Forecasting Portuguese ports throughput (2021-2030)

Dumitru Trofim

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Examination Committee:

President: Professor Ângelo Teixeira

Supervisor: Professor Tiago A. Santos

Members: Professor Manuel Ventura

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DECLARATION:

I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Signature

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ABSTRACT:

Now more than ever, ports require reliable and plausible forecast of the cargo throughput which is likely to be expected for the foreseeable future. The development of any port is tightly linked to its performance, which in turn directly depends on the volume of clients which is able to attract and serve. Port infrastructure and equipment are two of the major costs which are associated to the management process of these ports. The role of cargo throughput forecasts is of extreme importance for appropriately planning the development of the port. A good forecast study can lead to a better performance and readiness in terms of capacity of the port when dealing with future cargo trends and evolutions.

The objective of this thesis is to develop plausible forecasts of cargo throughput in the main Portuguese ports. For this purpose, quantitative techniques such as linear regression and extrapolation of existing trends, as well as qualitative assessments of cargo evolution, are applied. The data concerning cargo throughput, necessary for supporting the analysis, has been gathered from several sources, such as Instituto Nacional de Estatística (INE) and Port Authority's archives. The cargoes are split into different types as well as different ports. Time series have been collected, ranging between 16 and 42 years in length. Gross domestic products (GDP) of relevant nations have also been collected from OECD and the IMF, as required for the regression analyses.

In general, the Portuguese port system has been going through a period of growth in the last two decades, entering a negative trend more recently in 2017. Containerized cargo has been growing until 2018. In turn, general cargo has been relatively stable until 2015 and since then it started to drop in volume handled. The ro-ro cargo sector has been growing at a significant pace since 2013. As for the dry bulk and liquid bulk, both have maintained a constant behaviour over the last three decades.

Linear regression was the main method used to generate forecasts. However, as a secondary method, qualitative analyses were carried out with the aid of extrapolations based on certain periods of time in order to create alternative scenarios.

In sum, the cargoes with a positive forecast are the containerized and ro-ro sectors. The cargoes with a negative forecast are the liquid bulk, dry bulk and general cargo. As for the Portuguese port system as a whole, even though the total volume of cargo handled has slowed down since 2017, the resulting linear regression forecast predicts a positive evolution for the next decade given the positive trend seen from 1988 to 2017. The goal of handling 100M tonnes of cargo in Portuguese ports seems distant but achievable by 2030.

Keywords: Portuguese port system, forecasting techniques, cargo throughput, containerized cargo, bulk cargo, logistics.

RESUMO:

Actualmente, mais do que nunca, os portos exigem uma previsão credível e plausível da movimentação de carga que é mais esperada no futuro próximo. O desenvolvimento de qualquer porto está intimamente ligado ao seu desempenho que, por sua vez, depende diretamente do volume de clientes que consegue atrair e servir. A infraestrutura e os equipamentos portuários são dois dos principais custos associados ao processo de gestão destes portos. O papel das previsões de movimentação de carga é de extrema importância. Um bom estudo de previsão pode levar a um melhor desempenho e prontidão em termos de capacidade do porto ao lidar com as tendências e evoluções futuras da carga.

O objetivo desta tese é desenvolver previsões plausíveis de movimentação de carga nos principais portos portugueses. Para tal, são aplicadas técnicas quantitativas, como regressão linear e extrapolação de tendências existentes, bem como avaliações qualitativas da evolução da carga. Os dados relativos à movimentação de carga, necessários ao suporte da análise, foram recolhidos junto de diversas fontes, nomeadamente do Instituto Nacional de Estatística (INE) e dos arquivos das Autoridades Portuárias. As cargas são divididas em diferentes tipos, bem como por diferentes portos. Foram consultadas séries temporais com duração de 16 a 42 anos. O produto interno bruto (PIB) das nações relevantes também foi consultado na OCDE e no FMI.

De uma forma geral, o sistema portuário português tem atravessado um período de crescimento nas últimas duas décadas, entrando numa tendência negativa mais recentemente em 2017. A carga contentorizada tem vindo a crescer até 2018. Por sua vez, a carga geral tem estado relativamente estável até 2015, ano em que começou a diminuir o volume movimentado. O setor de carga ro-ro tem crescido a um ritmo significativo desde 2013. Quanto aos granéis sólidos e líquidos, ambos mantiveram um comportamento constante nas últimas três décadas.

A regressão linear foi o método principal usado para gerar previsões. No entanto, como método secundário, as análises qualitativas foram realizadas com o auxílio de extrapolações com base em determinados períodos de tempo, a fim de criar cenários alternativos.

Em suma, as cargas com previsão positiva são os setores contentorizado e ro-ro. As cargas com previsão negativa são granéis líquidos, granéis sólidos e carga geral. No que se refere ao sistema portuário português como um todo, embora o volume total de carga movimentada tenha abrandado desde 2017, a previsão da regressão linear resultante prevê uma evolução positiva para a próxima década dada a tendência positiva observada de 1988 a 2017. O objectivo de atingir 100M de toneladas de carga movimentada nos portos portugueses parece distante, mas atingível em 2030.

Palavras-chave: Sistema portuário português, técnicas de previsão, movimentação de carga, carga contentorizada, carga a granel, logística.

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ACRONYMS:

APL	Administração do Porto de Lisboa
ARIMA	Auto Regressive Integrated Moving Average
AdC	Autoridade da Concorrência
ANOVA	Analysis of Variance
ANN	Artificial Neural Network
CUF	Companhia União Fabril
COVID-19	Coronavirus Disease 2019
FEU	Forty-feet equivalent unit
GDP	Gross Domestic Product
INE	Instituto Nacional de Estatística
IMF	International Monetary Fund
MSC	Mediterranean Shipping Company
MLR	Multi Linear Regression
NA	Not Applicable
OECD	Organization for Economic Co-operation and Development
PSA	Port of Singapore Authority
RO-RO	Roll-On Roll-Off
TEU	Twenty-foot equivalent unit
TEN-T	Trans-European Transport Network
VIF	Variance Inflation Factor
WB	World Bank

SYMBOLOGY:

y_t – Variable stating an event y

x_t – Variable stating an event x

a_i – Variable storing the real value of a forecast

f – Variable storing the forecasted value

q_t – Variable storing the scaled error

e_t – Variable storing the forecasting error

Y_t – Variable storing the observed value at time t

Δ – Variable storing a percentage variation

MS_{ij} – Variable storing the marker share of port j in cargo segment i

X_{ij} – Variable storing the cargo throughput of type i in port j

HHI_i – Variable storing the Herfindahl Hirschman Index for cargo type i

PSI_i – Variable storing the port specialization index for cargo type i

y – Dependent variable

b – Constant intercept

m – Regression coefficient

x – Score on the independent variable

r_{xy} – Variable storing the normalized measurement of the covariance

1. INTRODUCTION

1.1 Background and Motivation

The exponential growth of population which humanity has been experiencing, has brought along a matching and ever increasing demand for resources and services. Such need is one of the main drivers for technological development of civilization. History has shown that it is inherent to our nature to seek efficiency and evolution.

Proving itself the most cost effective method of transportation of large scale goods, shipping has had a strong presence in society and has been growing worldwide at a fast pace. With globalization causing an overall increase in trade volumes, port authorities and port owners have been actively keeping up by developing and expanding their ports. The main targets are the ones which play crucial nodes in the global transportation network, such as the case of Maaskvale II which has been an essential expansion of the northern giant of shipping that is Rotterdam.

However, more eye-catching investments than expansions of existing ports have emerged. Such is the case of the several planned projects for new building of ports. To mention a few, the Tanzania Trade Hub in Tanzania, the Tema Port in Ghana and the Tianjin Port in China. With the main motivator for such projects being the further development of their respective economic zones and capture the huge market of maritime trading which those regions and the international world.

All these projects are backed up by forecasting studies which have been carried out with years of advance in order to create the most suitable development plan for such tremendous investments. Forecasting techniques of any type require some sort of information as input, and with the revolutionary phenomenon of the Big Data, it is of utmost importance to analyze and develop accurate and powerful forecasting methods with the ability to process a large number of variables.

There is a variety of techniques and methods available to carry out a forecast involving data such as the one presented in this study. One could choose to approach a forecast in a qualitative or quantitative manner. Within quantitative forecasting, time series analysis or causal prediction may be used. Recently, forecasts have been carried out relying on sophisticated techniques such as artificial neural networks. However, for this study in particular, linear regression has been chosen, as it was found to be the most suitable while keeping the problem at a relatively low complexity [1].

Even though some ports receive support from their countries' respective governments, similarly to other organizations and companies, they are mostly driven and kept running by profits. The revenue originating from the services which their clients receive, such as cargo handling, berthing and storing, must overcome the sum of all expenses the ports undergo, such as the salaries of their employees and the capital costs of the equipment used.

The present thesis is motivated by the crucial need that ports have of knowing as accurately as possible the behaviour and trends of the cargo throughput for short, medium and long terms. Large sums of money are at stake which are directly tied to the ports' efficiency and capacity to respond to the markets and trades in which they participate. Expansions must be carefully planned ahead of time as to maintain a balance between the port's capacity and its demand in terms of cargo handled. An under dimensioned port will suffer due to its inefficiency caused by the large queues of ships, eventually losing the clients' interest to other ports in the proximity with a better efficiency and times. On the other hand, an over dimensioned port's profits will struggle due to its large expenses which may overshadow their revenues.

These type of concerns are also present in the case of Portuguese ports, according to a report [2] there are several points regarding the Portuguese logistical network, specifically concerning the road, rails and maritime sectors. With the latter being the most relevant in this study, a few comments and suggestions stand out. The containerized cargo handled in Lisbon shall be shifted from the already crowded area to the port of Setúbal instead, which has the capacity required to host said cargo. Thus leaving Lisbon the room to specialize on the touristic and cultural aspects. In order for this shift to take place, it is also suggested that the administrations of the two ports undertake a process of fusion and collaborate in their management.

Another relevant topic approached in the report is the country's lacking intermodality. Giving emphasis to the issue of the poor rail network, especially when considering the difference between rails types when crossing the Iberian corridor from Portugal to Spain and eventually to France.

All of these topics require forecasting studies to be carried out in order to have a better perception and foundation for their respective development projects.

Another motivator for carrying out forecasting studies is the European Commission (EC) and its plans for improving the trans-European transport network (TEN-T). The EC has provided guidelines in order to further developing the connectivity between the European coastline and the inland hubs. With the intent of boosting growth and competitiveness in Europe's Single Market. In fact, on May 23rd of 2013, the European Commission approved an initiative targeted at optimizing port operations and onward transportation interconnections at the 329 major seaports that make up the trans-European transport network. This project is being implemented in stages using a combination of legislative and non-legislative methods [3].

1.2 Objectives

This thesis aims to complete the cargo handling database in Portuguese ports, with data from 1987 to 2000 and 2015 to 2019. With a focus on the ports of Leixões, Aveiro, Lisbon, Setúbal, and Sines.

The concrete objectives that follow up on that broad goal are as follows:

- Complete the cargo handling database in Portuguese ports with data for the periods 1987-2000 and 2015-2018;
- Perform forecast studies for the period 2019-2030;
- Evaluate the results of the forecasts and propose two most likely scenarios, one optimistic and one conservative with an argument for each of them;

1.3 Structure of the Thesis

The thesis is organized in six chapters and respective appendices. The contents of the chapters is detailed as follows.

Chapter 1 presents the topic to be discussed and highlights its relation with the maritime industry as well as its background and importance to the Portuguese port system. The goals and structure of the work are introduced as well.

Chapter 2 contains the literature review and state of the art of the subject. A few key studies which are essential for the foundation of this work. Their targeted cargo, location, historical data, methodology and forecasting period also presented.

Chapter 3 describes the ports subject of this forecast. It also summarizes their main technical and physical parameters. The major industries which are dependent on the same ports are also described, specifying which cargoes serve as a link between the two points.

Chapter 4 presents the yearly cargo handling values in the ports composing the Portuguese port system for the five major types of cargo, both for loading and unloading. The topic of wildcard events is also approached by briefly analyzing the effects of the COVID-19 pandemic.

Chapter 5 details the methodology behind the application of the linear and multi linear regression. It also presents the various cases of linear regression forecasts. Then the qualitative forecasting results are described.

Chapter 6 compiles the most important results, opinions and a few final conclusions from this thesis. Lastly, a set of recommendations for further work is put forward.

2. LITERATURE REVIEW

A forecasting method is in essence an algorithm which generates a point forecast. That is, a single value which is a prediction of the original value for a certain future period. And a statistical model allows for the stochastic data generating process which may then be used as an input to create a probability distribution for a future time period $n + h$. It is widely accepted that to denote a point forecast of y_{n+h} one can use the notation $\hat{y}_{n+h}$ with the data available for time n.

This chapter first indicates and describes the existing forecasting methods and showcases a set of typical examples of port throughput forecasting studies. Each of them is backed up by references, explaining their advantages, disadvantages, reliability and possible applications.

Forecasting methods fall in three major groups, causal prediction, qualitative analysis and time series analysis. A description of each of these groups as well as the error assessment processes is given below.

2.1 Causal Methods

In causal methods, one assumes that the dependent variable which is being forecasted is associated and influenced by another variable, called the independent or explanatory variable. There can be more than one independent variables and each of them may have different degrees of impact in the result.

The three main branches of causal methods are segmentation, index method and regression analysis. With the latter, being the most common computable method of causal forecasting. One way to assess whether an event is linked to the unfolding of another, the Granger [4] causality test comes in with interesting results and helps to predict such occurrences. The standard Granger causality test analyses whether there is bi-directional feedback or one-way causality between the variables. In the case of two variables x_t and y_t, the Granger causality test estimates the VAR (Vector Autoregression Model).

2.1.1 Segmentation

Segmentation is the break-down of a problem into individual sections of the same nature, making a forecast of each piece and merging each of the parts' forecasts. An electronics corporation, for instance, might predict market revenues for each product category and then integrate the forecasts into one.

This method offers benefits over regression analysis in which variables communicate, there are non-linear effects of variables on demand, and there are strong causal priorities. It is particularly helpful if errors are expected to be in various directions in segment forecasts. Such scenario is likely to emerge when the segments are independent and also of similar significance, and where data is reasonably reliable for each segment. For a relatively low risk, higher accuracy can be attained when segmentation is founded on a priori variable selection. One of the most renowned segmentation methods is the bottom-up method [5] as the technique helps the experts to better use their understanding of the issue.

According to one consulting expert [6], the main steps in a demand segmentation analysis are:

1. Define the policies;
2. Define a data set to do the Segmentation Analysis;

3. Run the segmentation based on the Multi-Dimensional ABC Analysis;
4. Choose an algorithm;
5. Run the forecast and compare the different results;
6. Come to a consensus within the company;
7. Change accordingly the consensus;
8. Trial and error;
9. Keep the focus based on your products life cycle and changes within your supply chain;

For situations with little information on the variable to be predicted, where many causal variables are of importance, and where prior knowledge of the effects of the variables is good, the index method is appropriate [7]. Previous empirical evidence must be used to determine forecasting variables and to evaluate the directional influence of each variable upon its result.

Each variable can be given a value of 1 or 0 and the sum of the values of all the variables is called the index score. Scenarios with higher index score are more likely to take unfold, and vice versa.

In cases where a selection undertaken, the index approach is particularly useful. One example is determining which geographical area provides the highest market for a commodity. The model has also been successfully tested to predict the results of U.S. presidential elections by relying on data about the biographies of the candidates [8] and the opinion of the voters towards the candidates' abilities to deal with the problems [9].

2.1.2 Regression

Regression is a mathematical technique for finding the straight line that best fits values of a linear function. Usually coupled with a plot on a scatter graph of the data points. This line that is obtained, may then be used to predict future values of the dependent variable by simply extending the line itself. Whenever the forecasting model is defined by more than one explanatory variables, the linear regression must be adapted, becoming a multi linear regression.

With that said, the following principles for developing a regression forecasting model can serve as a guide:

1. Existing ideas and theories and knowledge, shall be used to pick variables and to determine the directions for their results instead of statistical fitness;
2. If the estimated relationship conflicts with prior evidence on the nature of the relationship the variables must be discarded;
3. The model must be kept simple regarding the number of variables, number of equations and their form [10];
4. Out-of-sample accuracy must be favored over R^2 basis when choosing between theoretically acceptable models;

Since regression analysis tends to over fit evidence, no effect can be dampened on the coefficients used in the prediction method. This modification tends to improve the precision of out-of-sample forecasting, particularly in the case where the samples are small and the variables are many. Since this scenario is prevalent in many forecasting problems, unit models frequently provide more reliable predictions than models with statistically fitted or un-damped regression coefficients.

A study based on a linear regression approach [11] concluded that a simple linear regression can generate a credible and reliable forecast by correlating the containerized cargo with the GDP of the nation.

2.1.3 Artificial Neural Networks

Over the past years, neural networks have become immensely popular in a number of areas for predicting and forecasting, including economics, energy generation, medicine, water management and environmental science. While the idea of artificial neurons was first presented in 1943, research into neural networks applications has flourished after the implementation of the back propagation training algorithm for feedforward neural networks in 1986. Thus, neural networks can be considered a fairly new type of predictive and forecasting method.

Lapedes and Farber [12] record one of the first positive applications of neural networks in forecasting. The two constructed the feedforward neural networks using two deterministic chaotic time series generated by the logistic map and the Glass – Mackey formula, which can accurately emulate and predict these complex, nonlinear systems.

Neural networks have been used to solve many forecasting problems. A brief list includes inflation [13], cost flow [14], commodity prices [15], environmental temperature, ozone level [16], student grade point averages [17], total industrial output [18], oil well temperature profiles [19], airline passenger traffic [20], advertising [21], futures trading [22], political risk [23] and room occupancy [24].

Artificial neural networks are forecasting methods based on simple mathematical models of the brain. One of the advantages of this type of methods is that they allow complex nonlinear relationships between the response variable and its predictors.

A neural network at its core can be viewed as a network of neurons having an architecture organized in layers. The simplest form of these networks contain no hidden layers and are equivalent to linear regressions, as illustrated in Figure 2.1 which shows a neural network with four predictors. Each of these inputs have a coefficient attached called weight. The forecast can be obtained by combining the inputs in a linear manner, a task which is done by the neural network framework, equipped with a learning algorithm, by iterating the weights of each of the predictors.

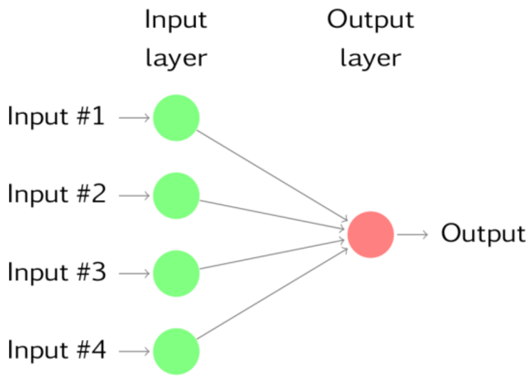

Figure 2.1 – Neural Network with four predictors

By adding an intermediate layer of hidden neurons, the same neural network is upgraded and becomes nonlinear. Earning the name of a multilayer feed-forward network, it functions by combining the inputs with each node using a weighted linear combination, and then modifying the results with a nonlinear function before generating the output, as depicted in Figure 2.2.

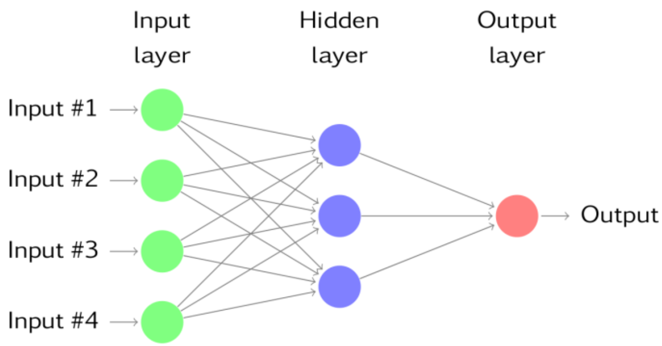

Figure 2.2 – Neural Network with four predictors and a hidden layer.

Figure 2.3 shows the relationship between the complexity and the performance of a conceptual ANN model. On the left side, low model complexity (relative to the corresponding DGP) is displayed: models work poorly both on learning and future data here since they place too simplistic assumptions upon its data generating process (DGP). In turn, on the right side, very intricate models are depicted. These models perform well on the data available, but struggle to reach an equally good result on the validation data produced by the same DGP. In the range where the validation error is low and the divergence between training and validation error is minimal, the optimal degree of complexity is reached.

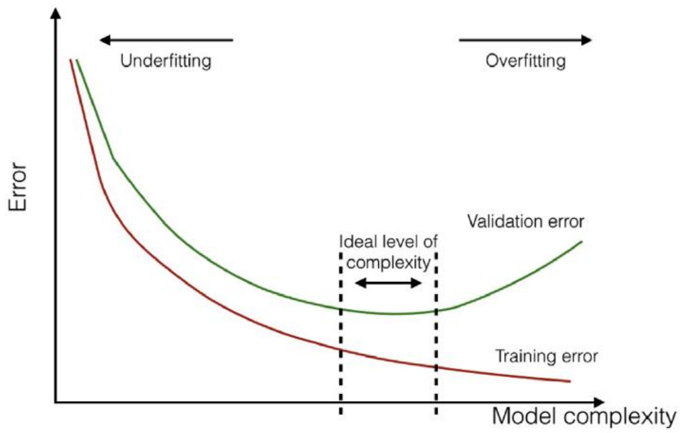

Figure 2.3 – Conceptual representation of the model complexity-performance relationship

According to Ripley [25], a typical technique to test for under or overfitting is to randomly divide the available data into training, validation and testing subsets.

