler models, such as the joint-ordering extension of the EOQ model, offered a clearer solution to reducing orders while still maintaining sufficient inventory control. In short, while the (R,S) model remains a promising candidate for future exploration, especially as data quality and forecasting capability improve, it was discarded here to prioritize simplicity, ease of use, and feasibility within the project timeline.
The EOQ model helps to calculate the ideal order quantity that minimizes the total cost of ordering and holding inventory. EcoCenter's goal of reducing the number of orders fits perfectly with this model because EOQ supports order consolidation. However, the basic EOQ model is too simple, since every purchase order that Ecocenter issues has more than one component.
The basic EOQ model is designed for single products, but in EcoCenter's case, many suppliers deliver multiple items. For example, S.EC.AM. SRL delivered 6 products in 2024 and each product was a purchase order, and grouping those into 3 orders is more advantageous than optimizing each one separately, since the main goal of Ecocenter is to reduce their annual purchases to 900. For suppliers with only one product and already just one order per year, there's no need to optimize further, since EcoCenter is already doing it well.
In the Appendix subsection 7.3 (Comparison of Inventory Management Models) we created a table where we compare the different inventory management models that we introduced in Chapter 3 and we apply them to the chosen KPIs. Looking at the table, while keeping into account EcoCenter's available data, we came to the

conclusion that the best choice to solve EcoCenter's problem is the joint-ordering extension of the EOQ Model with ABC Analysis.
The EOQ logic (square-root rule) is easy to show on a single slide and to recalculate in Excel whenever prices or demand change. This makes it straightforward for managers and auditors to see why a certain order calendar was chosen, and for future staff to maintain the system without outside consultants. In short, the joint-ordering EOQ model delivers the biggest administrative savings with the smallest implementation burden. At the same time, ABC analysis helps to prioritize items by importance, based on their consumption or value. By focusing most attention on high-priority (A-class) items and managing less "important" (not so frequent) items with easier approaches, EcoCenter can better organize their stock and avoid shortages.

4 Performance Execution & Evaluation

In this chapter, we answer the fifth sub-research question: What are the most suitable inventory models based on the available data and objectives and how can they be applied to the case of Ecocenter?

4.1 Justification of the Use of the EOQ Model

Because of seasonality or other factors, demand is often irregular. If demand is irregular, the Constant Demand Assumption that was required for all the EOQ models will not be satisfied. To determine whether the assumption of constant demand is reasonable, we suppose that during n periods of time, demands d_1, d_2,...,d_n have been observed [5]. In order to determine if demand is regular enough to support the application of EOQ models, we apply the following calculations [15]:
1)We start by determining the estimate $\bar{d}$ of the average demand per period given by the formula

$$\bar{d} = \frac{1}{n}\sum_{i=1}^{n} d_i$$

Applying this formula to the supplier S.EC.AM SLR we get the following value for the mean demand

$$\bar{d} \ = \ \frac{1}{6}\sum_{i=1}^{6} d_i \ = \ \frac{363.38 + 1.30 + 50.46 + 1000 + 1205 + 1206}{6} \ \approx \ 637.69$$

2)The second step is to determine an estimate of the variance of the per-period demand **D** from

$$\widehat{\text{Var}}(D) = \frac{1}{n}\sum_{i=1}^{n} d_i^2 \ - \ \bar{d}^2$$

Then the variance of demand of S.EC.AM SLR is

$$\widehat{\text{Var}}(D) = \frac{1}{6}\sum_{i=1}^{6} d_i^2 - \bar{d}^2 = \frac{363.38^2 + 1.30^2 + 50.46^2 + 1000^2 + 1205^2 + 1206^2}{6} - (637.69)^2 \approx 2.83\times 10^4 \tag{5}$$

3) The last step is to determine an estimate of the relative variability of demand VC and the formula looks like this

$$VC = \frac{\widehat{\text{Var}}(D)}{\bar{d}^2}$$

Hence, S.EC.AM SLR's relative variability of demand is

$$VC = \frac{\widehat{\text{Var}}(D)}{\bar{d}^2} = \frac{2.83 \times 10^4}{(637.69)^2} \approx 0.07$$

If all d_i are equal, VC will be zero. Hence, if VC is small, this indicates that the Constant Demand Assumption is reasonable [5]. Research indicates that the EOQ should be used if $VC < 0.20$ [15]. Because the value VC of S.EC.AM SLR falls well below 0.20, the constant-demand assumption of EOQ holds. Thus, it is justified to apply the EOQ joint- ordering model. This method was repeated for all relevant suppliers to check whether the constant demand assumption holds. The results showed that the highest variability value (VC) was 0.1789, and the lowest was 0.0236. These values are both well below the threshold of 0.20, meaning the EOQ model is suitable in most cases. A few suppliers had values above 0.20, but these were suppliers with only one or two purchase orders per year. As explained later in the report, for such suppliers, EcoCenter is already ordering at the correct frequency, and therefore the joint-ordering policy (extension of the EOQ model) was not applied to them.

4.2 Ordering Policy

In this subsection we want to apply the ABC Analysis and the chosen joint-ordering EOQ model. We start by determining which suppliers are considered Type A, Type B and Type C. We then proceed by applying the joint-ordering EOQ Model on one of the Type A Suppliers. To validate the results a Sensitivity Analysis is conducted.

4.2.1 ABC Analysis Evaluation

Inventory in any organization can run in thousands of part numbers or classifications and milons of part numbers in quantity. Therefore, inventory is required to be classified with some logic in order to be managed efficiently and correctly. We selectd the ABC classification, which is a practical approach applied for multi-item inventory problems. Different item classifications need different replenishment and inventory control policies [16].
Every year, Eco Center oversees over a thousand different supply lines, from chemicals for 26 wastewater treatment facilities to replacement parts for its only incinerator. To identify which suppliers deserve the tightest purchasing control, the ABC-classification logic was applied directly to Eco Center's three-year purchase ledger. A PivotTable, that sums each supplier's invoice net value across 2022-2024, was built. This gives the euro "sales" figure that ABC analysis ranks on. Next,

in an adjoining column each supplier's share of the overall spend was calculated. The formula that was used for the Grand Total:

$$\%GT_i = \frac{Spend_i}{\sum_j Spend_j}, \qquad implementedinExcelas = \texttt{G5/SUM(\$G\$5 : \$G\$1381)}.$$

Once the percentages were in place, the list was sorted from the largest invoice net value to the smallest. Compiling these percentages is a crucial step in determining the rate at which Eco Center's money is consumed by the first few suppliers. For that the running cumulative percentage formula was used: $Spend_i$, we accumulate these percentages top-down

$$Cum_k = \sum_{i=1}^{k} \%GT_i, \qquad implementedinExcelas \quad = \texttt{H5} + \texttt{IF(ROW()} = 2, 0, \texttt{I4)}.$$