2.2 Qualitative Methods

When past data is unavailable or impractical to gather, a qualitative approach may be chosen. These methods are essentially subjective opinions of experts. However, such analysis is more complicated as it requires years of accumulated experience and only highly skilled experts may provide a reliably accurate study on the subject.

One of the advantages of these methods is that rare or one-time events may be considered, the so call wild cards which are very difficult to implement in a purely mathematical model. However there is also the real and significant downside of the personal biases which are inherent to such types of studies. For that reason, the Delphi (also known as Estimate-Talk-Estimate or ETE) method may be applied in order to filter and minimize the biased results. This method, developed in 1948 by the American Rand Corporation and used primarily for military purposes, is based on the principle that a structured group of individuals generates forecasts (or decisions) more accurately than unstructured groups. The experts answer two or more rounds of questionnaires, and after each round, a facilitator or change agent generates an anonymized summary of the forecasts of the experts from the preceding round as well as the reasons for their judgments. Experts are therefore encouraged to revise their initial responses in the light of other panel members' replies. It is expected that the response range will reduce during this process, and that the group will converge to the "true" answer.

With the passing of years after its conception, the technique has been gaining more attention in the business sector [26]. To include a few examples of its application, forecasts for assessing an energy market, identifying internet connections, increasing dry bulk shipping, determining recreational interests in Singapore, interpreting rubber manufacturing, estimating oil prices, among others.

Another study [27] also concluded that this type of method can be used to generate reliable results in terms of traffic cargo forecasting in ports.

2.3 Time Series Methods

A time series is simply a series of data points ordered in time, where time is usually an independent variable. Time series methods imply that data of historical behavior needs to be gathered and compiled in order to predict future outcomes based on trends and on the assumption that the future is directly dependent on the past. Particularly in the shipping industry, these time-series methods allow the accounting of seasonality, the well-known shipping cycles as well as world economic oscillations.

These methods are subdivided into three broad classes, the autoregressive (AR) models, the integrated (I) models and the moving average (MA) models. With each of these classes having a linear dependence on past data. Combinations of these models have given birth to other models such as the autoregressive moving average (ARMA), autoregressive integrated moving average (ARIMA) and the autoregressive fractionally integrated moving average (AFIRMA) which generalizes the previous three. These methods are effective whenever one can define the general trends regardless of the variables influencing the projected parameter [28]. It is worth mentioning, there are also models for a non-linear dependence between the level of the series and the previous data points.

A study from 2015 [29] is a good example of how a time series can generate an informative forecast of cargo movement in ports with a relatively high accuracy.

2.3.1 Rule-based models

Rule-based forecasts are a type of time-series method which assist analysts to structurally and inexpensively combine evidence-based forecasting concepts and the information from managers regarding the situation with the time series. As a first step, the features of the series must be identified. Among the 28 different series features, there are the causal forces such as growth, opposing, supporting, regressing or unknown, data quantity, forecast horizon length, and outliers [30]. Inspection, mathematical analysis, or domain expertise may describe those features. There are currently 99 data adjustment and estimation rules for the starting value and short and the long range trends. In essence, RBF projections are a fusion of short and long range extrapolations.

In situations involving significant trends, low insecurity, stability and good expertise, these forecasts can have a higher level of accuracy than equal weight combined forecasts [31].

2.3.2 Naïve models

The most cost-effective forecasting model is naive forecasting, which serves as a standard against which more advanced models may be evaluated. Only time series data are eligible for this forecasting approach. Forecasts which are equal to the last observed value are created using the naive technique. This strategy is particularly useful for economic and financial time series, which frequently exhibit patterns that are difficult to anticipate consistently and precisely. If the time series is thought to exhibit seasonality, the seasonal naive technique, where the predictions are equal to the value from the previous season, may be more appropriate. Most often naïve models used are random walk (current value as a forecast of the next period) and seasonal random walk (value from the same period of prior year as a forecast for the same period of forecasted year).

2.3.3 State space models

A state space model (SSM) is a time series model in which the time series Y_t is interpreted as the result of a noisy observation of a stochastic process X_t. Where the values of the variables X_t and Y_t can be continuous (scalar or vector) or discrete. It is worth noting that SSMs belong to the realm of Bayesian inference, and they have been successfully applied in many fields to solve a broad range of problems.

Because the level, trend, and seasonal components are specified openly in the models, the philosophy of state space models fits well with the method of exponential smoothing. In autoregressive integrated moving average (ARIMA) models, however, these components are more difficult to discern.

The most well studied SSM is the Kalman filter, for which the processes above are linear and and the sources of randomness are Gaussian.

2.4 Forecasting Studies in the port industry

There have been numerous forecasting studies carried out in the port industry. The following ones are some of the ones which consulted for this thesis:

MDS Transmodal has published in 2007 a study targeting bulk fuels such as coal, liquefied gas, oil and petroleum and also roll-on/roll-off cargo as well as port traffic. One of the objectives was to assess the impact of port traffic growth on inland networks. The targeted location was the Great Britain Ports and the historical data used spanned 25 years. The forecast period goes from 2007 up until 2030. The method used was a mix between GDP and the future policy and market trends [32].

Ocean Shipping Consultants published a study targeting containerized cargo in all of the North American ports. The forecast period was 2014-2050 and the method included the GDP and multiplier scenarios as well as market share and risk factors [33].

Dorsser published in 2012 a study targeting the total port throughput in the Le Havre-Hamburg range. The historical data was between 1936 and 2009. The long term forecast period was 2012-2100 and the method used a GDP correlation [34].

Maria Manuel Teixeira published a study regarding the exported cement in the Port of Aveiro. The historical data period was 2005-2014 and the method used multilinear regressions and regression trees [35].

UNESCAP published a study targeting the containerized cargo in the Asian region. The historical data period was 1980-2005 and the forecast period was 2005-2015. The method used was through the extrapolation of average growth rate [36].

Group of International Shipbuilding Experts published a study of the demand for new ships produced. The forecasting period was 1978-1995 and the historical data was from 1975 to 1978 [37].

Graham Cox published a study of the port cargo traffic with a historical data period of 1970-2008. The method used a linear regression with UK GDP [38].

PORTOPIA published a study regarding the Maritime Traffic. The forecasting periods covered short, medium and long terms, from 1 to 5 years and over 5 years. The historical data varies and a number of different methods were used, including GDP correlation and qualitative methods [39].

Alen Jugović published a study of the container traffic in the Port of Rijeka. The forecasting period was 2008-2040 and the historical data spanned from 2000 to 2008. The forecasting method used linear regression with GDP [40].

Chou, Chu and Liang published in 2008 a forecast of the containers imported in Taiwan. The forecasting period was for long term and the historical data period was 1983-2003.The forecasting method included a modified regression model [41].

2.5 Forecasting Inaccuracies

Inherent to their nature, any and all forecasts have a certain degree of inaccuracies and uncertainties attached to them. There have been developed several ways for calculating the error of a certain forecasting method. Typically, for time-series based methods, around 80% of the historical data is used to generate the forecast itself and the remaining 20% serves to test its goodness.

"Above all, the forecaster's task is to map uncertainty, for in a world where our actions in the present influence the future, uncertainty is opportunity." – Paul Saffo 2007

Some of the methods for calculating errors include the following:

- Mean absolute percentage error, or MAPE for short:

$$\text{MAPE} = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{a_i - f_i}{a_i}\right| \qquad 2.1$$

In which a is the actual value, n the sample size and f the forecasted value;

- Mean percentage error, or MPE for short:

$$\text{MPE} = \frac{100}{n}\sum_{i=1}^{n}\frac{a_i - f_i}{a_i} \qquad 2.2$$

- Mean square error, or MSE for short:

$$\text{MPE} = \frac{100}{n}\sum_{i=1}^{n}(a_i - f_i)^2 \qquad 2.3$$

- Root of mean square error, or RMSE for short:

$$\text{RMSE} = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(a_i - f_i)^2} \qquad 2.4$$

These relative measures based on relative errors attempt to nullify the scale of the data through the comparison between the forecast results with a benchmark forecast method such as the naïve method. However both of these present some issues. Relative errors have a statistical distribution with unspecified mean and infinite variance while relative measures can only be evaluated if there are multiple forecasts in the same series and can therefore not be used to evaluate the accuracy of the out-of-sample forecast on a single forecast horizon.

In an attempt to solve such problems, Hyndman [42] proposed a new method for calculating errors which is suitable for all situations. As the name implies, the Mean Absolute Scaled Error aims to scale the error based on in-sample MAE from the naïve (random walk) forecast method. The scaled error is defined as:

$$q_t = \frac{e_t}{\frac{1}{n-1}\sum_{i=2}^{n}|Y_i - Y_{i-1}|} \quad 2.5$$

In the case which the error is less than one, it is implied that the forecast is better than the average one step naïve forecast computed in-sample.

The Mean Absolute Scaled Error is thus:

$$\mathrm{MASE} = \mathrm{mean}(|\mathrm{q_t}|) \quad 2.6$$

2.6 Choosing a forecasting method

Several methods for forecasting were taken in consideration in the literature review presented in Chapter 2. However, based on the aforementioned Literature Review, it was possible to discard the utilization of most of the forecasting methods presented and discussed in that chapter.

First, the qualitative methods were found to be unsuitable as they should be applied in forecasts in cases which historical data isn't easily accessible or is even non-existent. In this study, however, data is generally available and should be used as a foundation, avoiding relying on any subjective opinions when possible. There are however a few cases in which qualitative forecasting will be used, mainly due to sudden events that affect some ports. The Auto Regressive Integrated Moving Average (ARIMA) was also dismissed as usually it requires over 50 data points according to Box and Jenkins [43]. For the same reason, Neural Networks Analysis was ruled out as the accuracy of such method heavily depends on the number of data points used. In order to obtain reliable outputs, previous studies [44] advise relying on ANNs only if the number of data points available are at least over 50 times the number of estimated parameters.

Considering, primarily, the availability of data reported in Chapter 4 and summarized, in particular, in Table 4.5, the linear regression method has been chosen as it is a fairly low complexity method, of easy application and has a relatively low computational time cost, as it revolves around the usage of linear equations. The fitting of the model to the data points was improved by considering multiple explanatory variables, thus using the multiple linear regression method (MLR). In essence, linear regression is based on a linear approach to modelling the relation between a scalar response and one or more independent variables. And like all types of regression analysis, the linear regression focuses on the conditional probability distribution of the response given the values of the predictors, instead of on the joint probability distribution of all of the variables.

3. THE PORTUGUESE PORT SYSTEM

3.1 Structure of the Portuguese port system

In this chapter the targeted ports for this study are presented alongside a description of their characteristics such as yearly cargo throughput and their relevant physical dimensions. Figure 3.1 shows the Portuguese port system including all the commercial ports currently in operation. Out of these ports, the most important are Leixões, Aveiro, Lisbon, Setúbal and Sines due to their level of cargo handling, as such they will be analysed in this study.

Figure 3.1 – Commercial ports included in the Portuguese port system

The ports of Leixões, Lisbon, and Sines form part of the European core network, while the ports of Aveiro and Setúbal are part of the comprehensive network as seen in Figure 3.2.

Figure 3.2 – Core and Comprehensive Network ports in the Iberian Peninsula

Portuguese commercial ports are organized in Port Authorities, namely the following:

The ports of Viana do Castelo and Leixões are managed by the Port Authority of Leixões. This authority also oversees the Douro inland navigation waterway. The port authority of Aveiro manages mainly the coastal area surrounding the port of Aveiro. The Port Authority of Lisbon covers in total 11 counties Oeiras, Lisboa, Loures, Vila Franca de Xira, Benavente, Alcochete, Montijo, Moita, Barreiro, Seixal and Almada. In its fluvial-maritime jurisdiction it covers an area of 31,6 thousand hectares having as limits the Towers of São Julião and Bugio at downstream and the city of Vila Franca de Xira at upstream. Regarding the Port Authority of Setúbal, besides the entire port of Setúbal, it also oversees the port of Sesimbra. Lastly, the Port Authority of Sines supervises the port of Sines and also the southern ports of Faro and Portimão.

It is also important to note the relevance of the ports of Leixões, Aveiro, Lisbon, Setúbal and Sines in the in the European railway and road network named the “Trans-European Transport Network“ or TEN-T for short [45] as seen in Figure 3.3. With their advantageous location, the five ports have direct or nearly direct access to the other European nations through the “Atlantic” corridor. Thus, working as gateways of Europe, facilitating the access to deep water lines with the ports of Sines and Setúbal. And also linking short sea shipping lines like which connect Lisbon and Leixões to Rotterdam [46].

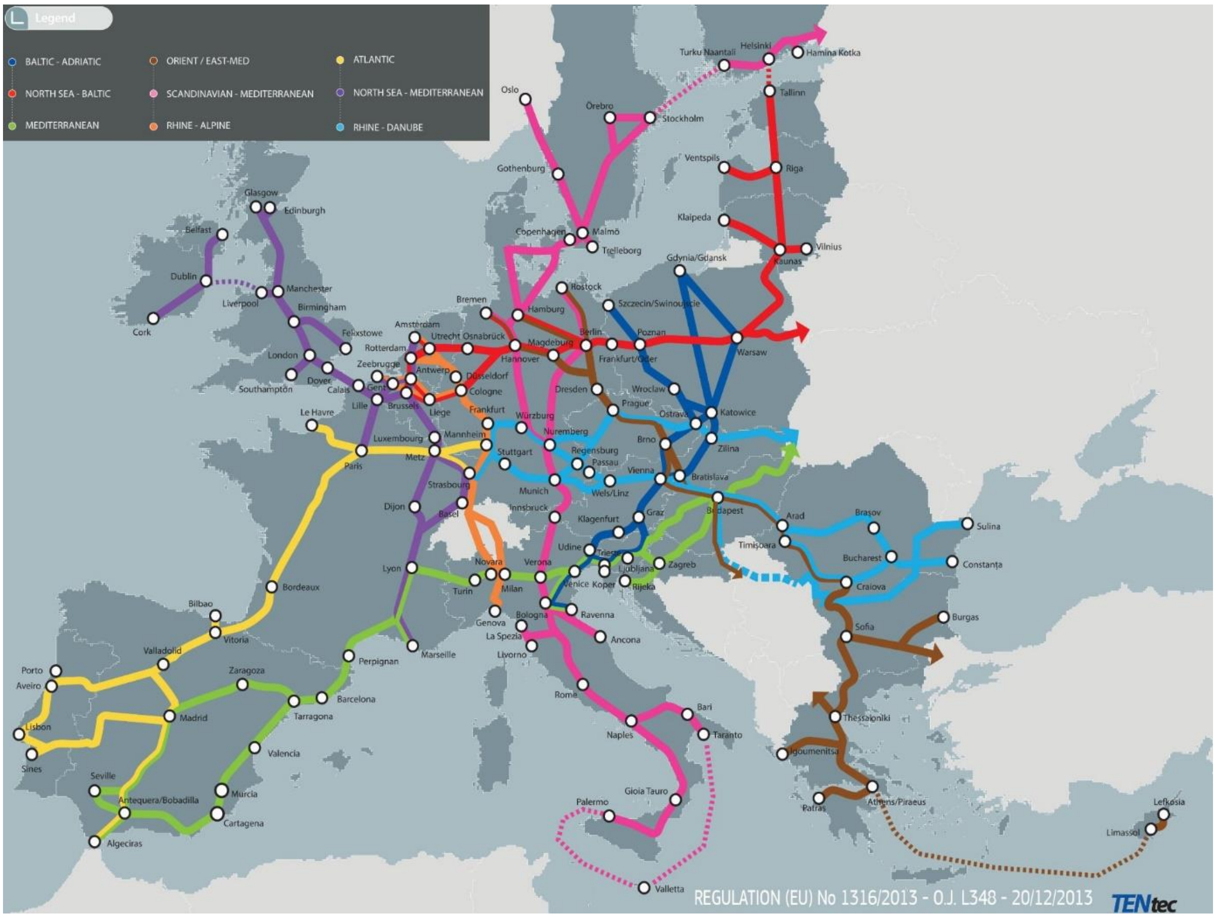

Figure 3.3 – Trans-European Transport Network (TEN-T)

3.2 Technical characteristics of the port of Leixões

With an entrance channel of 220 metres wide, the Port of Leixões, seen in Figure 3.4, is located in the north of Portugal, northwest of the Iberian Peninsula, about 4 kilometres north of the mouth of the Douro River and in the close vicinity of the city of Porto, being framed by the towns of Leça da Palmeira to the north and Matosinhos to the South.

One of the imposed restrictions is that the piloting is compulsory for all ship entries and departures, with the exception of coastal vessels and up to 500 GT national cabotage, local coastal fishing and recreational vessels. The Port Authority supplies the piloting service at all times.

Figure 3.4 – The port of Leixões

In regards to the conventional general cargo and solid bulk cargo, it is spread out along 4 docks. The key products handled there are: raw, pressed, and sawn wood, iron and steel, sheet rolls, granite stones, waste, agro-food bulk, general machinery and project loads, such as wind generators and transformers.

The liquid bulk transported at Leixões Port is mainly intended for the Petrogal Refinery in Leça da Palmeira as well as for CEPSA. The Port of Leixões is equipped with an Oil Terminal, granted to Petrogal-Petróleos de Portugal, SA, built on the submerged breakwater with 700 meters in length and reaching 15 meters above sea level. The terminal linked via pipelines to the Petrogal Refinery has three berths. In 2006 the unloading activity started at TOGL-Galp-Leça Ocean Terminal to receive crude oil into the Petrogal Refinery. Used by oil tankers of up to 150,000 DWT, this docking station has depths reaching 30m below the water level.

The two container terminals at the Port of Leixões are operated by the company Yilport Leixões. Split into the north and south terminals with depths of 10 and 12 metres respectively as well as 360 and 540 meters of available berth lengths respectively.

The Ro-Ro terminal situated at Dock 1 North, has a fixed pier platform spanning 21 metres in length, a maximum width of 22m and a slope of 7.7%. With depths reaching -10 metres, it can handle a maximum load capacity of 80 tonnes, and 24 tonnes per axle. In addition, the terminal has suitable characteristics for hosting Ro-Ro ships which have an aft door and the parking area can hold up to 100 trailers.

The Multiusos Terminal is intended primarily for ro-ro traffic. Situated on the Port of Leixões' South Jetty, it has an advanced pier with a length of 310 metres, a 26 metres long Ro-Ro ramp, a bottom at -10 metres and a handling capacity of 360 tonnes. It also has a pier perpendicular to the South Jetty with a length of 155 metres and the bottom at -10 metres, another 50 metres long pier and a Varadouro Ramp. This terminal is intended primarily for TMCD (Short Sea Shipping), for both Ro-Ro and Lo-Lo. The Terminal has an 8 hectare embankment area which serves as an area of support.

Its two cruise terminals handle approximately 80000 passengers per year, originating from all over the world, but mostly the UK, US and Germany. The largest terminal has a quay length of 340 metres and depth of 10 metres where ships with a length of 300 metres can berth.

There is also a recreational dock, a fishing port and several storage silos and warehouses spread throughout the ports' area.

3.3 Technical characteristics of the port of Aveiro

The Port of Aveiro holds a fortunate position on the west coast of the Iberian Peninsula, representing the large commercial hinterland of central and northern Portugal and central Spain.

As a newly designed port infrastructure, seen in Figure 3.5, it is a multifunctional port situated to mainly serve the numerous sectors of industry in the central region of Portugal. Access to the installed capacity, without congestion, gives it a dynamic, productive and sustainable character, enabling it to achieve an excellent degree of competitiveness and to respond to the most diverse challenges.

It is served by the key national road routes, with excellent road connectivity, in a highway system that connects it to the major cities of the country as well as Spain. As far as rail services are concerned, the Port of Aveiro is linked to the national network by an electrified branch with a connection to the corridor of the Trans-European Transport Network (Atlantic Corridor section).

In terms of main physical characteristics, it is presently capable of handling ships with a maximum draft of 9,75 metres and a length of 200 metres.

Figure 3.5 – The port of Aveiro

3.4 Technical characteristics of the port of Lisbon

Lisbon's port, seen in Figure 3.6, is a large European port with an Atlantic focus and a direct connection to the Iberian market, situated in the largest distribution hub (Lisbon and Tagus Valley region), which is a critical infrastructure for the Portuguese economy. Its geo-strategic position gives it an important role in the logistic chains of global trade and in the major cruise lines.

The Portuguese capital, has a multifunctional port, comprised of 18 port terminals devoted to all types of freight and cruise passengers, running 24 hours a day, 365 days a year and offering the best navigational conditions for any and all types of cargo vessels. It is currently the national leader in the cruises sector and in the category of agro-food bulk transport, being the strategic port in the Iberian Peninsula for importing and exporting the agro-food products.

It is a harbour of refuge with outstanding natural conditions, situated on the Tagus River estuary, meeting the Atlantic Ocean in a 32,000-hectare basin. Its hinterland reaches out to Spain, including the provinces of Extremadura, Andalusia and Madrid.

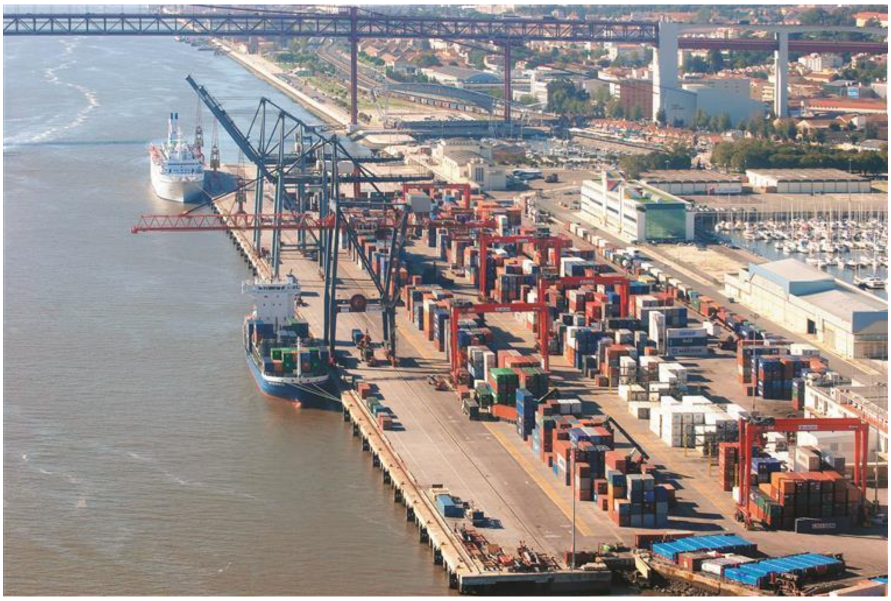

Figure 3.6 – The port of Lisbon

With its convenient location, the Port of Lisbon is closest to the country's main consumer centre. Protected and with outstanding natural resources, it has proved to be a valuable asset for the economy of Portugal. Container traffic is especially important for Lisbon. This can be seen with the significant number of direct services carried out by the major container ship lines which link the city to the major ports in Spain and Northern Europe through daily services.

The port has three specialized terminals in the containerized cargo market with a global capacity of about 1 million TEU, standing out as one of the main national references in the sector. It provides excellent conditions for the handling solid bulk, particularly in regards to agro-food bulk, serving as a transhipment site for American goods and distributed through the Iberian and European markets. For example, its Bulk Food Terminal in Trafaria is one of Europe's biggest cereal facilities with a holding capacity of 200,000 tonnes. In total, there are currently nine solid bulk terminals spread across the port's area.

As for fractionated cargo, it is handled mainly in two multi-use terminals located on the Tagus River North Bank. The container terminals transfer some fractioned freight as well, however in a residual way. Amongst the goods handled at the port of Lisbon, paper in reels, copper, iron, scrap and fruits stand out as some of the most important.

Liquid bulk products such as petroleum goods, additives, and edible oils are handled within the nine properly equipped terminals which excel in terms of efficiency, safety and environmental protection. Its set of facilities serve the local cargo market, deep sea and transhipment sector, and work as a strategic stocking.

The Alcântara advanced quay handles the Roll-on/Roll-off cargo. Cars and specialized vehicles can be moved and parked in this terminal. Any special safety measures which may be required by any sensitive goods are also guaranteed by the terminal.

Two cruise terminals, one in Alcântara and the other in Santa Apolónia bordering Lisbon's historic and cultural centre attract tourists wishing to visit the city. Both terminals are fitted with passenger and luggage X-ray machines. Finally, the port services over 1100 vessels within its four recreational docks located in the northern bank of the river.

3.5 Technical characteristics of the port of Setúbal

The port of Setúbal is a natural port in the Sado estuary, with natural maritime access and great safety conditions. It has immediate access to the national road network of motorways on an adjacent route to the city of Setúbal's urban limits and with no level crossings with the railway. There are also direct connections to the electrified railroad network which spreads from north to south of the country, and it links to the international network. It is the leading Portuguese port in the Ro-Ro sector, having a specialized terminal as see in Figure 3.7 and providing a gateway between the Autoeuropa factory in the close vicinity and the rest of the world.

Figure 3.7 – The port of Setúbal

The port comprises several terminals divided into public service terminals and private use terminals. The following terminals are currently in operation within the public service category: Terminal Multiusos Zona 1 – TERSADO, Terminal Multiusos Zona 2 – SADOPORT, Terminal Roll-On Roll-Off/Terminal Autoeuropa, Terminal Portuário SAPEC, Terminal de Granéis Líquidos.

The following terminals are operating under the private use category: Terminal SECIL ,Terminal de Praias do Sado (ex-Pirites Alentejanas) ,Terminal Tanquisado/Eco-Oil, Terminal de Granéis Sólidos da Mitrena – TERMITRENA, Terminal Teporset.

Several short sea shipping lines as well as deep sea lines connect with the port, including "MacAndrews POME 2020", "Arkas Line 2019", "MAPT 2019", "TARROS LINE - GPS", "Livestock Express", "Wec Lines PT-LIV / PRU" and "EURO - Shuttle 2019". Connecting the port with countries such as Belgium, Germany, China and Morocco with weekly to bi-monthly frequencies.

3.6 Technical characteristics of the port of Sines

The Port of Sines is an open deep-water maritime port with fantastic, unrestricted maritime accessibility, leading the port sector in terms of cargo handled and providing special natural characteristics to accommodate any sort of vessel. Being able to handle various types of freight, thanks to its modern and specialized terminals is one of its advantages.

Sines is the primary port on the Ibero-Atlantic range. Its geophysical characteristics makes it stand out and establish it as a strategically important city in terms of cargo flow. Highlighting the large volume of international cargo transferred from deep-sea lines such as the Asian ones to short sea shipping lines which branch out along the northern European coast. It is the leading energy supplier of the nation, handling products such as crude oil and its derivative products, coal and natural gas. It is also an important port for general and containerized cargo, showing a high growth opportunity and the prospect of becoming a port of reference at regional, European and global levels with its specialized terminal named “Terminal XXI” seen here in Figure 3.8.

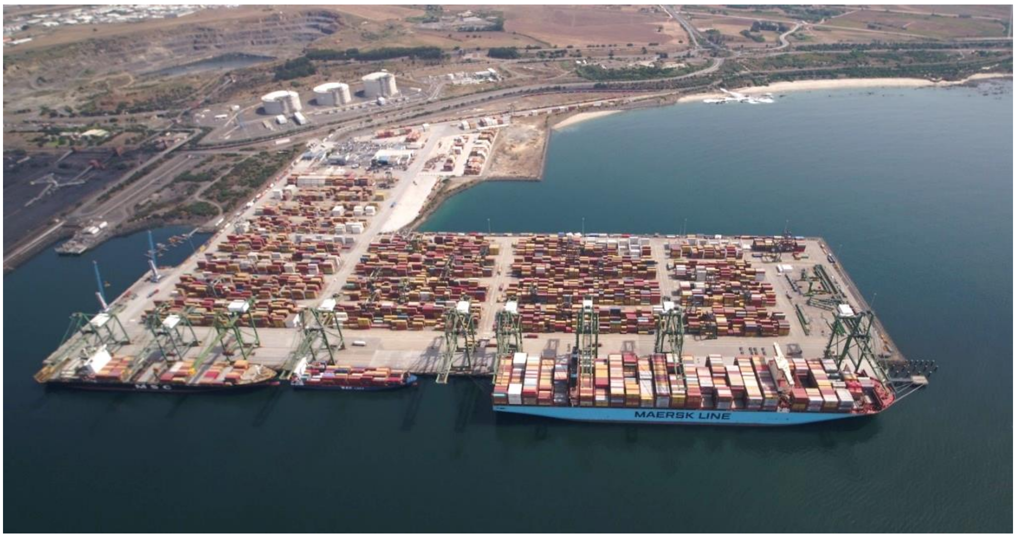

Figure 3.8 – Terminal XXI in the port of Sines

As a modern and independent of urban restrictions port, it ensures the capacity for long-term expansion. Providing strong land connectivity for existing traffic, it is included in a road and rail development program, enabling it to react to future growth demands. The port as well as its Industrial and Logistics support zone, spanning more than 2,000 hectares, is presently an international logistics hub, capable of receiving the key players in the shipping, maritime, industrial and logistics sectors.

4. CARGO HANDLING IN THE PORTUGUESE PORT SYSTEM: 1990-2020

4.1 General trends

In this section the evolution of the cargo handling in the most important Portuguese ports is presented and analysed. The objective is to systematize statistical information enabling understanding the reasons behind the observed trends and tendencies. For any forecasting project a strong statistical information foundation is of crucial importance. Independently of the forecasting method chosen, accurate and precise historical data will have a great level of influence over the results obtained. As such, the most trusted sources were consulted, namely the port authorities as well as INE (Instituto Nacional de Estatística). The data was collected from the earliest available archives and processed in order to be easily understood.

In order to better understand the evolution of cargo in the Portuguese port system, Table 4.1 proves to be of critical importance. This will help to point out the main ports which may have a higher influence over the total national cargo handled volumes, leading to finding explanations for periods of growth or decline more easily. The five main Portuguese ports are Sines, Leixões, Lisbon, Setúbal and Aveiro, by this order. Sines is very important on liquid bulks and containerized cargo. Leixões is strong on Ro-Ro and liquid bulks. Lisbon has a strong impact on solid bulks and some control over containerized cargo. Setúbal is specialized mainly on general cargo and ro-ro. Lastly, Aveiro holds great influence over general cargo and at a lower degree over dry bulk.

Table 4.1 – Activity of Portuguese ports in 2017 by type of cargo (Source: AdC[1])

Porto(s)	Fracionada	Contentorizada	Ro-Ro	Granéis Sólidos	Granéis Líquidos	Total
V. Castelo	5%	0%	0%	0%	0%	0%
Leixões	19%	17%	69%	11%	25%	19%
Aveiro	22%	0%	0%	12%	4%	6%
Fig. Foz	17%	0%	0%	4%	0%	2%
Lisboa	3%	13%	1%	25%	5%	12%
Setúbal	29%	4%	28%	14%	1%	7%
Sines	2%	59%	0%	30%	64%	50%
Continente	**97%**	**94%**	**98%**	**97%**	**98%**	**96%**
RAM	1%	2%	0%	1%	1%	1%
RAA	2%	4%	2%	2%	1%	2%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

[1] Autoridade da Concorrência (AdC)

Besides the table presented above, it was necessary to research other sources in order to complement the justifications of the aforementioned cargo handling trends. These include the most obvious ones such as the port authorities' websites and large organizations such as the European Commission. Other sources include the major local factories and refineries' websites as well as national and international news articles in the maritime sector.

This section will now present the general trends in the entire port system for each type of cargo, which includes containerized cargo, general cargo, ro-ro, dry bulk and liquid bulk. Some of the data sources provide information which needs to be processed. Such is the case of data on containerized cargo, which previously to 1997 was distributed into two main categories, large and medium, and small containers, as seen in Table 4.2. In order to convert the values into TEU (twenty feet equivalent unit), the table present in ANNEX I was used. Two assumptions were made, small containers are meant to be 20 feet long while medium and large ones include the 40 and 45 feet long containers.

Table 4.2 – Example of containers handled in the port of Leixões (Source: INE)

F - CONTENTORES - ***CONTENEURS***

90. – Movimento de contentores nos portos de Leixões e Lisboa, por países e portos de destino e de procedência

Mouvement de conteneurs dans les ports de "Leixões" et "Lisboa", par pays et ports de destination e provenance

1980

Contentores - *Conteneurs* / Países e portos de destino e de procedência - *Pays et ports de destination et provenance*	Carregados - *Chargés*						Descarregados - *Déchargés*					
	Contentores grandes e médios *Grands conteneurs et moyens*			Contentores pequenos *Petits conteneurs*			Contentores grandes e médios			Contentores pequenos		
	Cheios - *Pleins*		Vazios *Vides*	Cheios		Vazios	Cheios		Vazios	Cheios		Vazios
	nº	t (a)		nº	t (a)		nº	t (a)		nº	t (a)	
1	2	3	4	5	6	7	8	9	10	11	12	13
Porto de Leixões - *Port de "Leixões"*												
TOTAL	25 606	371 980	4 040	70	745	..	19 039	328 548	8 715	26	323	37
Continente - *Continent*	155	2 726	7	..	..	..	52	852	63	..	..	..
Lisboa	155	2 726	7	..	..	..	52	852	63	..	..	..

The following graphs contain the historical data regarding the total cargo handled in the entire Portuguese port system, including the archipelagos of Azores and Madeira.

Containerization has had a major role in the worldwide growth of the containerized cargo in ports, and the Portuguese ports were no exception as seen in Figure 4.1. There has been a balance between the imported and exported cargo, with them holding nearly even share over the last 31 years. More recently however, in the last decade the volume of exported containers has held an edge over the imports.

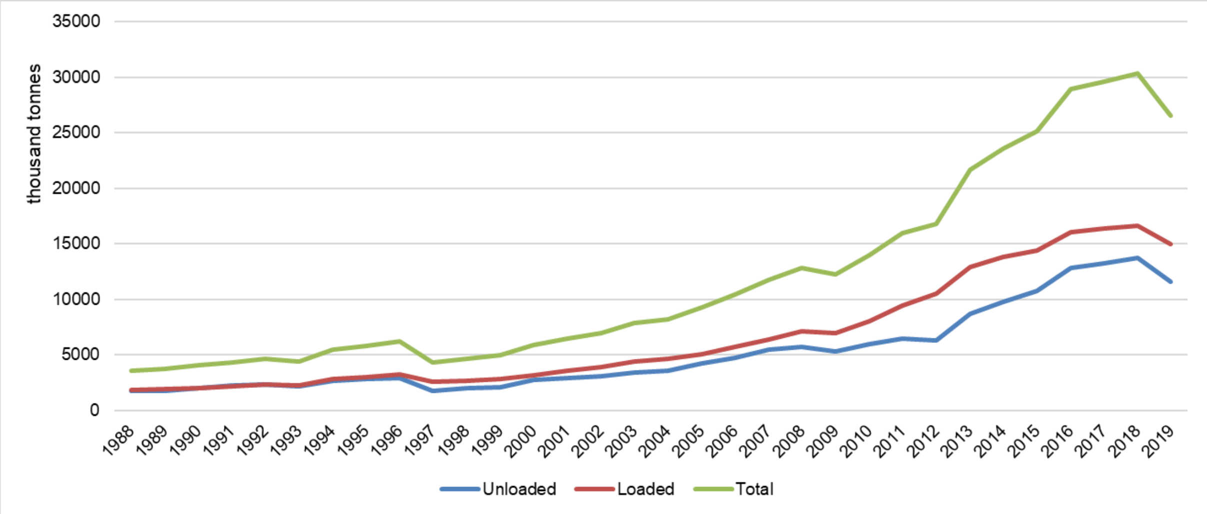

Figure 4.1 – Containerized cargo handled in Portuguese ports

Figure 4.2 demonstrates the total number of TEU handled in the Portuguese ports, including the archipelagos.

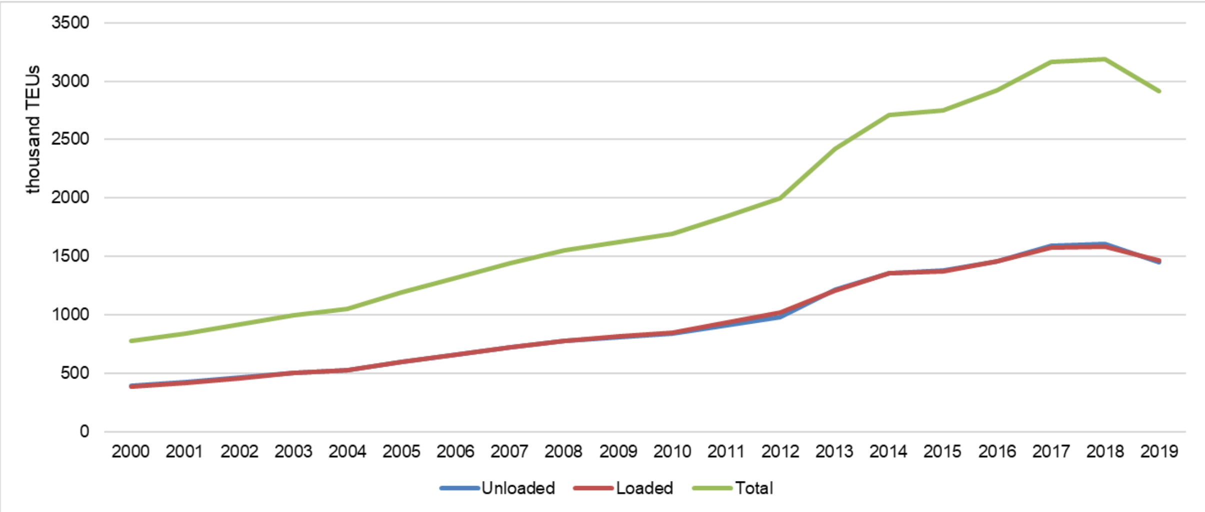

Figure 4.2 – Number of TEUs handled in the Portuguese ports

It is also interesting to note the drop of containers handled verified in 2019. This event is caused by the reduction seen in the port of Sines which holds a share of nearly 60% of the Portuguese containerized cargo.

An interesting case is the competition between the central ports of Lisbon, Setúbal and Sines in terms of domestic oriented container shipping. Allowing for a better perspective over this matter, Figure 4.3 presents the national containerized cargo handled by this trio. An observation that stands out is the loss of containers in Lisbon right after the time when Terminal XXI started its operation in the port of Sines, leading to the shift of MSC shipping company to the new terminal in Sines. Location, efficiency and costs are a few of the reasons behind this shift seen in this set of ports.

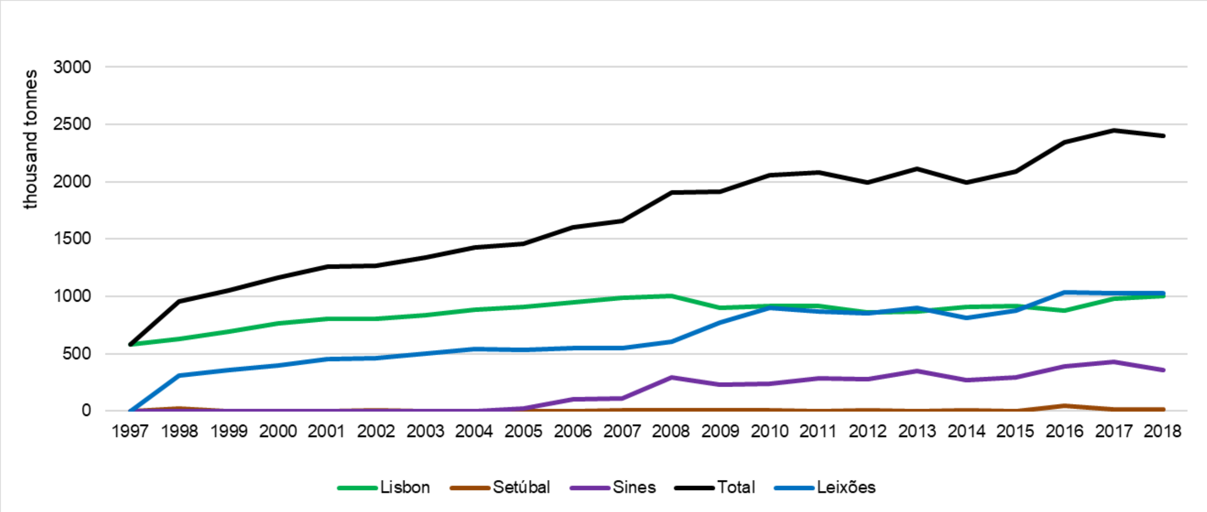

Figure 4.3 – Domestic containers (tonnes) handled in Portuguese ports

Although Sines has had a share of nearly 60% over the total volume of containers handled in Portugal and Lisbon only 13%, due to its large depths and specialized terminal, the former is focused on mainly transhipment of this type of cargo. In recent years the port of Sines has been reported to tranship 65% of its total volume of containers handled.

In what concerns the port of Setúbal, considering that in 2017 the port handled only 4% of the total volume of containers in Portugal. The low percentage is no surprise as the port focuses mainly on Ro-Ro, dry bulk and general cargo.

As a result of the trend of containerization, the imported general cargo has been slowly decreasing since at least the turning of the millennium, as may be seen in Figure 4.4. Although the exports have experienced a period of significant growth after the crisis of 2008, they are decreasing once again since reaching an all-time high in 2015.

Note that between 1993 and 2008 the loaded general cargo was much below the unloaded general cargo, meaning that imports were more important. Since 2008 loaded general cargo has been consistently more important than unloaded cargo, indicating a greater focus of Portugal on exports.