The formula simply seeds the first row at 0 and then keeps adding down the list. When this cumulative column reaches roughly 60% of annual spend we mark everything above that line as Type A (these are the few, high-impact suppliers that usually represent only 5-20% of items but 55-65% of spend [5]). The rows that push the cumulative total to about 90-95% are labelled Type B, and the long tail that brings the total to 100% are Type C. In Eco Center's file the breakpoints fell at 27 suppliers for Type A, 161 for Type B and 1 190 for Type C, mirroring the textbook rule-of-thumb that a small minority of items (here, suppliers) dominate financial exposure. Classifying the list this way tells management on which supplier to focus on:

$$TypeA : Cum_k \leq 60\%, \qquad TypeB : 60\% < Cum_k \leq 90\%, \qquad TypeC : Cum_k > 90\%.$$

For Eco Center this produced

$$\underbrace{27}_{TypeA}, \underbrace{161}_{TypeB}, \underbrace{1190}_{TypeC} \quad (N_{total} = 1378).$$

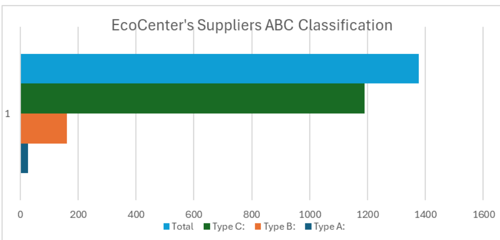

Figure 7: ABC Supplier's Calssifcation

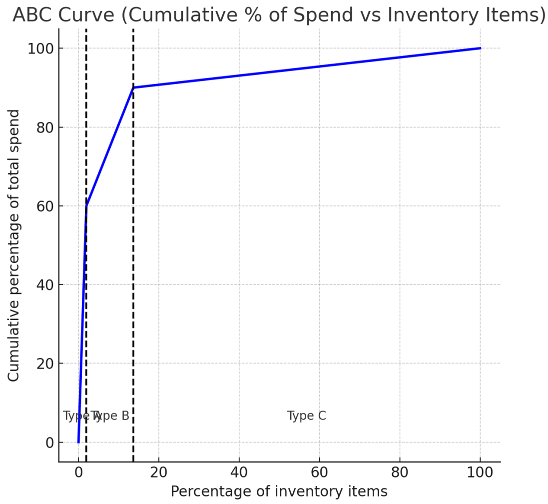

Figure 8: X-axis: % of suppliers & Y-axis: Cumulative % of total spend

ABC Analysis: Pseudocode and Example

Table 3: Input Data & Supplier Spend

ID	Supplier	Spend (€)
1	ALPERIA SMART SERVICES SRL	10990788,22
2	S.EC.AM. SRL	1084890,24
3	NORCHEM SPA	459934,95
4	MERKUR CHEMICAL SRL	137984,52
5	SIEL SPA	16672,08

List of suppliers with 3-year spend data: $Spend_i$ for $i = 1$ to N
Calculate total spend: $T \leftarrow \sum_{j=1}^{N} Spend_j$
For each supplier i: Calculate percentage share $\%GT_i \leftarrow Spend_i/T$
Sort suppliers in descending order of $Spend_i$
Initialize cumulative percentage: $Cum_0 \leftarrow 0$
$i = 1$ to N (in sorted order) $Cum_i \leftarrow Cum_{i-1} + \%GT_i$
$Cum_i \leq 0.60$ Classify supplier i as Type A
$Cum_i \leq 0.90$ Classify supplier i as Type B
The rest classify supplier i as Type C

Table 4: Output Table: ABC Classification Result

ID	Supplier	Spend (€)	% of Total	Cumulative %	Class
1	ALPERIA SERVICES SRL	10990788,22	7.89%	30.94%	A
2	S.EC.AM SRL	1084890,24	0.78%	58.90%	A
3	NORCHEM SPA	459934,95	0.33%	71.19%	B
4	MERKUR CHEMICAL SRL	137984,52	0.10%	85.36%	B
5	SIEL SPA	16672,08	0.01%	97.28%	C

4.2.2 EOQ Model Execution

After careful evaluation we selected the joint-ordering extension of EOQ as the most suitable option for EcoCenter. Thanks to the formula below we obtain n^*, which is the optimal joint-order frequency; how many times per year EcoCenter should place a consolidated order that contains all k items.

$$n^* = \sqrt{\frac{\sum_{i=1}^{k} D_i \, h \, C_i}{2\left(S + \sum_{i=1}^{k} s_i\right)}}$$

n^* optimal number of joint orders per year (order frequency)

D_i annual demand of product i (units, kg, L, tons ...)

h annual holding-cost rate (% per year)

C_i unit purchase cost of item i

S fixed order cost per joint replenishment

s_i item-specific ordering/handling cost of item i

k number of distinct items

We applied the joint ordering policy to all the Type A supplier and the most important Type B supplier. We will walk you trhough an example with the supplier S.EC.AM. SRL, which is a company that supplies Eco Center with chemical treatment reagents for use across multiple plants through open, multi-year orders. As explanied in the Section 2.2.1 Data Availabilty and Limitations, we use the data of 2024 to apply to the joint ordering EOQ model extension as it refelects the current situation of the company best. In 2024 EcoCenter purchased 6 times from S.EC.AM. SRL throughout the year:

- **Open order – liquid inorganic de-phosphating mix (Al/Fe)**
  Price: €39 240; Quantity that got ordered (Demand) : 363.38 tons; DDTs: 16.

- **Order – phosphoric acid**
  Price: €10 400; Quantity that got ordered (Demand) : 1.3 tons; DDTs: 1.

- **Order – ferric chloride 39–40 %**
  Price: €11 070; Quantity that got ordered (Demand): 50.46 kg; DDTs: 2.

- **Open order – ferric chloride solution 39–41 % (ATO plants)**
  Price: €364 000; Quantity that got ordered (Demand): 1000 tons; DDTs: 28.

- **Order – liquid inorganic de-phosphating mix Al/Fe (2024–2025)**
  Price: €134 960; Quantity that got ordered (Demand): 1205 tons; DDTs: 50.

- **Open order – liquid inorganic de-phosphating mix Fe/Al (Eco Center plants 2024)**
  Price: €132 545; Quantity that got ordered (Demand): 1206 tons; DDTs: 45.

The DDTs is the processing in the management system of any document that certifies the execution of the supply (goods), the execution of a service or a work (certificate of regular performance of service or employment relationship). We divide the orders in 3 categories based on their price, since depending on how costy an order is it takes more time to process it. We assign a 1 to all orders that are below 40000€, since it takes 1 hour to process such an order. We give a 2 to all orders that range from 40000€ to 140000€, because it takes 2 hours for an order this size. Eventually, we allocate a 3 to all orders above 140000€, since 3 is the number to process this big orders. Some orders have also some additional shipping cost, e.g. the first order and the last two orders have these extra shipping cost respectively; 480€, 600€ and 480€. These numbers are essential for calculating the product specific ordering cost s_i.

$$s_i \;=\; d_i\, w\, t_i \;+\; c_i^{ship}, \qquad i = 1, \dots, k,$$

d_i	number of DDTs for item i
w	hourly wage of an administrative job in South Tyrol, $w = 22$
t_i	processing time per order for item i (in hours)
c_i^{ship}	additional shipping cost for item i ($c_i^{ship} = 0$ when not applicable)

The unit purchase cost C_i of each item is obtained by dividing the total invoiced price of the order by the quantity supplied:

$$C_i \;=\; \frac{P_i}{D_i}, \qquad i = 1, \ldots, k,$$

C_i unit cost of item i (€ per unit)

P_i total price paid for the order of item i (€)

D_i annual demand of product i (units, kg, L, tons ...)

k number of distinct items

EcoCenter was unable to supply a single definitive figure for the fixed order cost S. To illustrate the impact of that parameter we evaluate the Joint Replenishment Model under three plausible values suggested by management:

$$S \in \{\, 1000 \;,\; 750 \;,\; 500 \,\}.$$

Unless stated otherwise, the annual holding-cost h is taken as [17]

$$h \;=\; 0.20 \quad (20\%)$$

based on the study conducted from the University Professor Paul Durlinger. In his study they found an average inventory costs of 22 percent among 50 companies during the HBO Minor Inventory Management. For the sake of simplicity we round it down to 20 percent.
To sum up the information that we have:

Order description	**Price (€)**	**Demand (t)**	**DDT**	s_i **(€)**	**Hours**	**Unit cost (€)**
Open order – liquid inorganic de-phosphating mix (Al/Fe)	39 240	363.38	16	832	1	107.99
Order – phosphoric acid	10 400	1.30	1	22	1	8 000.00
Order – ferric chloride 39–40 %	11 070	50.46	2	44	1	219.38
Open order – ferric chloride solution 39–41 % (ATO plants)	364 000	1 000.00	28	1 232	2	364.00

Order – liquid inorganic de-phosphating mix (2024–2025)	134 960	1 205.00	50	2 800	2	112.00
Open order – liquid inorganic de-phosphating mix (Fe/Al, plants 2024)	132 545	1 206.00	45	2 460	2	109.90

With the fixed order cost S=1000€, the optimal number of consolidated orders per year is determined by the following expression:

$$n^* = \sqrt{\frac{\sum_{i=1}^{6} D_i \, h \, C_i}{2\Big(S + \sum_{i=1}^{6} s_i\Big)}} = \sqrt{\frac{138\,443}{16\,780}} \approx \mathbf{2.87}.$$

After finding the optimal joint-order frequency n^*, the economic order quantity for every product is obtained simply by dividing its annual demand by the frequency n^*:

$$EOQ_i = \frac{D_i}{n^*}, \qquad i = 1, \dots, 6.$$

Applying n^*=2.87 to the six products supplied by S.EC.AM. SRL yields:

$$(EOQ_1, \dots, EOQ_6) = (126.51,\ 0.45,\ 17.57,\ 348.15,\ 419.52,\ 419.86).$$

This means that in 2025 ECoCenter should order 3 times from S.EC.AM. SRL and each order should include the optimal order quantity EOQ_i of each product. Thus, instead of placing a separate order for every product as was done in 2024, EcoCenter would switch to three joint orders per year, each containing all 6 products. In other words, the company would issue purchase orders three times fewer than last year while still meeting the same demand.
With the holding cost fixed at $h = 0.20$ we re-evaluate the joint-replenishment formula for the two alternative values of the order cost S.

$$S = 750 \ : n^* = 2.92, (\mathrm{EOQ}_i) = (124.61,\ 0.45,\ 17.30,\ 342.92,\ 413.22,\ 413.56);$$

$$S = 500 \ : n^* = 2.96, (\mathrm{EOQ}_i) = (122.68,\ 0.44,\ 17.04,\ 337.61,\ 406.82,\ 407.16).$$

Under all three scenarios studied ($S = 1\,000$, 750, and 500 €), EcoCenter should place three consolidated orders per year; each order must contain the item-specific quantities EOQ_i listed above for the chosen value of S.

Pseudocode of Joint Ordering EOQ Model
For each item $i = 1$ to k:

- Annual demand D_i
- Total order price P_i
- Number of DDTs d_i
- Processing time t_i (based on price category)
- Additional shipping cost c_i^{ship}

Hourly wage w, fixed order cost S, holding cost rate h
each item i Compute unit cost: $C_i \leftarrow P_i/D_i$
Compute item-specific ordering cost: $s_i \leftarrow d_i \cdot w \cdot t_i + c_i^{ship}$
Compute numerator: $NUM \leftarrow \sum_{i=1}^{k} D_i \cdot h \cdot C_i$
Compute denominator: $DEN \leftarrow 2 \cdot \left(S + \sum_{i=1}^{k} s_i\right)$
Compute optimal joint ordering frequency: $n^* \leftarrow \sqrt{NUM/DEN}$

For each item i
Compute EOQ: $EOQ_i \leftarrow D_i/n^*$
n^* and EOQ_i for each item $i = 1, \ldots, k$

4.2.3 Sensitivity Analysis

Sensitivity Analysis is a tool used in financial modeling to analyze how the different values of a set of independent variables affect a specific dependent variable under certain specific conditions. In general, sensitivity analysis is used in a wide range of fields, ranging from biology and geography to economics and engineering. Sensitivity Analysis is essential in deriving insights from decision-support models in a wide range of applications [18]. In other words, Sensitivity analysis is a "what-if" check that asks: If my input numbers are a little bit wrong, does my decision change in a big way?
For the joint-replenishment EOQ for EcoCenter, the two inputs that drive the answer most are:

- The fixed ordering cost S, which is the costs spent regardless of order amount each time an order is placed. This covers expenses for order processing, shipping, and handling. Since it is a fixed cost per order, the amount ordered has no bearing on it.

- The annual holding cost rate h, which is the total cost of holding one unit of inventory for one year. It includes a number of expenses such as insurance, storage, and the cost of capital invested in the inventory.