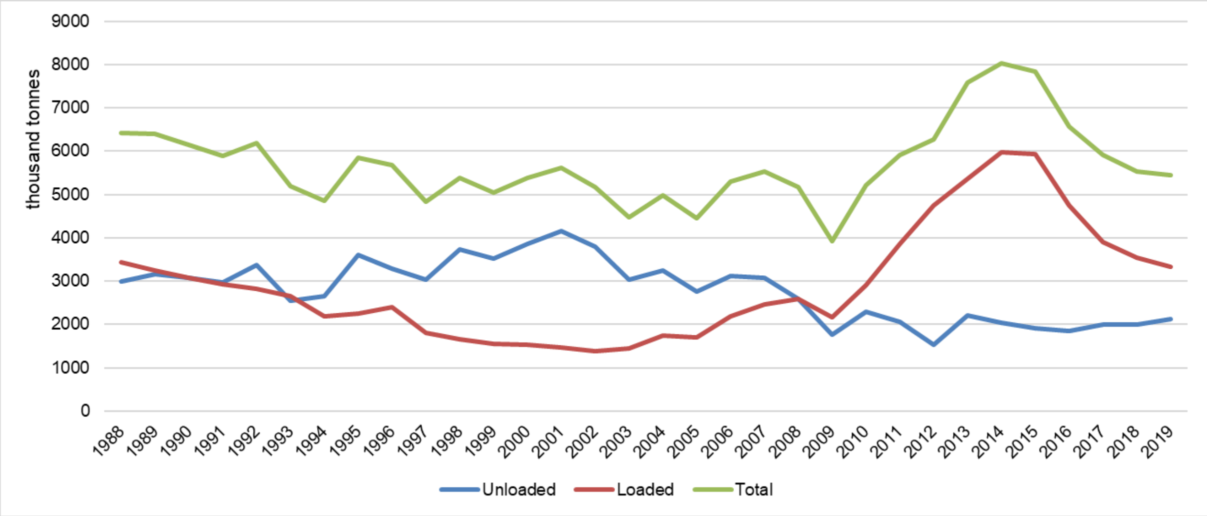

Figure 4.4 – General cargo handled in Portuguese ports

In Portugal, Ro-Ro is the most recent sector to be developed as seen in Figure 4.5. This figure shows that the national ports have had a fairly constant and relatively low performance up until 2013. From there after, both the exports as well as imports have greatly expanded with the addition of new regular Ro-Ro lines which connect the country to other European and trans-continental players.

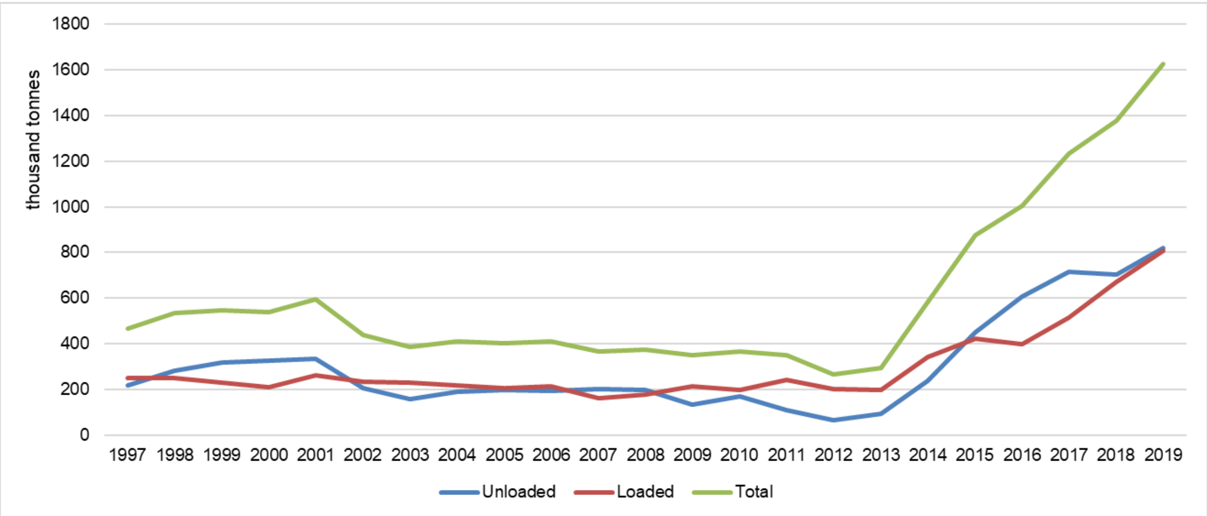

Figure 4.5 – Ro-Ro cargo handled in Portuguese ports

With the contribution of each of the Portuguese ports in the dry bulk category, the graph presented in Figure 4.6 is obtained after aggregating all the relevant data. Three observations can be made. Firstly, the overall stability seen in the sector stands out. This comes with no surprise as the major players are mostly factories and refineries which have a stable nature in terms of inputs and outputs over their lifetime. Another point that stands out is partition between loaded and unloaded cargo, where the former had a share of approximately three quarters over the total dry bulk handled in 2019. Lastly, the drop in dry bulk handled seen in the last couple of years can be explained mostly by the negative contribution of the port of Sines which in 2017 held a share of 30% in this sector.

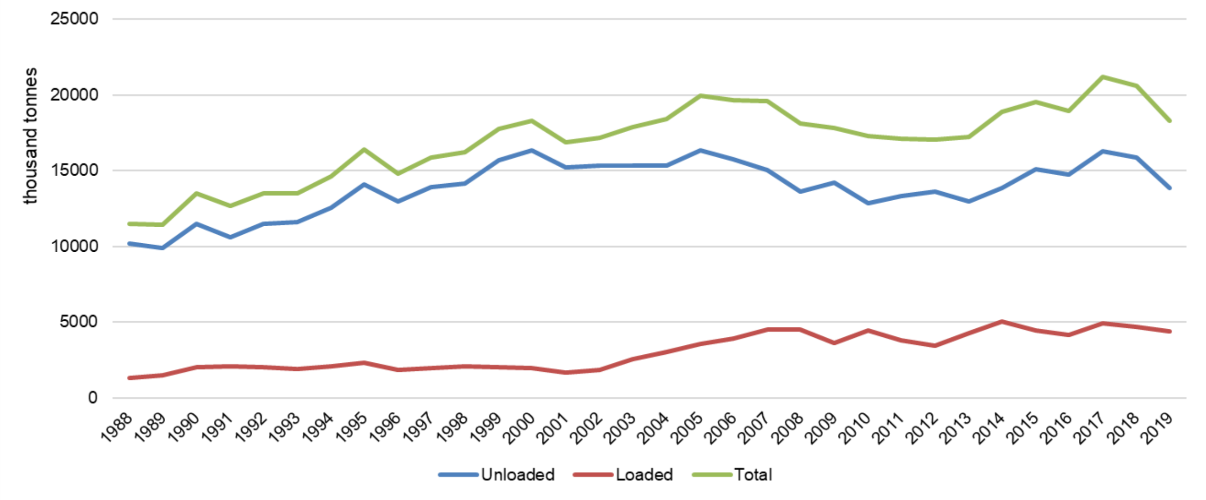

Figure 4.6 – Dry bulk cargo handled in Portuguese ports

Overall the liquid bulks sector in Portugal has had a very stable history as shown in Figure 4.7. In a similar way to the dry bulks, the main users of this type of cargo are mostly refineries and factories. Over the last 31 years the loaded cargo has had a share of approximately 27% and the unloaded cargo held the large majority with 73%, which is understandable as the industry requires larger amounts of raw materials and products.

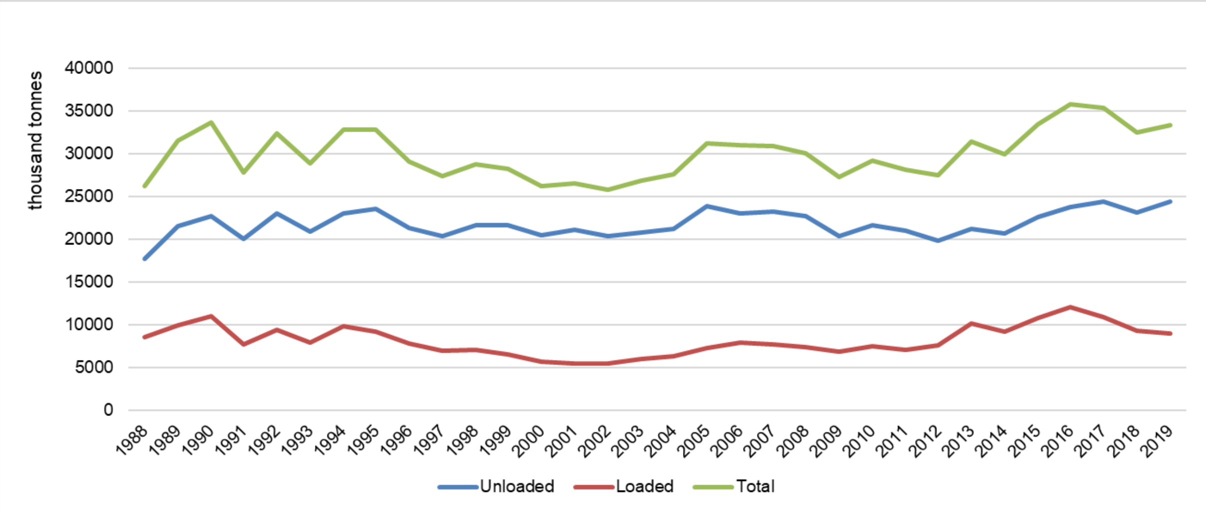

Figure 4.7 – Liquid bulk cargo handled in Portuguese ports

To summarize, shown here in Figure 4.8 the entirety of the Portuguese ports system has been stable and rather constant, hovering between the 50 and 60 million tonnes handled prior to 2004. Year in which it is possible to see the beginning of a growth period. However this positive trend was quickly hampered by the world economic crisis of 2007 and 2008. In these years there was stagnation, followed by a couple of years of decline. With the turning of the decade however, the Portuguese ports had a change of pace and resumed their growth. Eventually peaking in the beginning of 2018.

More specifically, the unloaded cargo has historically dominated with an average of 67% over the total cargo handled over the last three decades. With that said however, the loaded cargo has been growing at a faster rate

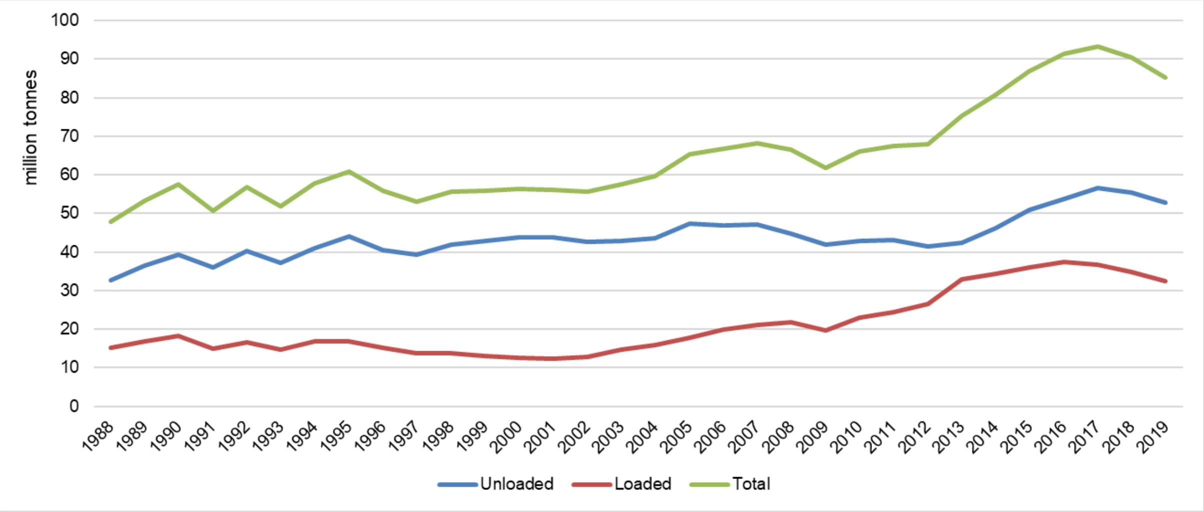

Figure 4.8 – Total cargo handled in all of the Portuguese ports

4.2 Cargo handling in the port of Leixões

Figure 4.9 depicts the performance of port of Leixões in terms of TEUs handled between 1974 and 2019.

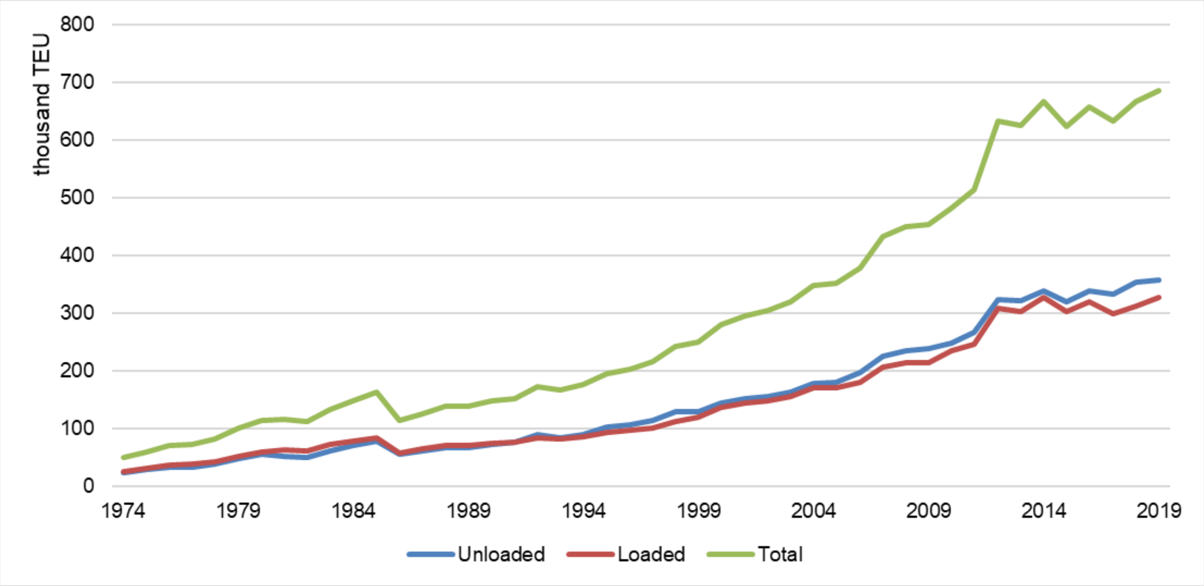

Figure 4.9 – TEUs handled in the port of Leixões

The port has been showing a nearly linear growth in terms of TEUs handled along the last 44 years. A notable event is the crisis [47] of mid 1980s caused by the rise in price of raw material coupled with the rise of taxes which led to a fall of cargo handled in the ports. This lead to the decade of 1980 being associated with the label of "Lost Decade". It is also interesting to highlight that there was a near stagnation in terms of containers handled in the last 8 years, this is due to the port having reached its maximum cargo handling capacity as seen in Figure 4.10. In addition, the lack of space for expansion due to the port's close proximity to the city urban limits hinder its expansion and require higher compelxity projects in order to overcome this constraint.

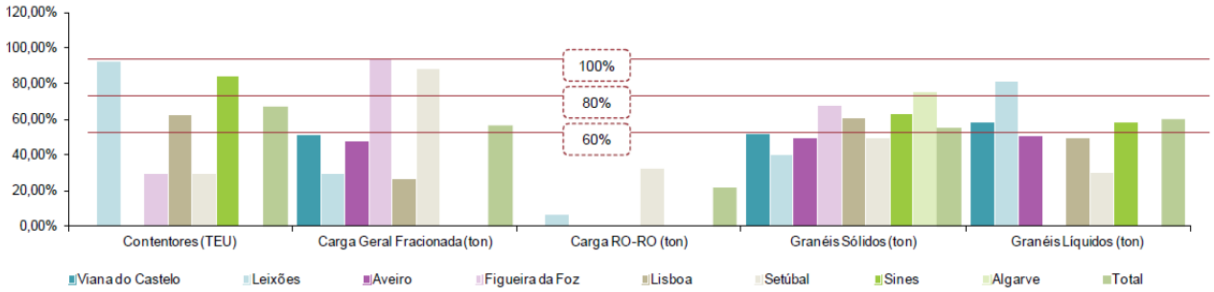

Figure 4.10 – Utilization rate of the maximum capacity of the Portuguese port system

Another significant event was the world crisis of 2008 which led the stagnation of the port's growth. However the port bounced back and and followed with an increase in the leading years as the economy recovered.

As seen in Figure 4.11, the port has been experiencing a slow reduction of the imports over the years in terms of general cargo. While for the exported general cargo a growth spur can be seen in the couple of years following the crisis of 2008, and plateauing thereafter.

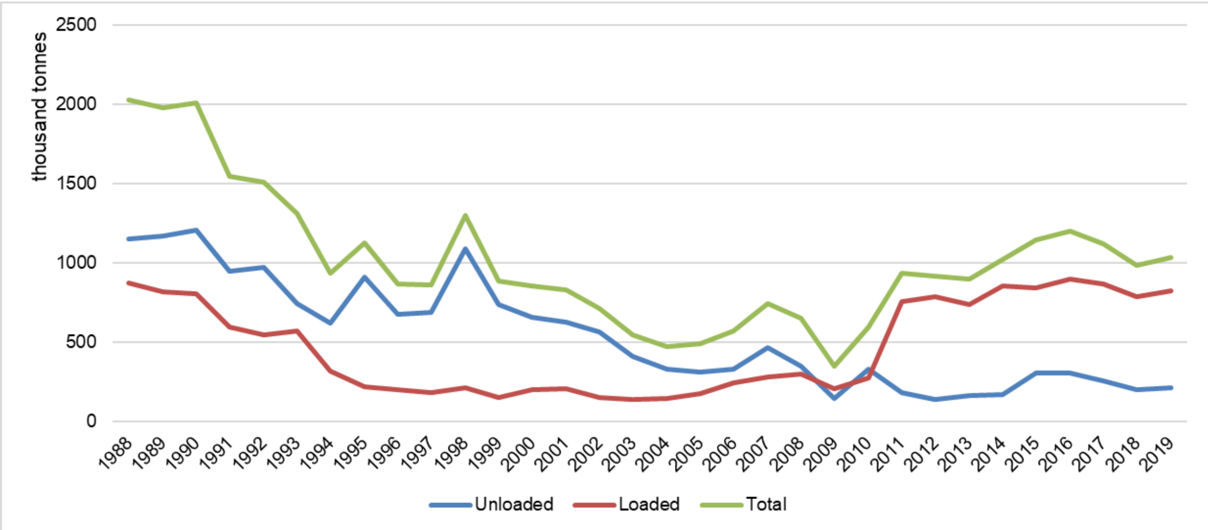

Figure 4.11 – General cargo handled in the port of Leixões

The main components of the general cargo handled in the port are iron and steel which account for approximately 81% of the total [48]. Wood and wood products were a large portion of the imports until 2007, before transitioning to the dry bulk category, thus explaining part of the reduction seen in the last two decades.

As shown in Figure 4.12, in terms of roll-on roll-off cargo, the port of Leixões had handled a few units every year from 1997 to 2012. That was until November of 2013, when the port held the inauguration of the first ever regular ro-ro line [49] connecting Leixões to the port of Rotterdam managed by CLdN Cobelfret. This line was a substitution of the previously existing lo-lo service between the two ports.

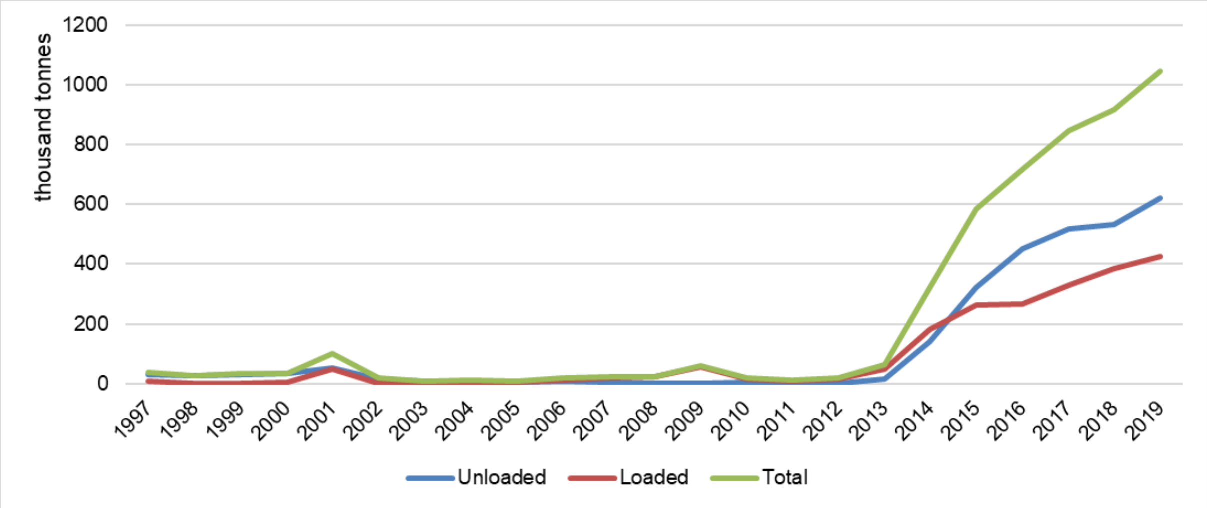

Figure 4.12 – Ro-Ro handled in the port of Leixões

The weekly line was first serviced by the ro-ro ship Adeline, agencied by Delphis, a shipping agency part of the Compagnie Maritime Belge group. Ever since its inauguration, the regular service line has been steadily increasing the volume of ro-ro cargo handled every year and allowed the port to take leadership in the sector at a nation wide level since 2014, after surpassing the port of Setúbal.