To ensure that the joint-ordering EOQ proposal for EcoCenter is reliable, we ran a two-way sensitivity analysis. First, we changed the fixed ordering cost S across the range suggested by the management department of EcoCenter—€1000, €750, and €500—while keeping the annual holding rate at the base value of h=20%, since it is the most plausible annual holding cost rate for a company [17]. The optimal order frequency n^* shifted only slightly, from 2.87 to 2.92 to 2.96 orders per year, so our practical recommendation did not change: EcoCenter should regardless group its six different purchase orders into three joint orders, instead of one order per component. Next, we took S=1000€ and tested wider holding-rate assumptions (h=15%, 20%, 25%, 30%). Within the 15–25% range, the model again suggested three orders per year; only at the 30% holding cost rate did the order frequency rise to four. The EOQ lot sizes for the purchase order of the Fe/Al mix decreased from 146 tons to 103 tons as holding cost increased, showing that inventory quantities scale predictably with holding cost. As EOQ increases, inventory carrying costs and average inventory increases [19]. Because neither cost dimension pushed the plan beyond three consolidated orders, we can be confident that EcoCenter can replace six separate 2024 purchase orders with three larger, coordinated orders in 2025.
To visualize how the optimal joint-order frequency n^* of the supplier S.EC.AM SLR responds to different fixed ordering costs S and different annual holding cost rates h a scenario grid was assembled in Excel. Down the left we listed every combination of fixed order cost S (€500,€750,€1000) and on the right side all annual holding-rate h (15%,20%,25%). The holding-rate scenarios are plotted as series, as they appear in 3 different colors. We set the horizontal axis to the calculated n^* figures so that each bar's position shows the order frequency that the joint-replenishment formula recommends for that cost scenario.

The result, shown above, makes the sensitivity story immediately clear: moving from €1 000 to €500 per order or from a 15% to a 25% holding rate shifts n^* from roughly 2.5 up to just above 3.3.

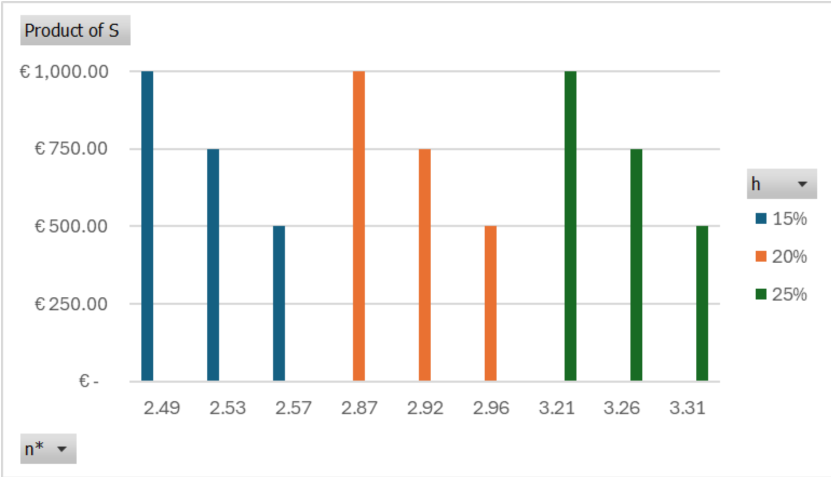

Figure 9: Sensitivity Analysis of the Supplier S.EC.AM SRL (n^* is the optimal number of joint orders per year (order frequency, h is thenannual holding-cost rate (% per year) and S is the fixed order cost per joint replenishment)

4.3 Total Costs

In EOQ (Economic Order Quantity) calculations, total costs refer to the sum of both holding costs and ordering costs.
Note that TC(Q) = annual cost of placing orders + annual purchasing cost + annual holding cost [5] hence the Total cost formula looks like this

$$\mathrm{TC}(Q) = C\,D + \frac{S\,D}{Q} + \frac{h\,C\,Q}{2}$$

Unit Purchasing Cost is simply the variable cost associated with purchasing a single unit. Ordering (Setup) Costs are the costs you pay every time you place an order or start making items yourself, no matter how big or small the order is. For example, filling out paperwork, running a machine setup, or hiring staff to process the order all count here. Holding (Carrying) Cost is the cost to keep one unit of inventory in stock for a certain period (usually one year). It covers things like rent for the storage space, insurance, taxes on your inventory, and any losses if items spoil, get stolen, or become outdated.
In the joint ordering policy the total cost function consists in total ordering costs added to the total holding costs

$$TotalCost = n^* \left(S + \sum_{i=1}^{k} s_i \right) + \sum_{i=1}^{k} \frac{h\,C_i\,Q_i}{2}$$

The variables used in this cost function coincide with those defined for the optimal ordering frequency function in Subsection 4.2.2, “EOQ Model Execution”. Applying this formula to the Supplier S.EC.AM SLR and using the values obtained through the joint ordering model like $n^* = 3$, we get in €

$$\mathrm{TC}_{S.EC.AM.\ SRL} = 25\,170 + 24\,097.2 = 49\,267.2$$

For the fixed order cost S we used 1000€.
If we would apply the same costs function but use the values of 2024, hence $n^* = 6$, we would get just for the ordering costs part 50340€. The EOQ joint-ordering policy suggests placing just three consolidated orders per year, cutting the ordering expenses roughly in half.

5 Results

In this chapter we want to answer the sixth sub research question: In what ways can the developed inventory model be used for the benefit of the company and how can it be integrated into EcoCenter's operations?

5.1 Application of the Model

After validating the joint-ordering logic on S.EC.AM. SRL, the same procedure was applied to each remaining supplier on the Type A list and to the most relevant Type B supplier that still drives a material share of annual spend. The company requested to put more focus on the Type B suppliers that sell chemicals as their annual demand is constant. For every line of the master table (see Appendix B) the annual demand D_i, unit cost C_i, product-specific handling cost s_i and the fixed set-up charge S were fed into the joint-replenishment formula. Three plausible values of S (€1000, €750, €500) were again utilized, while the reference holding rate was kept at $h = 0.20$.
It is worthy to mention that when applying the joint replenishment EOQ model to low-volume service suppliers (those from which EcoCenter makes only one or two purchases per year) the formula consistently recommends increasing annual purchases by one. For instance, suppliers such as Calce Barattoni Spa, Thermo Fisher Scientific Spa, Tillmanns Spa, Norchem Spa, Biomar Srl, VTA Austria and Norit Italia Spa, all of which EcoCenter purchased from only once or twice in 2024, show a suggested increase in purchase frequency. However, this is contrary to EcoCenter's goal of reducing purchase frequency. Therefore, the conclusion is that the joint replenishment EOQ model should not be applied to low-volume service suppliers with fewer than three annual purchase orders.
In the case of ERDBAU GmbH, we observe that the supplier has two large and three small orders, with the smaller orders mainly related to services such as transport and maintenance. The large orders, however, involve significant supplies such as the cleaning of the white water channel and excavation work at the leachate plant. When applying the joint replenishment EOQ model, combining all five orders into one joint order results in an optimal order frequency (n*) of approximately 3.6. On the other hand, if we combine just the three smaller orders they result in a optimal order frequency of approximately 0.9. To optimize the ordering process, it is recommended to join the three smaller orders while keeping the two larger orders separate. By doing so, the frequency of orders is reduced to three annual purchase: one for the three smaller orders combined, and one each for the larger orders.
We have a similar case for Biomontan Produktions und Handels GMBH, where EcoCenter places three orders per year. These orders include two Type 1 orders,

both having an annual demand of less than €40,000. The third order is a Type 2 order, a larger order of €139,000. When applying the joint replenishment EOQ model, it would be more efficient to combine the two Type 1 orders into a single order. This reduces the number of orders for these two products. By consolidating the two Type 1 orders, EcoCenter can reduce the total annual purchases to two orders per year—one joint order for the two Type 1 items and one separate order for the Type 2 item. If all three orders are combined into one joint order, the result would be a frequency of three orders (n*=3.05) per year, which does not provide any significant reduction in the number of orders compared to the original situation. As a result, it is more efficient to combine just the two Type 1 orders.
The Joint Replenishment EOQ Model works particularly well for suppliers from which EcoCenter buys at least three times a year, especially when each order is categorized as a Type 1 order, meaning it has a value of less than €40,000. In such cases, the model allows EcoCenter to optimize its ordering process by consolidating orders, which helps reduce administrative costs and increase order efficiency. A few examples are the suppliers of chemicals with steady demand, such as SNF Italia SRL Socio Unico, Sartori Sergio SRL, and Merkur Chemical SRL. EcoCenter bought from them 4, 4, and 5 times respectively in 2024. By applying the model, the number of annual orders was reduced to 2 and 3 per year. Another example is Elettro S.E.A. SRL, where EcoCenter made 7 purchases in 2024. By applying the model, the order frequency would decrease to 2.74, which rounds to 3 orders per year. Even though this supplier mainly sells repair parts for equipment breakdowns, the model remains useful, as EcoCenter can already predict the required quantity of each part for future repairs.
Considering all this, the Joint-Replenishment EOQ model proves to be an effective tool, especially for suppliers with at least four orders a year, for lowering order frequency and cutting process costs. For small volumes purchases, however, single orders remain the better choice. Overall, the model gives EcoCenter a solid basis for continually refining its purchasing strategy and responding flexibly to shifting demand.

5.2 Findings

The Key suppliers of EcoCenter are 41: 27 Type A Suppliers and 14 Type B Suppliers that provide EcoCenter with chemicals. When we applied the joint replenishment EOQ model to the 41 key suppliers, the number of purchase orders dropped from 73 in 2024 to 57 in 2025. That is a cut of 16 orders, or about 22%. EcoCenter bought over the last 3 years from 1378 suppliers in total. For most of these suppliers, EcoCenter used to buy in large scale in the years 2022 and 2023, but already in 2024 the numbers of purchases dropped drastically. The EOQ model does not apply to many of these suppliers, where Ecocenter orders once, twice, or three times a year, because EcoCenter has already achieved an ideal ordering frequency. If we assume the long-tail suppliers change little, but the high-volume ones keep the pattern we just saw, it is realistic to expect the whole system to end up with roughly 14% fewer orders overall. Even a ten-percent cut means about 140 fewer purchase forms each year, which saves many hours of staff time and reduces the risk of last-minute rush orders.

Metric	**2024**	**2025**
Total orders from 41 suppliers	73	57
Orders saved	$73 - 57 = 16$	
% reduction	$100 - \frac{57 \times 100}{73} = 21.92\%$	

Table 6: Order reduction after applying EOQ to the 41 suppliers.

If the same logic is rolled out to *all* 1 378 suppliers, we expect a smaller but still useful reduction.

Suppliers	**Share of all orders**	**Observed/expected cut**
Type A	$\approx 65\%$	22%
Type B	$\approx 25\%$	10%
Type C	$\approx 10\%$	2%

Applying a simple weighted average gives the likely reduction:
$0.65 \times 22\% + 0.25 \times 10\% + 0.10 \times 2\% = 14.3\%$
Approximately 140 fewer orders can be placed annually due to a 14% reduction among 1378 suppliers, which let us achieve the goal set by Ecocenter to decrease the annual number of purchases to 900.
In the Appendix in the subsection Ordering Policy 6.5 a table illustrates how much EcoCenter should order from each supplier in 2025.
By testing the joint-ordering EOQ rules on the 41 most-active suppliers, we cut their purchase orders from 73 in 2024 down to 57 for 2025; 16 fewer forms, a drop of almost 22 percent. This calculation assumes that the demand in 2025 remains similar to that observed in 2024. Although this assumption simplifies the forecast, it is justified because 2024 was the first year after major purchasing changes, and the available data best reflects the company's current structure and needs.
If we apply the same logic to EcoCenter's whole supply base (1378 suppliers in total), the "Type A" suppliers should fall by about 22 %, the "TypeB" by roughly 10 % and the small "Type C" by only 2 %. When we weight these cuts by the share of orders each group makes, the overall fall works out to about 14 %. So a

14 % fall means roughly 900 fewer orders every year. That meets the company's target. Thanks to the joint-EOQ ordering plan, EcoCenter hits its goal; about 900 fewer purchase orders a year.

6 Conclusion and Outlook

In this chapter, we conclude how we have answered our main research question and make recommendations on how the processes can be enhanced by gathering additional data and further research. By doing that we aim to answer the final sub-research question: How can the inventory model be improved and applied in the future?

6.1 Conclusions

Following the sub-research questions based on the CRISP-DM methodology, we have answered the main research question: Which optimization techniques and models can be applied to reduce the number of orders while ensuring stock availability for essential items? Thanks to our approach we managed to decrease the number of annual purchases.
To focus efforts on the most critical suppliers, we began by conducting an ABC analysis. This classification helped us identify which suppliers contribute most to total purchasing value. We then applied the chosen inventory management model primarily to Type A and the most important Type B suppliers. We looked at five ways to plan orders: Wagner-Whitin (dynamic lot-sizing), Stochastic (s,S) with continuous review, Periodic (R,S) review policy, Economic Order Quantity (EOQ) and an extension of the EOQ Model; the joint-ordering policy. For each inventory management model, we checked how well it would: Lower the total number of orders per year, Prevent stockouts of critical supplies, Keep turnover healthy (so inventory isn't sitting too long), Give us predictable order-cycle times.
Our aim was to develop a simple and useful inventory model that will help EcoCenter decrease annual purchases while minimizing costs. We started by analyzing the current method of decision making as well as the historical data available. EcoCenter's purchasing strategy was to order whenever something was missing (standard orders). In other words, what's needed, when it's needed, and how much is needed. Due to bureaucratic changes the company takes longer to process their orders. The current purchasing system is explained in detail in Section 2.1 . We analyzed the data and we explored suitable inventory management models by conducting a literature search to get an understanding of what methods match the characteristics of the data. Testing a wide range of models provided us with further insights on the characteristics of the data and allowed us to compare what the ideal model is to