With the main industry revolving around the Leixões hinterland maintaining relatively stable production levels along the last couple of decades, the port has been keeping up with the demand of the sector. As seen in Figure 4.13 the imported dry bulk cargo has a slight tendency to grow while the exports have been decreasing since the crisis of 2008. The main products are wood chips, metal scrap, wheat and sugar. It is also interesting to note that the imported cargo has nearly 8 times the volume of the exported cargo, indicating that the area is mainly populated with facilities and services which require large ammounts of such cargo and export little to none through the same port. The main export is granite.

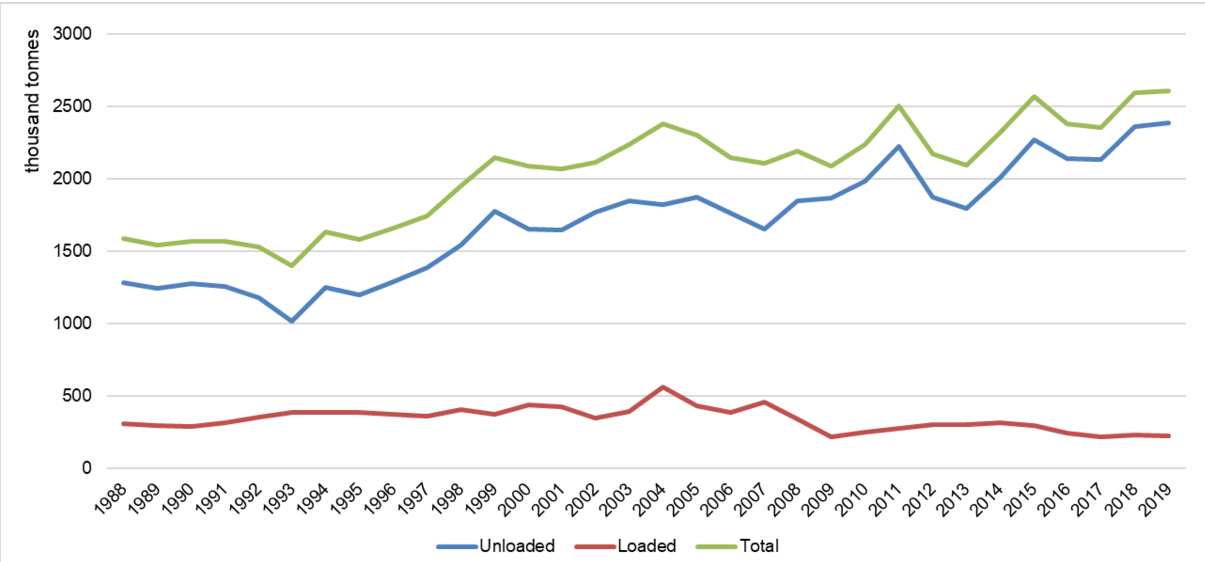

Figure 4.13 – Dry bulk handled in the port of Leixões

In a somewhat similar fashion, the liquid bulk sector has shown a stable behaviour regarding the total volume handled. However it can be seen in the Figure 4.14 that the exported liquid bulk has been increasing since 2001, while the imported cargo has been slowly decreasing since its peak in 1999. With the main consumer of crude being the Galp refinary situated in close proximity. With a processing capacity of 4.4 million tonnes of crude oil [50] per year it translating into approximately 83% of the unloaded liquid bulk in the port, meaning it has a great impact over the port's cargo handing volume.

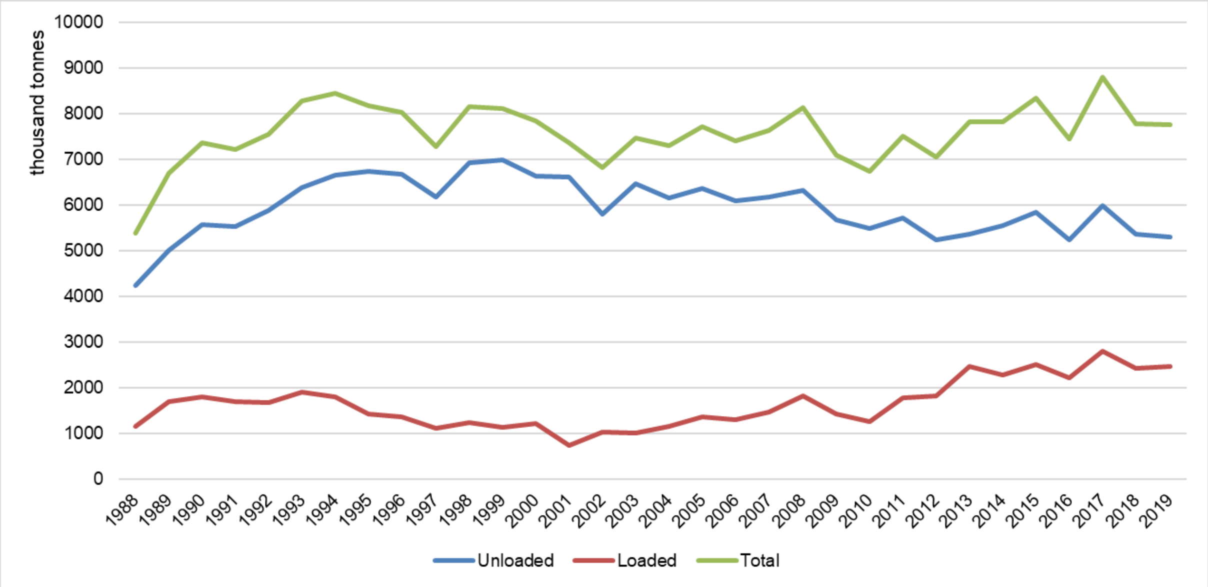

Figure 4.14 – Liquid bulk handled in the port of Leixões

Part of the reason behind the slight growth regarding exported liquid bulk might be explained by the modernization of Galp's refineries with new conversion units with the latest technology. The goal of this transformation project was to adjust the production profile of the refineries to the needs of the Iberian industry by optimizing diesel production by 2.5 million tonnes, starting in 2011, through the reduction of fuel oil production.

4.3 Cargo handling in the port of Aveiro

The port of Aveiro has no significant containerized or Ro-Ro cargo handling. It does however handle some liquid bulks, but mainly general cargo and dry bulks. Figure 4.15 shows the the general cargo handled in the port of Aveiro. The behaviour seen can be considered fairly constant in the last 31 years with most of the general cargo handled consisting of chemical wood, cement, metals and wood. In recent years, the the landscape has switched as the imports overtook the exports, for the first time since 2009.

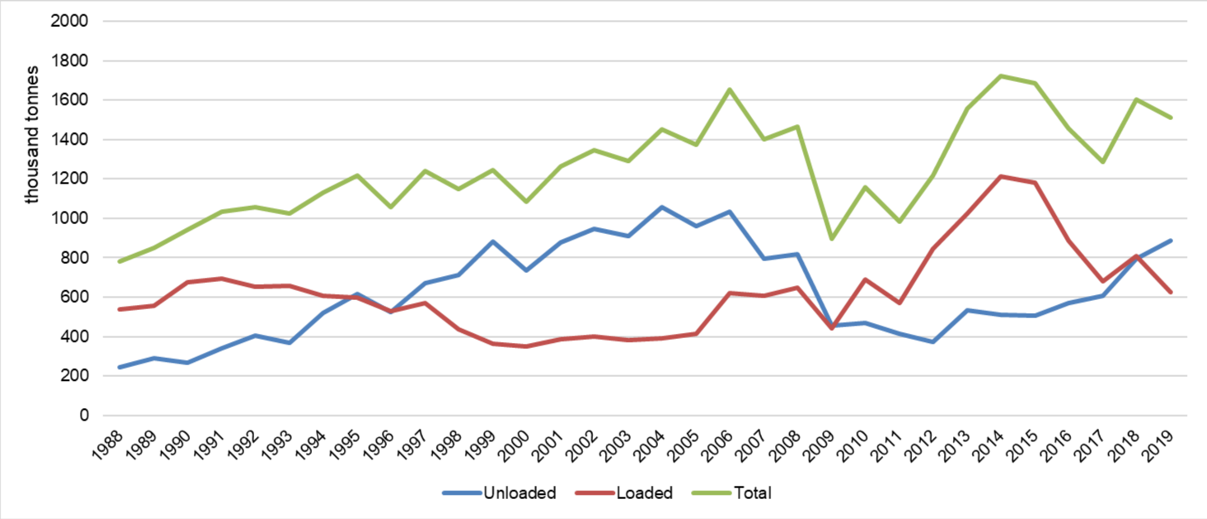

Figure 4.15 – General cargo handled in the port of Aveiro

In Figure 4.16 the dry bulk throughput can be seen. Cement, clay and carbonate are the major part of the dry bulks handled there. With wood chips, glass scraps and corn comprising over three quarters of the imported cargo. Even though the loaded cargo has been fairly constant since the end of the crisis of 2008, the unloaded cargo has been steadily rising, earning the port a positive result in terms of total cargo handled.

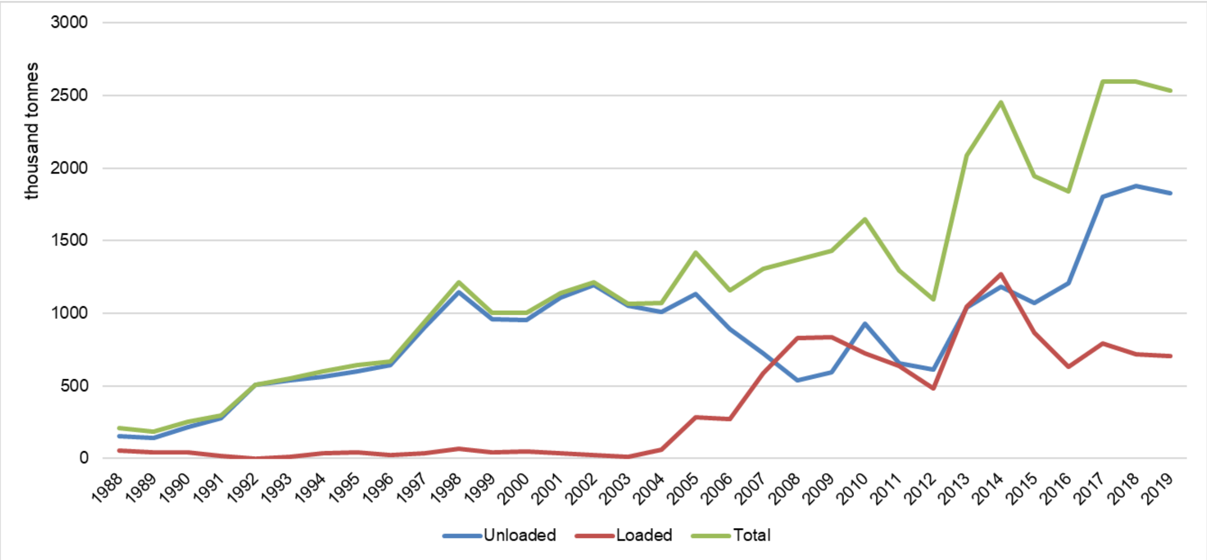

Figure 4.16 – Dry bulk handled in the port of Aveiro

With the exception of the anomaly of 2009 which can be partly explained by the crisis of 2008, liquid bulk has earned the title for the most steadily growing type of cargo handled in the port of Aveiro. As seen in Figure 4.17 the imports stand out, taking the large majority of the total cargo handled.

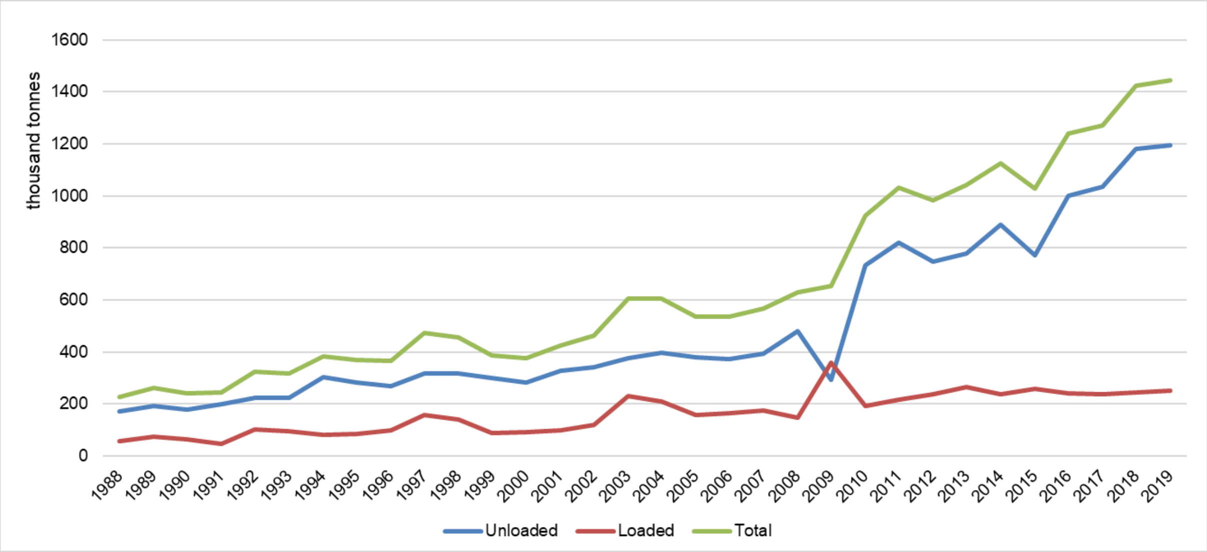

Figure 4.17 – Liquid bulk handled in the port of Aveiro

The main drivers are the players in the chemical industry such as APD Química, CUF, CIRES, DOW and FINSA which keep expanding their operations. Two other giants belonging to the petroleum and biodiesel business are BP and PRIO Energy. These also incentivize and keep the port busy in the liquid bulk terminals. On the other side however, the exports have remained practicaly constant since 1988. The main liquid bulks handled are diesel, vinyl chloride, isocyanide, benzene and methanol.

4.4 Cargo handling in the port of Lisbon

Figure 4.18 shows the performance of port of Lisbon in terms of TEUs handled between 1974 and 2019.

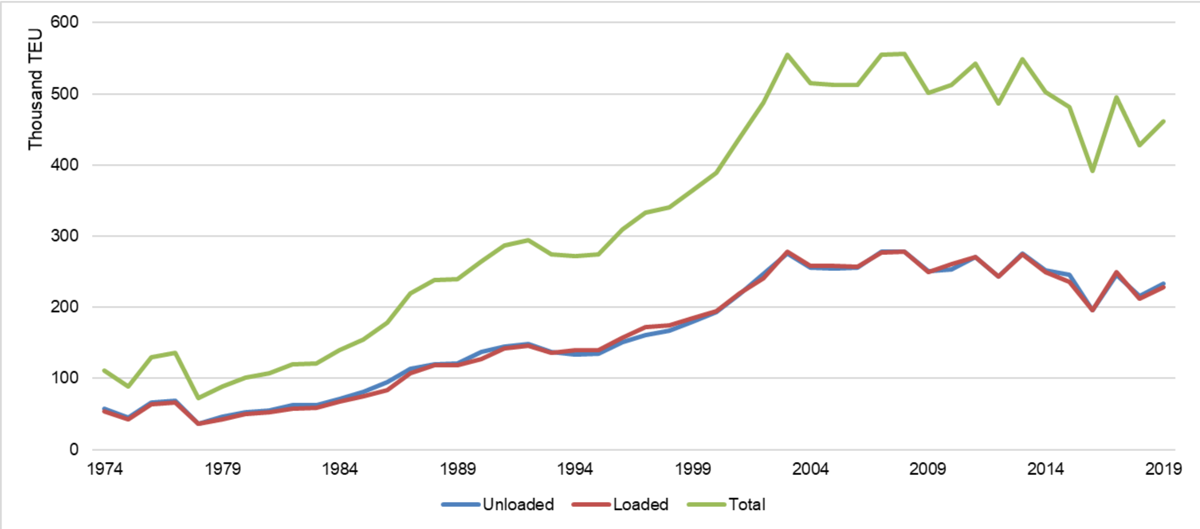

Figure 4.18 – TEUs handled in the port of Lisbon

It has been showing a nearly linear growth in terms of TEUs handled between the years if 1978 and 2000. Similarly to the port of Leixões, Lisbon was also negatively affected by the rise in price of raw materials and fuel observed in the mid 1970s. In the year of 2000 the port experienced a heavy drop in cargo flow due to the termination of the partnership with the PSA.

Figure 4.19 reveals how the cargo output has overall decreased consistently over the last 25 years. The main two reasons are the gradual containerization of cargo and also the change in the strategy for transporting cement, as it has been gradually shifting from general cargo to dry bulk. The major cargoes handled are cement, scraps of plastic, vehicles and bananas.

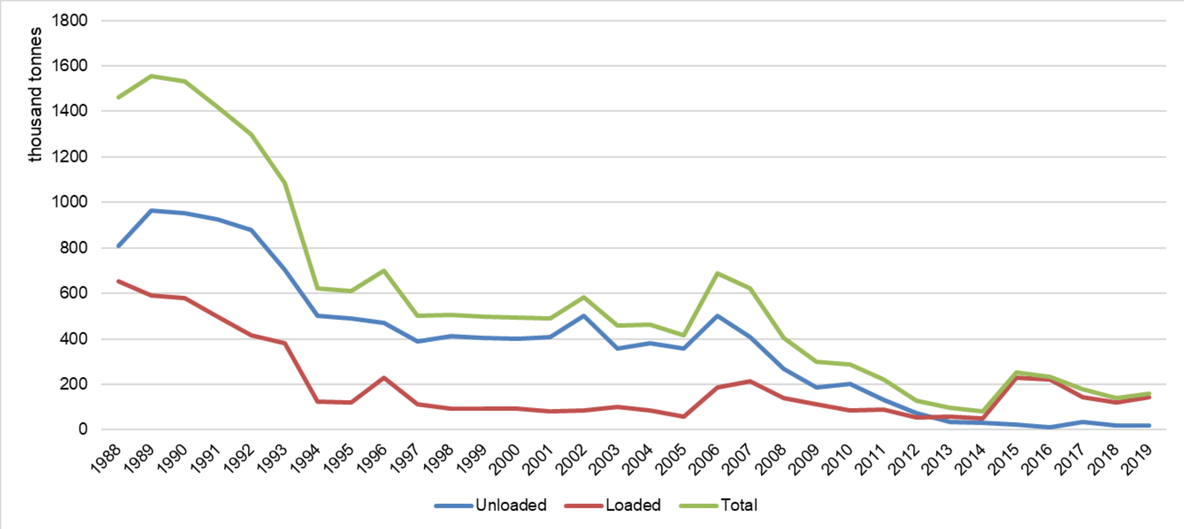

Figure 4.19 – General cargo handled in the port of Lisbon

Concerning the ro-ro sector, it may be seen that after peaking in 2009 with exports reaching all-time highs in the port, the ro-ro sector has been gradually fading out, as seen in Figure 4.20. One of the reasons may be the existing competition which the port of Setúbal imposes with its specialized and modernized ro-ro terminals.

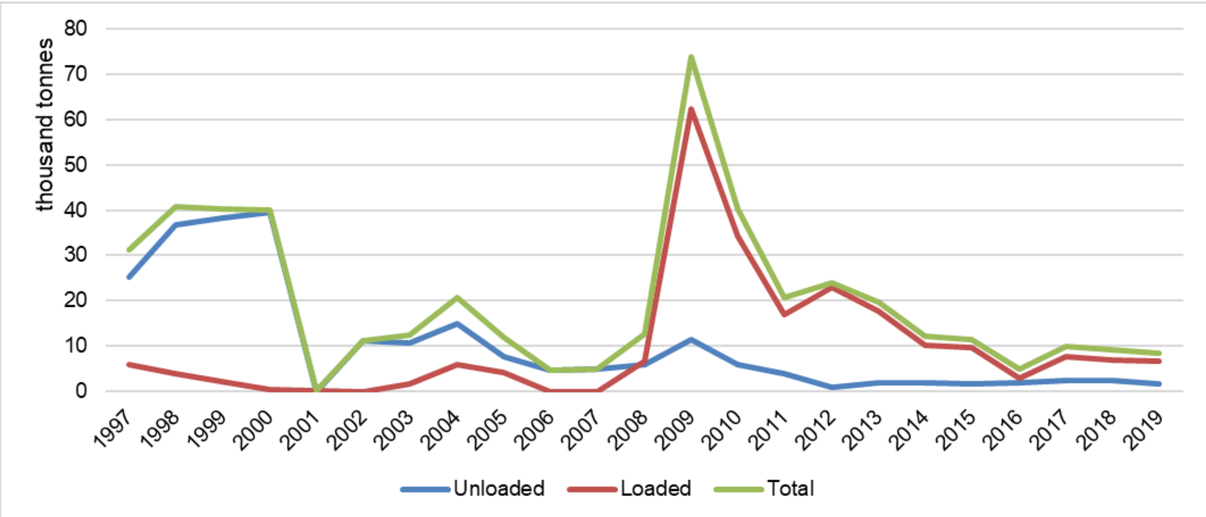

Figure 4.20 – Ro-Ro handled in the port of Lisbon

With dry bulk being its main cargo, the port of Lisbon has had a very stable performance in this sector as seen in Figure 4.21. The exported cargo shows a slight trend to grow, although it had a share of only 13% of the total dry bulk handled in 2019. On the other side, with a shave over 77% the imports have been decreasing at a steady rate over the last decades.

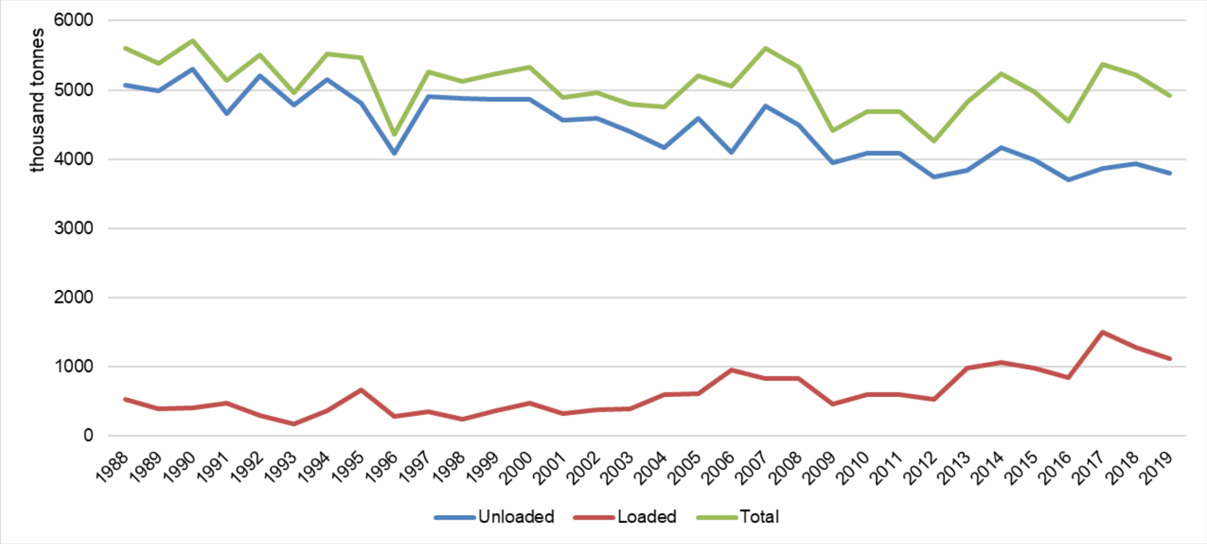

Figure 4.21 – Dry bulk handled in the port of Lisbon

The major dry bulks imported consist of mostly cereals such as corn, soy, wheat and sunflower seeds, sugar, barley and also also scrap metal [51]. These accounted for over 92% of the total imports in 2019. As for the exports, the main cargoes were cement, natural sand, fodder and fertilizer, which in 2019 accounted for 94% of the total exported dry bulk.

The total liquid bulk handled in the port of Lisbon shows severe decrease in volume in the years between 1996 and 2000. This behaviour was motivated by the closing of operation of the Lisbon oil refinery. As seen in Figure 4.22 the exported liquid bulks reached only 15% of total in 2019, while the exports maintained the stable behaviour which it has been showing since early 2000 with a share of 85%.

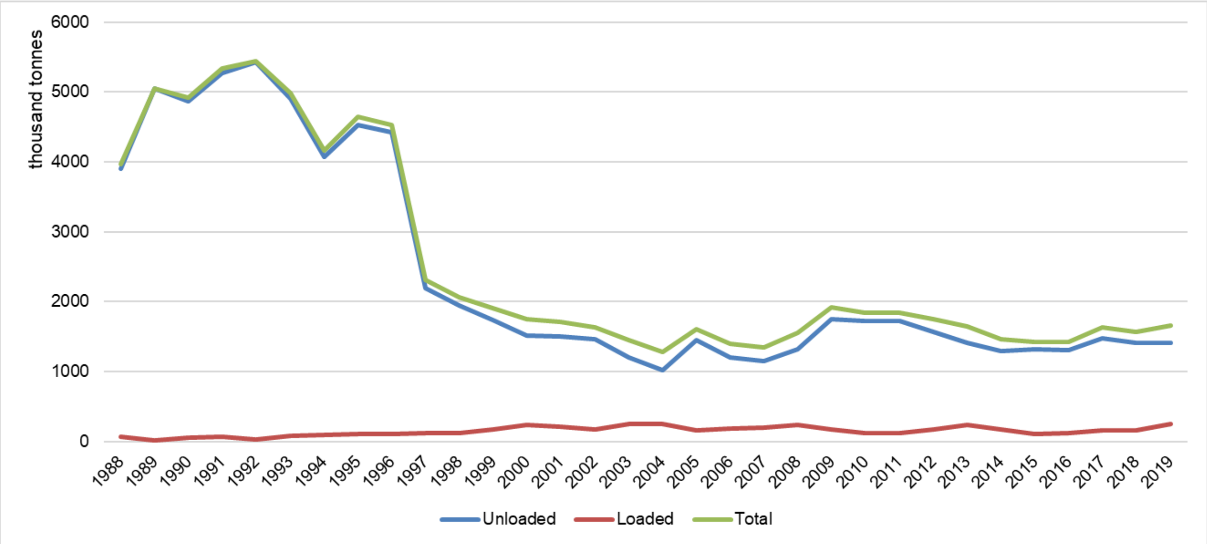

Figure 4.22 – Liquid bulk handled in the port of Lisbon

The main unloaded products are diesel, fuel oil, gasoline and ammonia which made up over 88% of the imports in 2019 according to APL [51]. As for the loaded cargo, the major products were biodiesel, fuel oil diesel and soy oil, consisting of 93% of the exported liquid bulks in 2019.

4.5 Cargo handling in the port of Setúbal

Figure 4.23 depicts the performance of the port of Setúbal in terms of TEUs handled between 1974 and 2019. It is notable how the number of loaded TEUs are nearly identical to the unloaded ones, while both have been growing since after the crisis of 2008 with a couple of exceptions in 2012 and more recently in 2018, where it suffered a decrease.

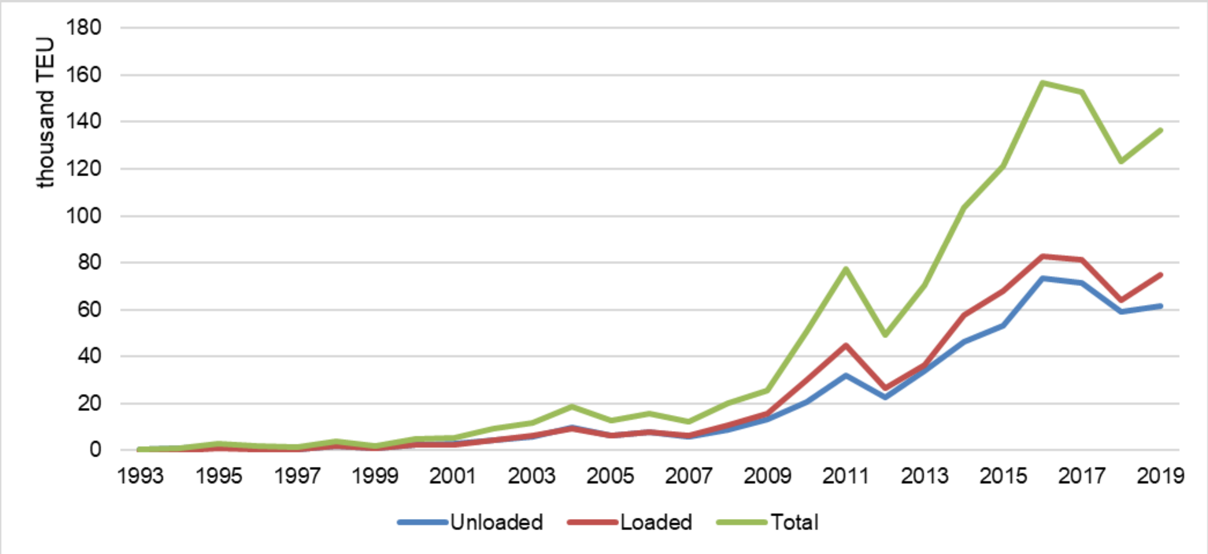

Figure 4.23 - TEUs handled in the port of Setúbal

The cargo which is most transported in the containers is primarly paper, however, with the increase of the worlwide trend in containerization, other materials and products are expanding their share in this sector.

As seen in Figure 4.24, the total general cargo handled in the port of Setúbal has had a few periods of growth, mainly in 1994 and more recently during 2011-2015 and entered a decline in the following years up until the present. This is mainly due to the loaded cargo returning values which the port hasn't seen since the global crisis of 2008, while the loaded cargo has kept a fairly steady behaviour along the years.

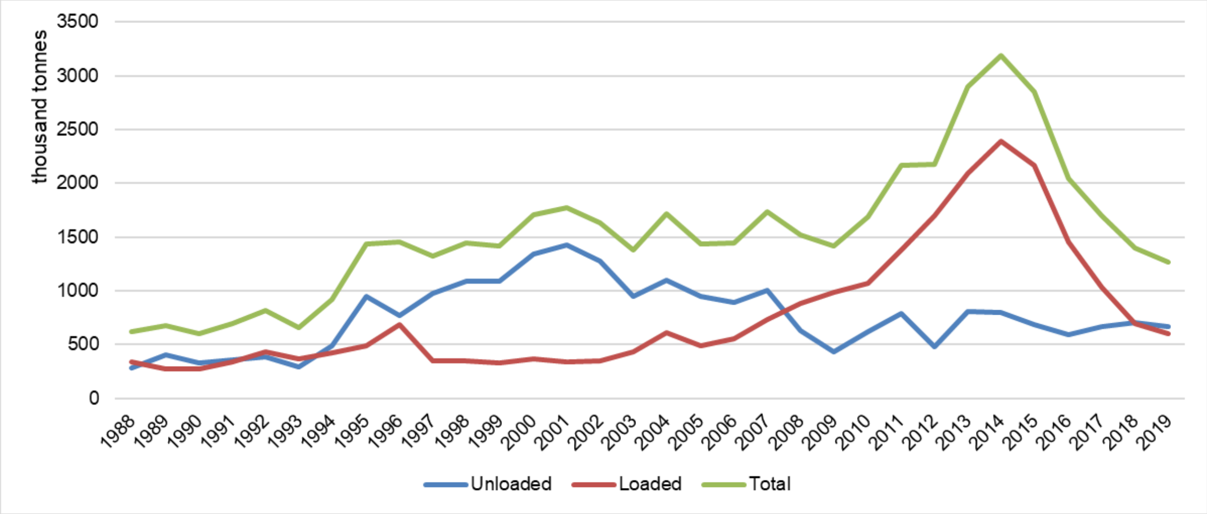

Figure 4.24 – General cargo handled in the port of Setúbal

On one hand, a large majority of the general cargo imported consists of unprocessed iron and steel as well as wood. On the other hand, most of the exports are made up by iron and steel products as well as packaged cement originating from the cement factory Secil which has its facilites in close proximity on the edge of Serra da Arrábida. The cargo that has been declining since the years of 2006 and 2008 is clinker and cement. This trend is simply a reaction of the slowing down of the giant economical and industrial growth that China has been experiencing in the last decade.

Leader in the automotive ro-ro sector at a nation wide level and equipped with a specialized terminal, the port of Setúbal held a share of over 21% in this sector in 2020 [52]. The total volume of ro-ro cargo handled in the port has decreased since the shut down of the Opel factory in Azambuja in early 2000 and lasted until 2012 as seen in Figure 4.25. However the port was able to turn the trend around in 2013 and has been growing ever since, while reaching all-time highs in 2019 as the exports kept rising.

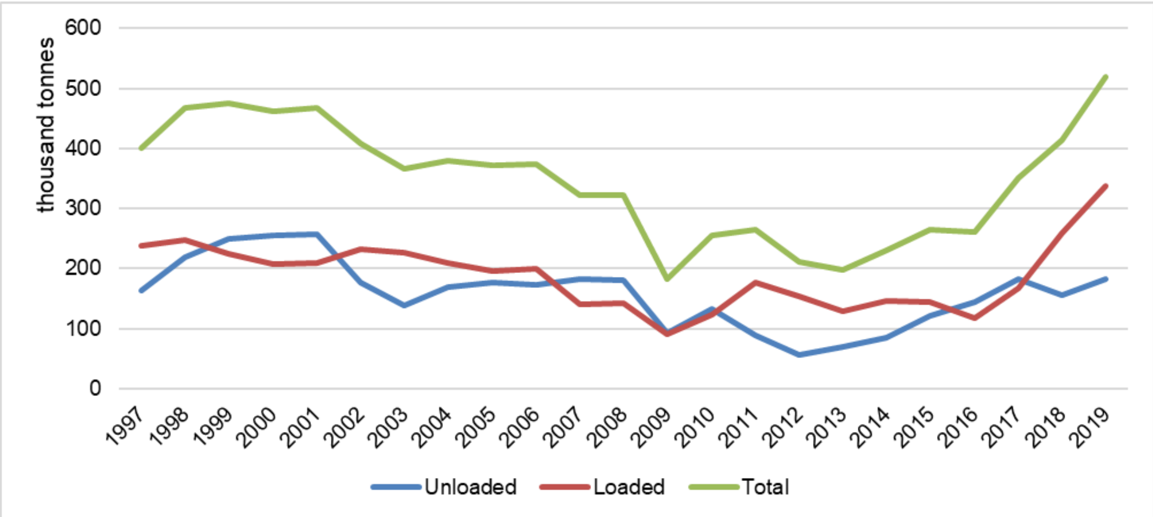

Figure 4.25 – Ro-Ro handled in the port of Setúbal

It is important to note that most of the ro-ro cargo handled consists of vehicles produced at the Autoeuropa factory. While Leixões is a link in the regular line of container oriented ro-ro logistics chain operated by the CLdN group.

Figure 4.26 shows that exports and imports traded leadership three times, in 1995, 2002 and more recently in 2018. Despite the few ups and downs, the total dry bulk has been relatively constant in the last two decades.

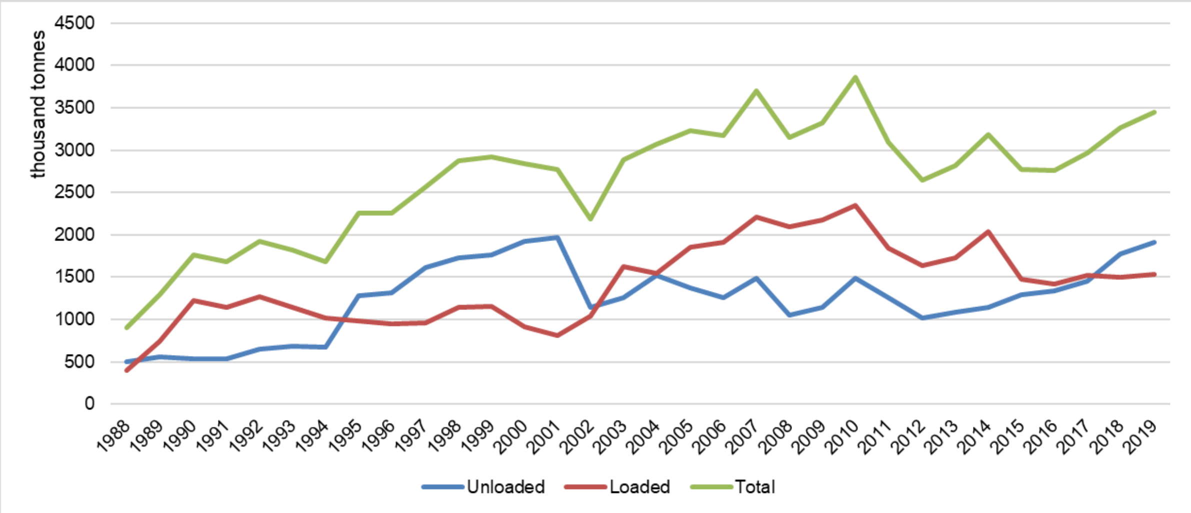

Figure 4.26 – Dry bulk handled in the port of Setúbal

The major materials being imported are coal, fertilizers and wood accounting for approximately 90% of the total imports. As for the epxorted cargo, the main players are clinker, cement, wood, marble and minerals like copper which account for around 90% of the total exports.

To finalize, the liquid bulks handled in the port of Setúbal are nearly exclusively imports. As seen in Figure 4.27 there has been a decline in the period between the years of 2006 and 2016. However the activity has stabilized in more recent years and shows a slight trend of growth. The main products handled are petroleum products and acids which account for over three quarters of the total. The main reason for the decline in unloaded liquid bulks is the closing down of the Setúbal thermal power plant running on heavy fuel.

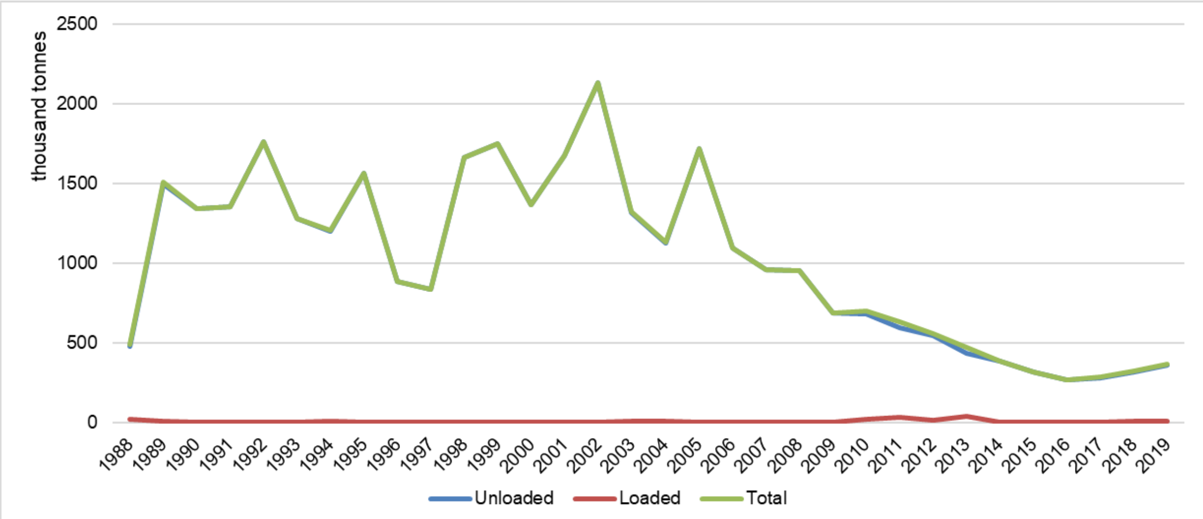

Figure 4.27 - Liquid bulk handled in the port of Setúbal

4.6 Cargo handling in the port of Sines

Figure 4.28 depicts the performance of the port of Sines in terms of TEUs handled since the inauguration of the container terminal "Terminal XXI" in 2003 up until the year of 2019. Overall the port has experienced a stable growth since its first year of operation, with the exception of 2019 where it has showed a reduction of approximately 19% relative to the previous year.

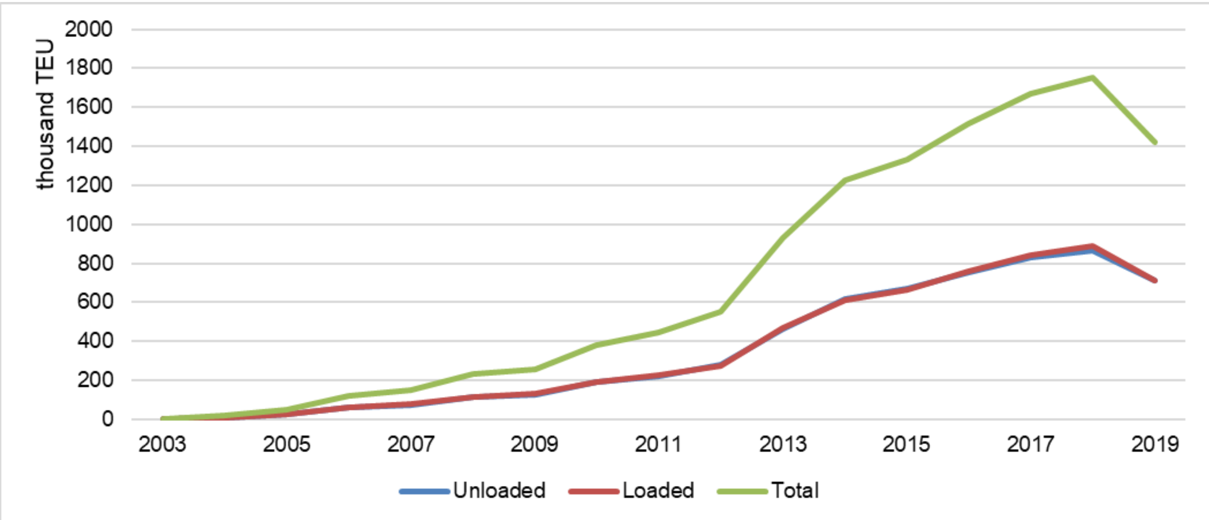

Figure 4.28 – TEUs handled in the port of Sines

With its strategically advantageous location, linking the largest shipping nations in the world, the port of nearly 67% of the containerized cargo handled in the port was transhipped. In 2020 the port leads the continental Portugal containerized cargo sector with a share of 56%, with Leixões in second place at 27%. Less stable than any other type of cargo, as seen in Figure 4.29 the total general cargo handled in the port of Sines has had two peaks that stand out, one in 1995 and a higher one in 2013. It is noteworthy the increase of the exported general cargo after the crisis of 2007 which peaked in 2013. With the main cargo in this sector being wood chips. As for the imported general cargo, it has been following the global trend of switching to containers whenever the size and weight of the cargo allows, thus translating into a steady decrease in the last years.