use in the future as well. The selection of the best method was made based on the KPI values of each model for the testing set. We chose to use the extension of the Economic Order Quantity Model, which is the joint-ordering policy with the ABC classification. The method is simple but fits the data well and provided accurate results. Over time, as we collect more data, these numbers should become more accurate. The more data we gather the more we can expect the model to improve. For now, it was of high importance to develop a model with higher accuracy and more automation than the current method. Orders annually, stock outs, turnover, and order-cycle time are the four KPIs that we will continue to monitor and adjust our holding cost estimates as necessary. As explained in Subsection 4.4 Findings by applying the developed model we achieve roughly a reduction of 14% of annual purchase orders in 2025, which made us achieve EcoCenter goal to reduce their annual purchases to 900 per year.In addition to reducing orders, it also positively impacted other key performance indicators (KPIs):

- Stockouts: By focusing the model on critical Type A and Type B suppliers, and keeping order frequencies aligned with actual demand levels, the model helps ensure that essential materials remain available, even with fewer orders.
- Inventory Turnover Rate: The EOQ-based lot sizes balance ordering and holding costs, avoiding excessive inventory buildup while still reducing the number of transactions.
- Order Cycle Time: Fewer but better-planned joint orders simplify the bureaucratic approval process, allowing faster completion of purchases and less administrative burden.

In short, the EOQ model with ABC Analysis gives EcoCenter a simple, transparent, and data-driven way to cut annual purchases.
In the Appendix, in the subsection Review of the sub research questions 6.6 a detailed table can be found, where it is explained, where each sub-research question got answered throughout the report.

6.2 Recommendations

In this section, we discuss how the reduction of annual purchases impacted the annual number of DDTs and Invoices, as well as discuss how the model accuracy can be improved in the future by gathering additional data for further analysis.

Even though EcoCenter successfully cut the number of purchase orders in 2024 by about one thousand compared to 2023, the total count of delivery notes (DDTs) and invoices stayed nearly the same. This suggests that while orders were consolidated into larger batches, the underlying volume and frequency of deliveries remained unchanged. EcoCenter should start keeping detailed records of all the costs involved in a purchase order. In particular, it would help to track the fixed cost of placing each order (for example, the time spent by staff on paperwork, any mailing or electronic submission fees).

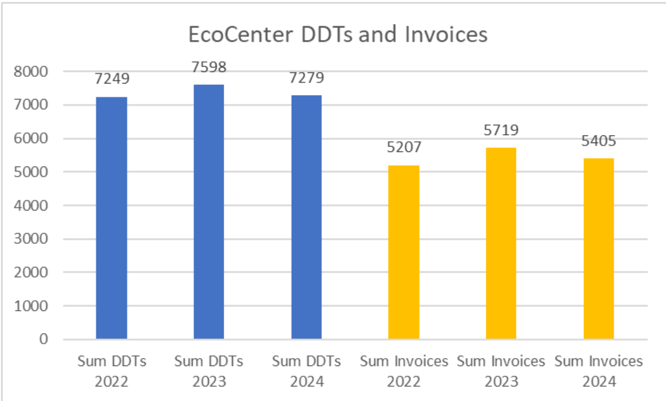

Figure 10: Total number of annual DDTs and Invoices over the years 2022, 2023 and 2024

In conclusion, we recommend EcoCenter to give their best to monitor their annual expenses more accurately. The model accuracy would increase if real fixed ordering cost and the corresponding annual holding cost would be utilized, instead of the assumed values based on literature. In the long run, tracking both fixed and holding costs will make the purchasing process not only simpler but also more cost-effective.

6.3 Limitations

Some of the assumptions employed in this study may constrain the models; more research might be done to address them. We go over the assumptions that were made, the reasons behind them, and how this could potentially be improved upon in the future.

For inventory management models, we emphasized the benefits of simplicity over complexity to ensure that the model can be smoothly utilized in the future. A limitation lies on the fact that, since EcoCenter is a public company, it does not have fixed order costs and fixed annual holding costs. This is the reason why assumptions based on literature were made and the assumptions reflect reality for the majority of companys. We assumed a single reference holding-cost rate of h 20% [17] and three fixed ordering costs S (€1000, €750, €500) across all suppliers, even though actual ordering costs differ between inert chemicals, spare pumps and laboratory reagents.

The company believed that years prior to 2021 were unimportant for the research, even though data for 2021 and earlier was accessible. For approximate background averages, we utilize the data from 2022 and 2023 due to the "order-at-once" method of those years. As the bureaucratic reforms were implemented, many things have evolved and changed. Order timeliness, the average order size, have all changed. Thus, after discussing with the supply chain manager, we can conclude that data from 2022 and 2023 is not fully representative of the current situation. This is the reason why, for demand, we only used data from 2024. The downside is that the model now covers just one full year, so when we run out of stock or use an emergency delivery, we have to guess what the “real” demand was. If we kept a more detailed log of these events, we could use more advanced methods, including machine-learning models, to spot patterns across many years.
To sum up, more research can assist the model become more exact, which could result to an improvement in accuracy. Though they may be viewed as research constraints, the assumptions were made for convenience and because they frequently represented reality.

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7 Appendix

7.1 Research Design per sub-question

Research question	**CRISP-DM phase**	**Research type**	**Research population**	**Research strategy**	**Activity plan**
How does the current purchasing system operate at EcoCenter?	Business Understanding	Exploratory	EcoCenter supervisor	Qualitative	Talk with EcoCenter's purchasing team to understand current processes and challenges
How is the data structured, and what insights can be drawn from an initial analysis?	Data Understanding	Exploratory	EcoCenter purchasing data 2022–2024	Quantitative	Access historical data, clean and check data, search for patterns and trends
How should the data be cleaned and structured for effective analysis?	Data Preparation	Exploratory	EcoCenter purchasing data	Quantitative	Remove errors, group data by supplier and material type
Which models are best suited to minimize annual purchases?	Modeling	Descriptive	Literature on inventory models	Qualitative	Study academic articles and models, review theory for inventory optimization
What is the most suitable inventory model based on the available data and objectives of EcoCenter?	Modeling	Explanatory	Literature, EcoCenter data	Qualitative & Quantitative	Test models, compare results with KPIs, recommend best model for EcoCenter

In what ways can the developed inventory model be used for the benefit of the company and how can it be integrated into EcoCenter's operations?	Evaluation & Deployment	Explanatory	EcoCenter supervisor	Qualitative & Quantitative	Check how well the model works, prepare step-by-step guide for implementation
How can the inventory model be improved and applied in the future?	Evaluation	Descriptive	EcoCenter supervisor	Qualitative	Analyze results, explain how EcoCenter can keep using the model in the future

7.2 Comparison of Inventory Management Models

Red indicates that the forecasting method does not meet the criteria, yellow indicates that it meets the criteria adequately, and green indicates that the criteria is fully met.