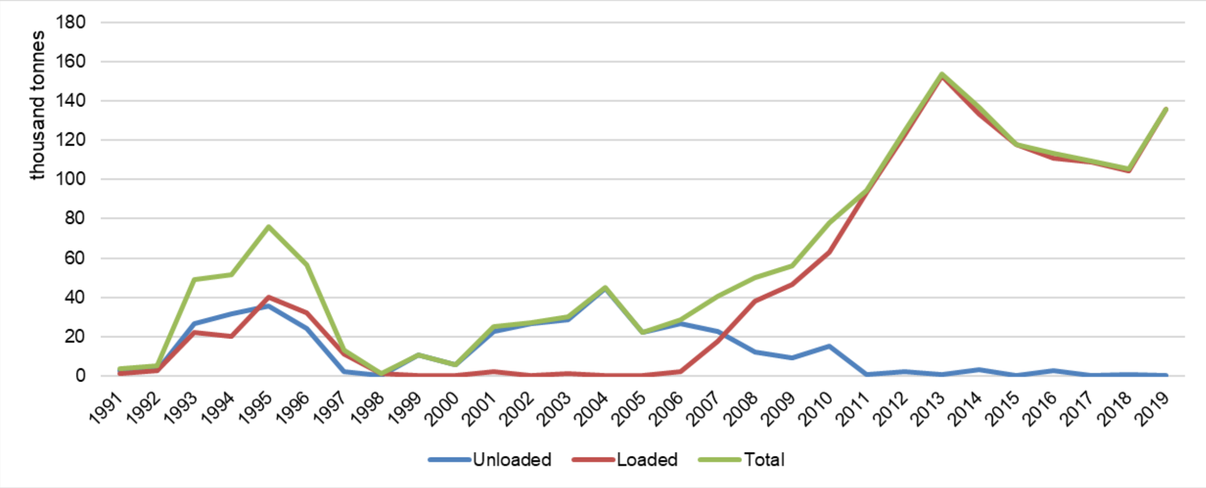

Figure 4.29 - General cargo handled in the port of Sines

The only terminal in the port of Sines to handle ro-ro, built in 1992 and further expanded in 1999 the Multipurpose Terminal has experienced a steep growth starting in 2015 in the roll on-roll off category as seen in the Figure 4.30.

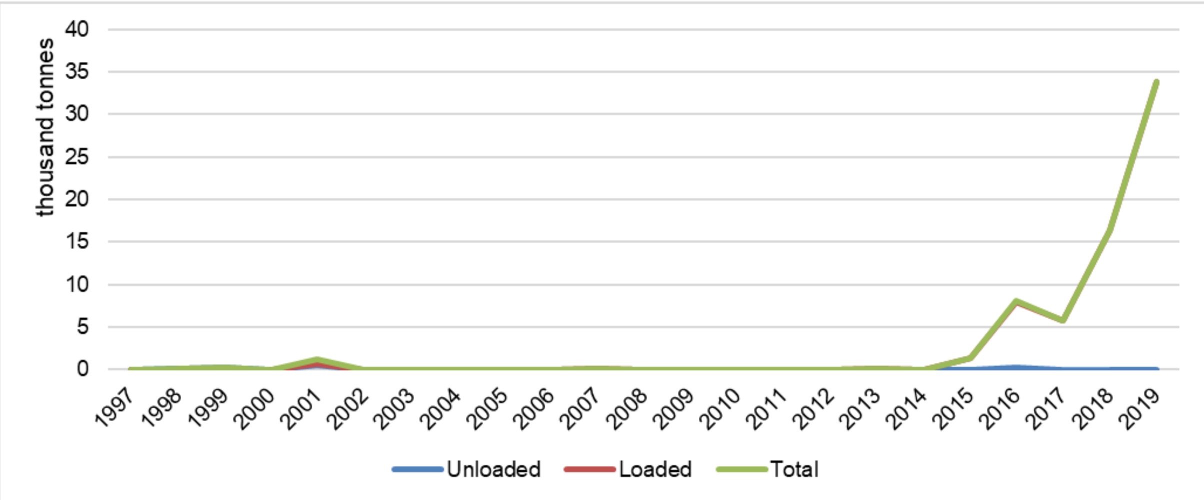

Figure 4.30 – Ro-Ro handled in the port of Sines

Host to the largest energy generating central in Portugal and the port with the deepest berths, Sines is also one of the largest importer of dry bulk in the nation. The 35 year old thermoelectric central has an installed power of 1256MW and a maximum coal consumption of 11000 tonnes/day is a giant that has kept the port of Sines busy since 1985. With coal having a share of over 98% of the imported dry bulk in the port, the relationship between the energy central and the dry bulk terminal can be described as nearly symbiotic.

Figure 4.31 demonstrates an energy dependant behaviour along the years. An initial growth phase since the start of the operation of the thermoelectric central until 1995 and stabilizing the following years. The minor ups and downs are partly a reflection of the natural behaviour the port demonstrates in an attempt to manage its stocks of coal from year to year.

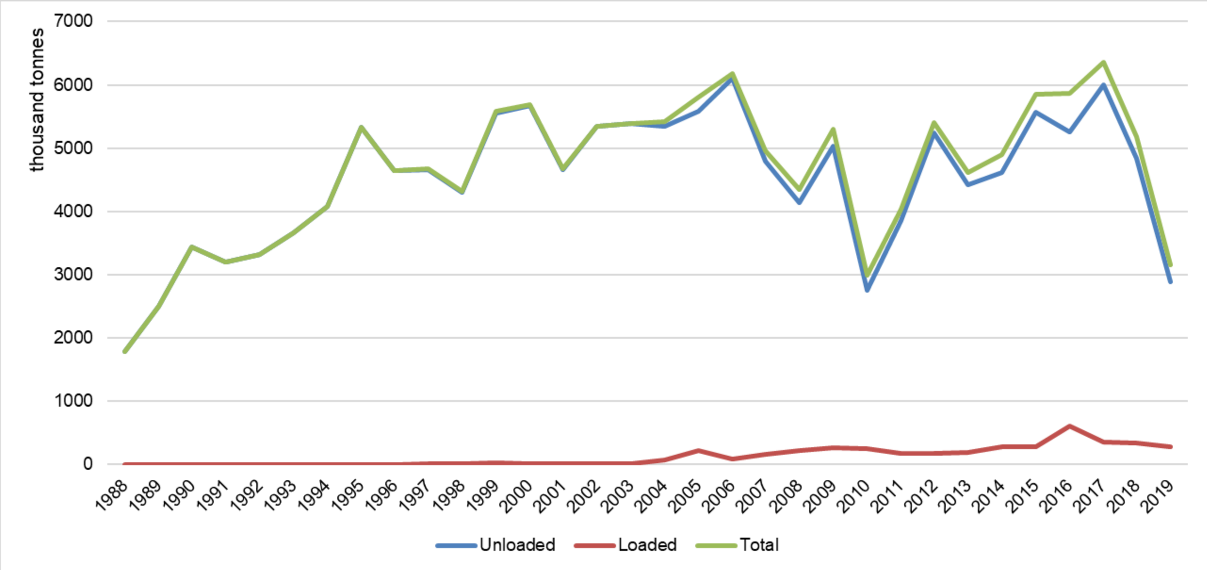

Figure 4.31 – Dry bulk handled in the port of Sines

Since early 2018 the imported dry bulk has been plummeting as expected with the thermoelectric central slowly reducing the output and entering its shut down phase. The last piece of coal being burnt in January of 2020 has officially freed the nation of coal usage for energy production. As for the central itself, there have been put on the table plans for either substituting the coal for biomass originating from the Portuguese forests or converting it into a large scale environmentally friendly hydrogen production centre [53]. Besides its thermoelectric plant, alike Leixões, Sines also hosts a refinery which requires great volumes of crude oil in their daily operation. The now 42 year old Galp refinery has a processing capacity of 10 million tonnes of crude oil [54] per year. Meaning that approximately 69% of the liquid bulk imported in the port of Sines in 2019 was destined to be delivered to this single refinery, which translates into an understandably stable and regular level of liquid bulk imported through the port.

As seen in Figure 4.32 the handled liquid bulk in the last 31 years can in fact be overall described as relatively constant, with few peaks and troughs. The modernization of the Sines refinery in 2011 may explain part of the growth of liquid bulk seen in the years between 2011 and 2016.

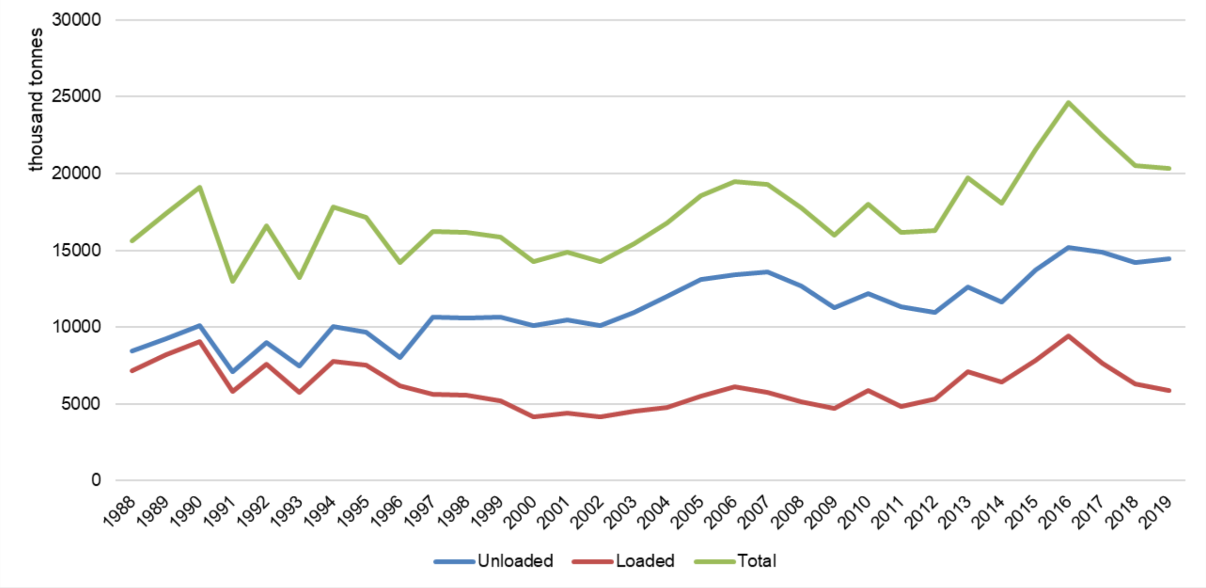

Figure 4.32 - Liquid bulk handled in the port of Sines

4.7 Impact of Covid pandemic

Wildcard events are, at best, extremely hard to predict. A great example is the ongoing COVID-19 pandemic which has slowed down the worldwide shipping industry and the global economy. Even though some methods of forecasting may account for unexpected events to some extent, the accuracy of said forecasts hardly improves. In fact, if such events are to be taken into account in a forecasting model, its margin of error is higher than other models, in an attempt to guarantee that the actual results fall within the forecasting window.

According to the report of Autoridade da Mobilidade e dos Transportes of May of 2020 [52], it is possible to assess the effects of the COVID-19 event by comparing the cargo handled in the first five months of 2020 with the homolog period in 2019.

Overall, there is a decrease of -9.3% in terms of cargo volume handled between the months of January and May when comparing with the previous year in the Portuguese ports. This corresponds to a decrease of -3.49 million tonnes, with a heavy contribution from the ports of Sines and Lisbon which suffered reductions of nearly -1.82 and -1.09 million tonnes respectively. The ports of Leixões, Setúbal and Aveiro also show reductions in terms of cargo volume handled. With their respective results being - 410250 tonnes (-5%), -182980 tonnes (-6.4%) and -98050 tonnes (-4.4%). With the smaller ports of Figueira da Foz, Faro and Viana do Castelo recording positive results of +90390 tonnes (+12.1%), +10240 tonnes (+27.1%) and 2710 tonnes (+1.6).

In order to better understand the reasons for these cargo behaviors between the two homolog periods, it is essential to analyze the types of cargo and the ports which were more penalized by the effects of the pandemic crisis.

Table 4.3 summarizes the variation of each type of cargo handled in the Portuguese ports in the last few years.

Table 4.3 – Portuguese cargo handling evolution

CARGO TYPE	2016 [t]	2017 [t]	2018 [t]	2019 [t]	2020 [t]	Δ% 2019/2020	Δ% AVG 2010/2020	Δ% AVG 2016/2020
Containerized	12650221	15511208	14018606	13417624	12776848	▼ -4.8	▲ 8.6	▼ -1.3
Breakbulk	2646771	2501611	2198155	2246618	2226989	▼ -0.9	▲ 1.1	▼ -4.5
Ro-Ro	467561	549913	667125	793160	673317	▼ -15.1	▲ 37.7	▲ 11.1
Total Containerized	15764553	18562732	16883886	16457402	15677154	▼ -4.7	▲ 6.9	▼ -1.4
Coal	2274481	2280210	1837357	1801280	234742	▼ -87.0	▼ -2.3	▼ -26.1
Mineral	398809	494356	352291	459458	499586	▲ 8.7	▲ 1.3	▲ 3.9
Agricultural	1985799	2103648	2036620	1930528	1950970	▲ 1.1	▲ 0.1	▼ -1.2
Other Solid Bulk	3115256	3361976	3509957	3342795	2989169	▼ -10.6	▲ 1.9	▼ -0.8
Total Solid Bulk	7774345	8240190	7736225	7534061	5674467	▼ -24.7	▲ 0.3	▼ -6.5
Crude Oil	6391078	5696924	5940033	4785998	5026683	▲ 5.0	▲ 2	▼ -6.4
Petrolium Products	6082565	7321176	7105898	7790815	6768124	▼ -13.1	▲ 2.5	▲ 2.7
Other Liquid Bulk	870392	934439	817784	1123056	1053545	▼ -6.2	▼ -0.7	▲ 6
Total Liquid Bulk	13344035	13952539	13863715	13699869	12848352	▼ -6.2	▲ 2	▼ -0.9
Total General	36882933	40755461	38483826	37691332	34199973	▼ -9.3	▲ 3.6	▼ -2.2
Δ%	▼ -0.2	▲ 10.5	▼ -5.6	▼ -2.1	▼ -9.3	-	-	-

Starting with perhaps the most obvious cargo type, the crude oil and its derivate products. A great reduction is observed in terms of fuel consumption both at national and international levels, especially in the ports of Leixões and Sines. This led to the inevitable exhaustion of available storage in the Matosinhos and Sines refineries. A decrease of -938.9 million tonnes corresponding to -28.1% of the handled volume in the homolog period in 2019.

One other market which was also significantly affected by the effects of the pandemic is the Ro-Ro sector, after Autoeuropa and PSA of Mangualde having suspended the production line during the months of March and April. This translated into a retraction of the number of exported automobile units and a respective reduction of total volume of cargo handed in the ports of Setúbal and Leixões.

In addition to the aforementioned sectors where the impact of declining economic activity was felt most significantly, the paper industry, whose level of development, namely the Navigator community, also a reported major slowdown, which impacted the port movement of Figueira da Foz and Leixões in particular, but also of Sines, Aveiro and Setúbal in terms of container shipment and fractional load.

All in all, the two sectors which contributed the most to the negative performance of the global port system of continental Portugal was coal in Sines and containerized cargo in Lisbon. Responsible for drops of -1.54 million tonnes and -783.3 million tonnes respectively. The explanation behind the first one is the near full stop of coal importing at a national level given the reductions of -98.8% and -74.4% of energy production in the thermoelectric centrals in Sines and Pego.

As for the drop in containerized cargo handled in Lisbon, it can be explained by the high labor instability which the port experienced due to the workers' strikes between the months of March and May. This becomes even more evident when comparing with the activity in the other national ports where this cargo has a relevant weight. Leixões shows a growth of +8.9%, Setúbal +24.6% and Sines +13.9%, while Lisbon lost -57.8%.

4.8 Main trends in cargo handling in the Portuguese ports

Table 4.4 summarizes the cargo handling volumes (in tonnes) in the main Portuguese ports during 2019. It is worth noting that some of the volumes are much more significant than other. The most important volumes are containerized cargo and liquid bulk in Sines, ro-ro and general cargo in Setúbal and Leixões and lastly dry bulk in Lisbon. The row entitled “Total” takes into account all of the Portuguese ports.

Table 4.4 – Summary of cargo handling volumes (in tonnes) in Portuguese main ports in 2019

	Containerized Cargo (TEU)		General Cargo (tonnes)		Ro-Ro cargo (tonnes)		Dry bulks (tonnes)		Liquid Bulks (tonnes)	
Port	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**
Leixões	358,506	327,304	209,736	822,543	622,166	425,077	2,385,957	220588	5298889	2460382
Aveiro	-	-	885,958	626,563	-	-	1,829,438	706657	1194531	251968
Lisbon	232,876	228,764	16,777	142,434	1,705	6,774	3800918	1123439	1407565	253356
Setúbal	61,438	75,117	669,066	598,304	181,951	337,500	1907832	1537865	358350	9005
Sines	711,607	711,607	-	135,983	-	33,832	2884953	274711	14437348	5894205
Total	1,452,530	1,462,760	2,112,258	3,338,336	819,954	807,423	13883207	4393184	24444754	8998384

Table 4.5 shows the length in years of the available data regarding the cargo handled in each of the Portuguese ports and for each type of cargo. In general, time series extends to 31 years for general cargo, dry bulks and liquid bulks. For Ro-Ro cargo statistics cover 22 years, as this is probably the period of time for which such cargo has been recorded by port authorities as such. For containerized cargo, in the ports with older container terminals (Lisbon and Leixões) 45 years of data are available, while in ports with more recent terminals (Setúbal and Sines) 26 and 16 years of data are available (corresponding with the periods of time throughout which containers have indeed been handled).

Table 4.5 – Length of time series for cargo handling volumes (in tonnes) in Portuguese main ports

	Containerized Cargo (TEUs)		General Cargo (tonnes)		Ro-Ro cargo (tonnes)		Dry bulks (tonnes)		Liquid Bulks (tonnes)	
Port	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**
Leixões	1974-2019 45 years	1974-2019 45 years	1988-2019 31 years	1988-2019 31 years	1997-2019 22 years	1997-2019 22 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years
Aveiro	-	-	1988-2019 31 years	1988-2019 31 years	-	-	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years
Lisbon	1974-2019 45 years	1974-2019 45 years	1988-2019 31 years	1988-2019 31 years	1997-2019 22 years	1997-2019 22 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years
Setúbal	1993-2019 26 years	1993-2019 26 years	1988-2019 31 years	1988-2019 31 years	1997-2019 22 years	1997-2019 22 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years
Sines	2003-2019 16 years	2003-2019 16 years	1991-2019 28 years	1991-2019 28 years	1997-2019 22 years	1997-2019 22 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years
Total	2000-2019 19 years	2000-2019 19 years	1988-2019 31 years	1988-2019 31 years	1997-2019 22 years	1997-2019 22 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years	1988-2019 31 years

Table 4.6 indicates the percentages of cargo unloaded or loaded in terms of the total volume in a given port and for a certain cargo type. Ports and cargo types dominated by unloaded cargo (mostly imports) are shown in red, while ports and cargo types dominated by loaded volumes (mostly exports) are indicated in green. In yellow are the cases in which unloaded and loaded volumes are balanced.

Table 4.6 – Summary of cargo handling volumes (percentage of total tonnes) in Portuguese main ports in 2019

	Containerized Cargo (TEU)		**General Cargo (tonnes)**		**Ro-Ro cargo (tonnes)**		**Dry bulks (tonnes)**		**Liquid Bulks (tonnes)**	
Port	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**
Leixões	52	48	20	80	59	41	92	8	68	32
Aveiro	-	-	59	41	-	-	72	28	83	17
Lisbon	50	50	11	89	20	80	77	23	85	15
Setúbal	45	55	53	47	35	65	55	45	98	2
Sines	49	51	-	100	-	100	91	9	71	29
Total	50	50	39	61	50	50	76	24	73	27

Table 4.7 shows the cargo handling average variation in the last three years of each type of cargo in each of the five major ports.

Table 4.7 – Average variation in the last 3 years (%)

	Containerized Cargo (TEU)		**General Cargo (tonnes)**		**Ro-Ro cargo (tonnes)**		**Dry Bulks (tonnes)**		**Liquid Bulks (tonnes)**	
Port	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded
Leixões	+2	+1	-11	-3	+12	+17	+4	-3	+1	+5
Aveiro	NA	NA	+16	-9	NA	NA	+17	+5	+6	+1
Lisbon	+7	+7	+36	-11	-3	+46	+1	+17	+3	+31
Setúbal	-5	-2	+5	-25	+10	+42	+13	+3	+10	NA
Sines	-2	-1	NA	+8	NA	+88	-15	-22	-2	-14

Table 4.8 shows the trends of each type of cargo in each of the five ports. Blank spaces indicate a negligible volume or none at all of a specific type of cargo in a certain port.

Table 4.8 – Summary of trends (mainly over last three years) in cargo handling volumes in Portuguese main ports in 2019.