KPI/Model	**Wagner-Whitin**	**Stochastic (s,S)**	**(R,S) Model**	**EOQ**	**Joint-EOQ**
Total number of orders per year	Fully optimizes via dynamic lot-sizing	Reactive, not optimized	Periodic but not optimized	Same square-root logic; cuts orders to cost-minimum level	Bundles many items; achieves the fewest POs overall
Stock-out frequency	Assumes no shortages allowed	Explicit reorder point & safety stock	Service-level–based review	Needs added buffer because model is deterministic	Same as EOQ; joint orders still require a safety buffer

Inventory turnover rate	Minimises cost, but not turnover specific	Focuses on levels, not turnover	Tied to review interval only	Same cost balance; gives efficient turnover	Adds setup-cost sharing → still optimal, sometimes higher turnover
Order-cycle time	Ignores lead-time dynamics	Models lead time L explicitly	Fixed review	Same zero-lead-time assumption	Same as EOQ (joint batches still planned on zero-lead-time basis)

Table 8: KPI comparison of inventory models for EcoCenter

7.3 ABC Analysis Execution

Sum of Imponibile	Column Labels						Running cumulative		
Row Labels	2022	2023	2024	Grand Total	Grand Total	% of Grand Total		ABC Type	Type A:
PROV.AUTON.BZ - RIP. 29 AGENZIA PROVINCIALE PER L'AMBIENTE E LA TUTELA DEL CLIMA	7052946.4	18505202.6	6566820	32124969	32124968.98	23.05%	23.05%	A	27
ALPERIA SMART SERVICES SRL	6013803.99	3389579.08	1587405.15	10990788.2	10990788.22	7.89%	30.94%	A	
ATZWANGER AG	926897.01	239061.75	5059897.15	6225855.91	6225855.91	4.47%	35.41%	A	Type B:
BIOGARDA SRL	1865415.46	2273302.39	1628767.2	5767485.05	5767485.05	4.14%	39.54%	A	161
EVERGREEN ITALIA SRL	1510837.88	1532294.69	1005401.43	4048534	4048534	2.91%	42.45%	A	
UNIONBAU AG	343013.11	1163877.23	2530440.13	4037330.47	4037330.47	2.90%	45.35%	A	Type C:
TILLMANNS SPA	517950.8	1069473.2	1314740.8	2902164.8	2902164.8	2.08%	47.43%	A	1190
ERDBAU GMBH	93686.2	413602.3	1446963.5	1954252	1954252	1.40%	48.83%	A	
ALAN SRL	664590.3	694560.57	524896.85	1884047.72	1884047.72	1.35%	50.18%	A	Total
MARTIN AG FÜR UMWELT- UND ENERGIETECHNIK	1111874.25	553471.5	192453.9	1857799.65	1857799.65	1.33%	51.52%	A	1378
ELETTRO S.E.A. SRL	317470.49	113508.77	1264015.22	1694994.48	1694994.48	1.22%	52.73%	A	
CENTRO RISORSE SRL	530977.78	495534.54	654694.1	1681206.42	1681206.42	1.21%	53.94%	A	
ECOROTT SRL	485601.31	482051.53	663851.84	1631504.68	1631504.68	1.17%	55.11%	A	
BRUNNER & LEITER GMBH		334087.07	1247564.25	1581651.32	1581651.32	1.13%	56.24%	A	
BIOMONTAN PRODUKTIONS UND HANDELS GMBH	185024.08	633706.22	629843.24	1448573.54	1448573.54	1.04%	57.28%	A	
SOC. CHIMICA EMILIO FEDELI SPA	503577.14	366612.41	294520.86	1164710.41	1164710.41	0.84%	58.12%	A	
S.EC.AM. SRL	164615.99	379935.41	540338.84	1084890.24	1084890.24	0.78%	58.90%	A	
MARTIN GMBH	358765.48	367761.92	309184.1	1035711.5	1035711.5	0.74%	59.64%	A	
THERMO FISHER SCIENTIFIC SPA	599156.9	65543.31	293126.27	957826.48	957826.48	0.69%	60.33%	A	
ROTTENSTEINER G.M.B.H.		145692.01	808509.05	954201.06	954201.06	0.68%	61.01%	A	
MOKESA AG	404039.46	388056.82	37478.4	829574.68	829574.68	0.60%	61.61%	A	
LAI SRL	450735	325147.4	8561.96	784444.36	784444.36	0.56%	62.17%	A	
ARA PUSTERIA SPA	322718.04	91329	347538	761585.04	761585.04	0.55%	62.72%	A	
FERTITALIA S.R.L.	233050.81	328992.71	173912.46	735955.98	735955.98	0.53%	63.25%	A	
SCHÄFER E.TECHNIK U.SONDERMASCHINEN GMBH			731800	731800	731800	0.53%	63.77%	A	
JÜNGER+GRÄTER SCHWEIZ GMBH			678068.88	678068.88	678068.88	0.49%	64.26%	A	
BEZIRKSGEMEINSCHAFT PUSTERTAL - COMUNITÀ COMPRENSORIALE VALLE PUSTERIA			666893.7	666893.7	666893.7	0.48%	64.74%	A	
STE BAU SRL	586439.73	15402.55	47438.62	649280.9	649280.9	0.47%	65.20%	B	
KANADEVIA INOVA SERVICE AG			638941.5	638941.5	638941.5	0.46%	65.66%	B	
AVESCO AG	396348.95	237245.26		633594.21	633594.21	0.45%	66.11%	B	
BEZIRKSGEMEINSCHAFT BURGGRAFENAMT - COMUNITA' COMPRENSORIALE BURGRAVIATO	8846.57	13321.24	601131.23	623299.04	623299.04	0.45%	66.56%	B	
VIENNA SERVIZI SRL	140312.5	220411.95	257272.33	617996.78	617996.78	0.44%	67.01%	B	

Figure 11: Screenshoot of the Excel Spreadsheet of the Execution of the ABC Classification for EcoCenter's supplier

7.4 Ordering Policy

From the table below, we can see how often Ecocenter should order from each Type A (and the most important Type B) supplier in 2025.

Supplier	2024	2025
ELETTRO S.E.A. SRL	7	3
S.EC.AM. SRL	6	3
ERDBAU GMBH	5	3
MERKUR CHEMICAL SRL	5	3
SNF ITALIA SRL SOCIO UNICO	4	2
SARTORI SERGIO SRL	4	2
BIOMONTAN PRODUKTIONS UND HANDELS GMBH	3	2
SOC. CHIMICA EMILIO FEDELI SPA	3	3
MARTIN GMBH	3	3
LAI SRL	3	3
VTA AUSTRIA GMBH	3	3
THERMO FISHER SCIENTIFIC SPA	2	2
ALPERIA SMART SERVICES SRL	2	2
ARA PUSTERIA SPA	2	2
CENTRO RISORSE SRL	2	2
SCHÄFER E. TECHNIK U. SONDERMASCHINEN GMBH	2	2
NORCHEM SPA	2	2
BIOMAR SRL	2	2
NORIT ITALIA SPA	2	2
TILLMANNS SPA	1	1
MARTIN AG FÜR UMWELT- UND ENERGIETECHNIK	1	1
STE BAU SRL	1	1
EVERGREEN ITALIA SRL	1	1
PROV. AUTON. BZ – Agenzia Provinciale per l'Ambiente	1	1
BIOGARDA SRL	1	1

ALAN SRL	1	1
ECOROTT SRL	1	1
JÜNGER + GRÄTER SCHWEIZ GMBH	1	1
CALCE BARATTONI SPA	1	1
FORNACI CALCE GRIGOLIN SPA	1	1

7.5 Review of the sub research questions

Sub-Research Question	**Approach / Description**	**Chapter**	**Section / Sub-section**
1) How does the current purchasing system operate at EcoCenter?	Interviews with Supply Chain Manager and process walk-through	2: Current Method and Data Analysis	2.2: Current purchasing system
2) How is the data structured, and what insights can be drawn from an initial analysis?	Inventory of available files & trend and seasonality analysis	2: Current Method and Data Analysis	2.3.1: Data Availability and Limitations
3) How should the data be cleaned and structured for effective analysis?	Data cleaning, grouping by material and supplier	2: Current Method and Data Analysis	2.3.2: Data Reliability & 2.3: Order Patterns
4) Which models are best suited to minimize annual purchases?	Literature review comparing dynamic lot-sizing, stochastic, (R,S), EOQ+ABC, ML	3: Theoretical Framework	(entire chapter)

5) What are the most suitable inventory models based on the available data and objectives, and how can they be applied to EcoCenter?	KPI evaluation and model application	4: Performance Execution & Evaluation	(entire chapter)
6) In what ways can the developed inventory model be used for the benefit of the company and how can it be integrated into EcoCenter's operations?	Implementation steps of the model and ordering policy examples	5: Results	5.1: Aplication of the Model & 5.2: Findings
7) How can the inventory model be improved and applied in the future?	Conclusions, limitations, and future data-gathering recommendations	6: Conclusions and Outlook	6.1: Conclusions & 6.2: Recommendations

7.6 EOQ Execution in Excel

These three pictures below document the joint-replenishment EOQ steps, from raw data through sensitivity analysis, so that any reader can follow or reproduce our calculations in full. These pictures show the applied joint ordering policy for four Type A suppliers with the fixed order costs S=1000€, S=750€ and S=500€, while the annual holding costs is 20%.

Supplier	Annual Purchase Orders	Ordertype	Taxable amount of the order (€)	Demand (kg) or (pieces) or (T)	Number of DDT	P
BIOMONTAN PRODUKTIONS UND HANDELS GMBH	3	Nitrillife	2460	4000	1	
		Supply of various chemical products for industrail waste	139000	134100	13	
		Polyelektrolyten	6139.5	1050	1	
THERMO FISHER SCIENTIFIC SPA	2	Spare parts of ICP equipment	1252	4	1	
		Exploris GC 60k MS/MS	196481.99	2	1	
ELETTRO S.E.A. SRL	7	Electrical works replacement classifier	9873.14	370	1	
		Urgent refurbishment of the Scrubber electrical panel (due to da	31300	3	1	
		Electrical works for the adaptation of light and FM electrical pan	6890.02	287	1	
		Installation of the central plant controller	22638.04	8	1	
		Preventive maintenance contract for the years 2024-2025 for the	3610	4	1	
		Electrical works installation of wallbox and adjustment of pits	7500	3	1	
		OfficeOrdinary maintenance 2024 of the medium voltage cabins	4850	1	1	
S.EC.AM. SRL	6	Open order for the supply of liquid inorganic defosfating mixed	39240	363.38	16	
		Order for the supply of phosphoric acid	10400	1.3	1	
		Order for the supply of ferric chloride 39-40%	11070	50.46	2	
		Open order for the supply of ferric chloride in solution 39-41% fo	364000	1000	28	
		Order for the supply of liquid inorganic defosfating mixed alumi	134960	1205	50	
		Open order for the supply of liquid inorganic defosfating mixed i	132545	1206	45	

Product specific ordering cost *si*	Number of hours worked per orde	Unit Cost (€)	Fixed Order Cost S (€)	Annual holding cost h	Optimal n* policy	Joint orders n*
22	1	0.62	1000	20%	1	0.91
572	2	1.04	1000	20%	2	keep the order
22	1	5.85	1000	20%	1	0.91
22	1	313.00	1000	20%	1	3.46
632	2	98241.00	1000	20%	3	not apply EOQ
22	1	26.68	1000	20%	1	2.74
22	1	10433.33	1000	20%	1	
22	1	24.01	1000	20%	1	
22	1	2829.76	1000	20%	1	
22	1	902.50	1000	20%	1	
22	1	2500.00	1000	20%	1	
22	1	4850.00	1000	20%	1	
832	1	107.99	1000	20%	1	2.87
22	1	8000.00	1000	20%	1	
44	1	219.38	1000	20%	1	
1232	2	364.00	1000	20%	3	
2800	2	112.00	1000	20%	2	
2460	2	109.90	1000	20%	2	

Optimal EOQ	Total EOQ joint (kg)	Toal EOQ joint (pieces)	2nd option fixed order costs S(€	Joint orders n*	Optimal EOQ	Total EOQ joint (kg)
4407.31	5564.23		750	1.04	3843.56	4852.49
keep the order			750		keep the order	
1156.92			750		1008.93	
		0.00	750	3.75	1.07	
		0.00	750		0.53	
135.02		136.00	750	3.10	119.50	120.00
1.09		2.00	750		0.97	1.00
104.73		105.00	750		92.69	93.00
2.92		3.00	750		2.58	3.00
1.46		2.00	750		1.29	2.00
1.09		2.00	750		0.97	1.00
0.36		1.00	750		0.32	1.00
126.51	1332.05		750	2.92	124.61	1312.06
0.45			750		0.45	
17.57			750		17.30	
348.15			750		342.92	
419.52			750		413.22	
419.86			750		413.56	