	Containerized Cargo		General Cargo		Ro-Ro cargo		Dry bulks		Liquid Bulks	
Port	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**
Leixões	↔	↔	▼▼	↔	▲▲	▲▲	↔	↔	↔	↔
Aveiro	NA	NA	▲▲	▼	NA	NA	▲▲	↔	▲	↔
Lisbon	▲	▲	▲▲	▼▼	↔	▲▲	↔	▲▲	↔	▲▲
Setúbal	↔	↔	↔	▼▼	▲▲	▲▲	▲▲	↔	▲	NA
Sines	↔	↔	NA	▲	NA	▲▲	▼▼	▼▼	↔	▼▼

Legend of Table 4.8					
Fast decrease	Slow decrease	Stagnating	Slow growth	Fast growth	Not Applicable
▼▼	▼	↔	▲	▲▲	NA
Δ < -10 %	-10% < Δ < -5 %	-5% > Δ < 5%	5% < Δ < 10%	10% < Δ	-

Table 4.9 summarizes the most significant volumes of cargo handled in Portuguese ports in 2019. All types of cargo with volumes unloaded or loaded in a given port below the 350,000 tonnes threshold have been removed and the corresponding cell shows "INS" meaning the value is insignificant. The use of this term should be considered in the sense that such cargo type volume is much lower than most other cargos in the Table, which are in most cases in the order of millions of tonnes. After this removal of insignificant cargo volumes, 97% of non-containerized cargo still remain in the Table.

The TEU volumes have been kept as when converted to tonnes they would represent in any case more than 350,000 tonnes. Ro-Ro cargo loaded in Leixões has been kept as it is not far from the mentioned threshold. The Table also shows the major related industries/activities that explain the large volumes of cargo of a given type. Any forecast for these cargos depends mainly on the performance of the relevant industry/activity. Containerized and general cargo represent in fact a variety of different cargo types and no single industry is responsible, therefore no related industry/activity is shown.

Table 4.9 – Summary of significant cargo handling volumes (in tonnes) and major related industries/activities in Portuguese main ports in 2019

	Containerized Cargo (TEU)		General Cargo (tonnes)		Ro-Ro cargo (tonnes)		Dry bulks (tonnes)		Liquid Bulks (tonnes)	
Port	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**
Leixões	358,506	327,304	INS	822,543	CLdn line 622,166	CLdn line 425,077	Agro-food 2,385,957	INS	Refinery 5,298,889	Refinery 2,460,382
Aveiro	INS	INS	885,958	626,563	INS	INS	Agro-food 1,829,438	Cimpor 706,657	Refinery 1,194,531	INS
Lisbon	232,876	228,764	INS	INS	INS	INS	Agro-food 3,800,918	Cimpor 1,123,439	Fuel 1,407,565	INS
Setúbal	61,438	75,117	669,066	598,304	Autoeuropa 181,951	Autoeuropa 337,500	Factories 1,907,832	Secil 1,537,865	Navigator 358,350	INS
Sines	697,002	726,218	INS	INS	INS	INS	Thermal powerplant 2,884,953	INS	Refinery 14,437,348	Refinery 5,894,205

The linear regression forecasting cases will target the cargo types and ports shown in green color in Table 4.9.

4.9 Main trends in the Portuguese port system

The main trends and characteristics of the Portuguese port system is analysed and described in this section through means of four different parameters, marker share, Herfindahl Hirschman Index, rank-size rule regression and the port specialization index.

4.9.1 Market Share

Market share is a commonly used term in business, and it is normally considered as an indicator of consumer preference for a certain product in comparison to other competing goods. The market shares of different ports in a port system are often measured based on their port throughputs and used to illustrate the demographic makeup of cargo [55] [56].

$$MS_{ij} = \frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}} \times 100\% \qquad 4.1$$

Where MS_{ij} represents the market share of port j and cargo type segment i. The total number of ports is represented by n. In this case study n=5. X_{ij} is the port's throughput of cargo type i in the port j. The larger the market share is, harder it becomes for other competitors to enter the same market.

According to INE yearly report of 2020, the Portuguese ports' overall market share in the year of 2019 is presented in Figure 4.33 which was obtained by applying the formula do the Portuguese port system as a whole. The two dominating cargo types are liquid bulk and containerized cargo, each capturing over 30% of the total cargo throughput in 2019.

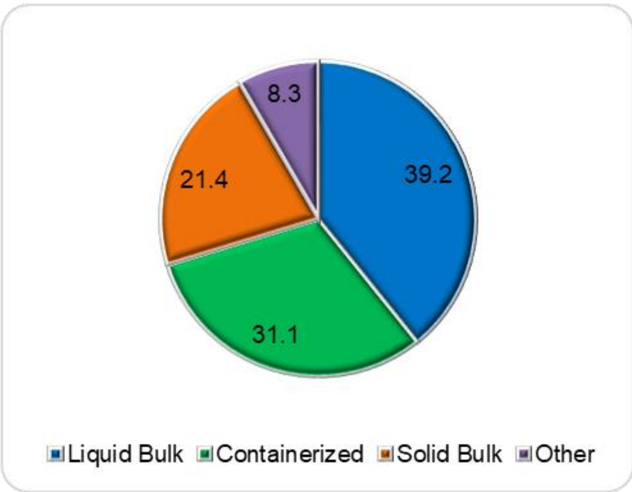

Figure 4.33 – Cargo type distribution of Portuguese ports in %

In more detail, Figure 4.34 shows the distribution of each type of cargo in each of the major ports in Portugal for the year of 2019 according to INE. The left side represents the loaded cargoes and the right side the unloaded cargoes.

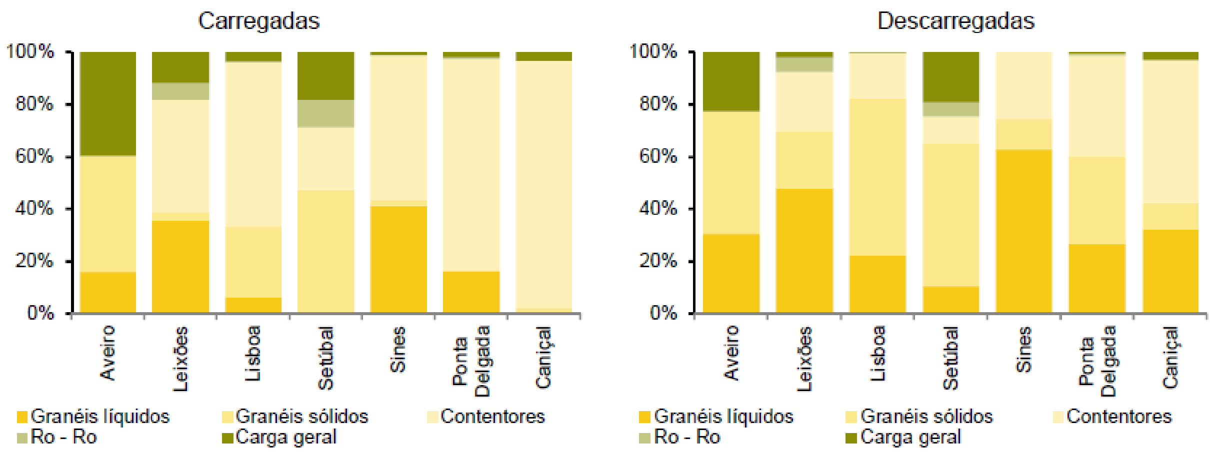

Figure 4.34 – Cargo type distribution in Portugal, by port (INE)

4.9.2 Herfindahl Hirschman Index (HHI)

The HHI is a common tool for calculating the degree of market concentration in a given sector. It is also a prominent method for determining the degree of market concentration in the port industry. In this study, the HHI is calculated with the following formula:

$$HHI_i = \left(\frac{X_{ij}}{\sum_{j=1}^{n} X_{ij}}\right)^2 \ and \ \frac{1}{n} \leq HHI_i \leq 1 \qquad 4.2$$

In which HHI_i is the index for cargo type i in the port system. n is the total number of ports. And X_{ij} represents the total port throughput of cargo type I in tonnes in the port j.

To interpret the results, a high HHI value indicates a high concentration level, and vice versa [57]. The market is considered moderately concentrated if the HHI value is between 0.15 and 0.25. While a HHI value greater than 0.25 indicates a high concentration [58].

Table 4.10 summarizes de HHI index of the main Portuguese ports, by cargo type.

Table 4.10 – Herfindahl Hirschman Index for main Portuguese ports

Cargo Type	Leixões	Aveiro	Lisbon	Setúbal	Sines
Liquid Bulk	0.06	0.00	0.00	0.00	**0.41**
Containerized	0.07	0.00	0.03	0.00	**0.27**
Solid Bulk	0.02	0.02	0.09	0.04	0.04
General Cargo	0.06	0.14	0.00	0.10	0.00
Ro-Ro	**0.42**	0.00	0.00	0.10	0.00

The values indicated in bold in Table 4.10 can be considered as high. These values imply that Sines has a high concentration level of both liquid bulk as well as of containerized cargo, which is understandable given the port's relatively high capacity of handling these types of cargoes. Leixões has a high concentration of roll-on/roll-off cargo given its capacity to handle this type of cargo in contrast to the other ports in Portugal.

4.9.3 Port Specialization Index (PSI)

In order to address the issue of competition between ports, the port specialization index can be used a measure. There have been many studies in this field, carried out by several experts and academics [59] [60]. Many formulas and methods have been proposed, however there isn't one universal way of measuring port specialization. In this study, the formula developed by Wang et al is used [60]:

$$PSI_i = \frac{n_i}{n_i - 1} \times \sum_{J=1}^{n_i} \left(t_{ij} - \bar{t}\right)^2 \; and \; \bar{t} = \frac{\sum_{j=1}^{n_i} t_{ij}}{n_i} \qquad 4.3$$

In which PSIi is the PSI of port i. ni is the number of cargo types handled in port i. tij represents the ratio of port throughput of cargo type j to the total port throughput of port i. The PSI shall always fall between 0 and 1. A port is considered to be specialized on one specific cargo type whenever the PSI has a high value. Table 4.11 summarizes specialization level of the main Portuguese ports. Most of these show a similar level of specialization, while Sines stands out with a relatively higher value. This can be justified by the port's imbalance in terms of volumes of the different cargo types handled. That is, the port handles different cargo types but the containerized cargo and the liquid bulk represent a vast majority of the total volumes.

Table 4.11 – PSI values for the main Portuguese ports

Port	**PSI**
Leixões	0.14
Aveiro	0.14
Lisbon	0.22
Setúbal	0.17
Sines	0.60

5. FORECASTING CARGO HANDLING IN THE PORTUGUESE PORT SYSTEM: 2021-2030

5.1 General methodology

Multiple linear regression is considered as appropriate for containerized and general cargo and will be used in the cases indicated in Table 5.1 as MLR. Some other types of cargos in specific ports have been considered to be not very significant in terms of the overall cargo throughput in Portuguese ports. These are indicated in Table 5.1 as insignificant (INS) and the criterion for this categorization was having a low throughput value in 2019 (generally below 300,000 tonnes). Most of the other significant cargos are closely related to specific industries situated around the ports and their behavior will be forecasted using extrapolations of their trends and qualitative considerations connected with the activity of related industries.

Table 5.1 – Summary of significant cargo handling volumes (in tonnes) and major related industries/activities in Portuguese main ports in 2019

	Containerized Cargo (TEU)		**General Cargo (tonnes)**		**Ro-Ro cargo (tonnes)**		**Dry bulks (tonnes)**		**Liquid Bulks (tonnes)**	
Port	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**	**Unloaded**	**Loaded**
Leixões	MLR	MLR	INS	LR with GDPs and Extrapolation	Extrapolation	Extrapolation	Grains 2,385,957	INS	Galp (crude oil) 5,298,889	Galp (products) 2,460,382
Aveiro	INS	INS	Extrapolation	Extrapolation	INS	INS	Grains 1,829,438	Cement (Cimpor) 706,657	Oil Products 1,194,531	INS
Lisbon	MLR	MLR	INS	INS	INS	INS	Grains 3,800,918	Cement (Cimpor) 1,123,439	Fuel 1,407,565	INS
Setúbal	MLR	MLR	Extrapolation	Extrapolation	LR with Portuguese GDP growth	LR with world GDP growth	Diverse Industries 1,907,832	Cement (Secil) 1,537,865	Paper (Navigator) 358,350	INS
Sines	MLR	MLR	INS	INS	INS	INS	Coal (EDP thermal powerplant) 2,884,953	INS	Galp (crude oil) 14,437,348	Galp (Products) 5,894,205

5.2 Linear regression forecasting

One of the most fundamental and widely used method of predictive analysis is the linear regression. The aim of a regression is to look at two things:

- Is it possible to forecast an outcome (dependent) variable using a series of predictor variables?
- Which variables in particular are important predictors of the outcome variable, and how do they influence the outcome variable?

5.2.1 General equations

These regression estimates are used to describe how one dependent variable interacts with one or more independent variables. The formula below is the simplest version of the regression equation with one dependent and one independent variable.

$$y = b + mx \qquad (5.1)$$

Where y is the dependent variable, b is the constant intercept (when x=0), m is the regression coefficient and x the score on the independent variable.

5.2.2 Explanatory Variables

In order to create a forecast of port throughput with a linear regression, it is necessary to choose a parameter to serve as a foundation. In these forecasting exercises, the GDP has been chosen due its high impact on the nation's consumption behavior which in turn dictates the level of activity in each of the major ports. On one hand, periods of economic growth lead to higher consumption from the population as these find themselves in a financially advantageous situation. While on the other hand, whenever a nation is going through periods of financial instability or stagnation, the majority of the population - i.e. the middle class - will be more cautious and avoid unplanned spending. Thus leading to a reduction of the cargo volume handled in the nation's ports. This type of events are amplified in extreme conditions such as is the case of world economic crisis of national financial instability during political controversies – e.g. the ongoing crisis seen in Venezuela marked by a mix of hyperinflation, escalating crime, starvation, disease, and mortality rates.

In addition to the Portuguese GDP, it would be interesting to include the GDP of other countries which are directly connected to Portugal via major shipping lines. According to AMT [61], the most active export destinations are USA, Spain, UK and Netherlands, with the main products being oil products, cement, lime and basic chemicals.

Among the major imported products are crude oil, natural gas, cereal, energy derivatives and coal with main origins in Angola, Nigeria, Ukraine, Spain and Colombia respectively.

With that said, initially the historical GDP data of the following seven nations has been chosen to forecast the cargo throughput in the aforementioned Portuguese ports: Portugal, Italy, Germany, USA, Netherlands, France and Brazil.

5.2.3 Data preparation and evaluation

After gathering all the data for the independent variables as well as the dependent variable, it is important to prepare them before proceeding with the implementation in the model.

The first step is to test for multicollinearity between independent variables. In statistics, independent variables must not be correlated. Otherwise this can undermine the statistical significance of an independent variable, this leading to the introduction of errors in the model and reducing its predicting accuracy. In order to test multicollinearity, one must measure the strength of the correlation between all independent variables by pairs.

Excel's data analysis add-in "t-Test: Paired Two Sample for Means" can be used to obtain the Pearson's correlation coefficient, denoted by "r". This measures the linear correlation between two data sets. It is the covariance of two variables, divided by the product of their standard deviations, thus can be considered a normalized measurement of the covariance, such that the result always has a value between −1 and 1. Pearson coefficient is given by:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - y)}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{5.2}$$

A correlation coefficient above 0.5 can be considered as high, meaning there is a strong correlation [62].

Additionally, one can calculate the variance inflation factor or VIF for short. If the independent variables are correlated, the VIF determines how often the variance of an estimated regression coefficient increases. We're looking for precise estimates, so more variance is bad. The model will become less accurate as the variance of the coefficients increases. Typically values of VIF above 10 indicate that there may be a problematic case of multicollinearity. Variance inflation factor is given by:

$$VIF = \frac{1}{1 - R^2} \tag{5.3}$$

Where R is the correlation coefficient between two independent variables.

Another parameter to be taken into account in a MLR analysis is the p-value. For each term, the p-value is used to evaluate the null hypothesis that the coefficient is zero (has no effect). The null hypothesis can be dismissed if the p-value is less than 0.05. In other words, since changes in the predictor's value are related to changes in the response variable, a low p-value predictor is likely to be a useful addition to the model. A higher p-value, on the other hand, implies that changes in the predictor are unrelated to changes in the response. In this case the independent variable can be considered insignificant to the model [63].

5.3 Linear Regression applied to Containerized cargo

5.3.1 Domestic containerized cargo

With all the data gathered and ordered, it is possible to proceed with the generation of the forecast with the aid of Excel's functions. Although it will be seen that the MLR model is inadequate for this study, it was kept in the first forecast as an example of its issues. Below are the main parameters of the multiple linear regression obtained through the Excel "Data Analysis" add-on.

Table 5.1 – Main parameters of the multi linear regression

Regression Statistics	
Multiple R	0.996
R^2	**0.993**
Adjusted R^2	0.991
Standard Error	43971
Observations	46

Table 5.2 – Analysis of variance (ANOVA) parameters

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8	9.99502E+12	1.24938E+12	646.2	**2.5E-37**
Residual	37	71537228090	1933438597		
Total	45	1.00666E+13			

Table 5.3 – Characteristics of the explanatory variables

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	134861	48799	2.76	0.01	35985	233738
BRA	0.23	0.07	3.27	0.00	0.09	0.37
FRA	-0.30	0.61	-0.49	0.63	-1.55	0.94
DEU	-0.03	0.12	-0.28	0.78	-0.28	0.21
ITA	-0.57	0.22	-2.60	0.01	-1.01	-0.13
NED	0.11	0.99	0.11	0.91	-1.89	2.11
PRT	1.24	2.17	0.57	0.57	-3.16	5.65
GBR	1.06	0.49	2.14	0.04	0.06	2.05
USA	-0.03	0.07	-0.40	0.69	-0.17	0.11

The first and most important parameter worth being mentioned is the R^2, with a value of 0.993 it gives the model a great fitness. This means that 99.3% of the variation seen in the historical data of the TEUs handled are explained by 8 variables used. Secondly, the “Significance F” of 2.5E-37 means the group of variables pass the null hypothesis test ($p\text{-value}<0.05$).

Even though the MLR model has a great fitness, as seen in Table 5.3, most of the independent variables have no significance ($p\text{-value} > 0.05$). Meaning that they add no value to the model, only making it more complex and prone to generate inaccurate forecasts due to overfitting.

The values of the VIF parameter between GDPs (e.g. PRT vs ITA, FRA vs USA, etc.) were found to be higher than 10, which also indicates that the MLR is not a suitable method in this case due to multicollinearity.

Plotting the results, Figure 5.1 is obtained. The circles represent the historical data of the containers handled in TEUs, the squares demonstrate the trend extrapolated until 2030. The diamond shaped marks are a simple linear regression based only on the Portuguese GDP. Lastly, the triangle markers represent the multi linear regression (MLR) equation until 2020 and the forecast for the period between 2020 and 2030 based on IMF forecasts for economic growth. The MLR equation is based on 8 explanatory variables, being the GDP of Brazil, France, Germany, Italy, Netherlands, Portugal, Great Britain and the USA.

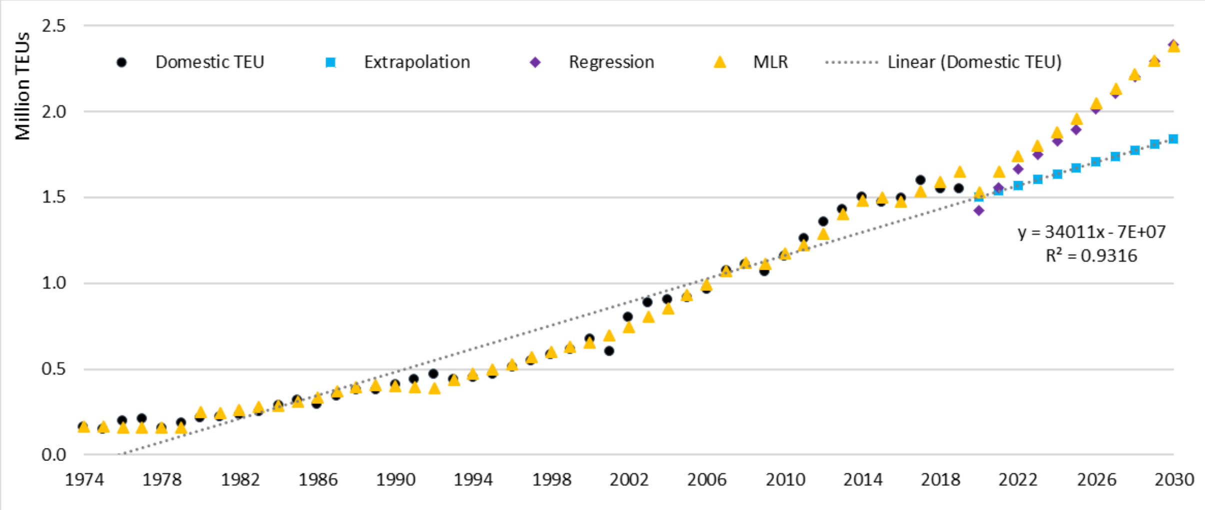

Figure 5.1 – Forecast of the Portuguese domestic TEUs handled

The equation representing the multi linear regression is the following:

$$Y = 134861 + 0.23 * BRA - 0.3 * FRA - 0.03 * DEU - 0.57 * ITA + 0.11 * NED + 1.24 * PRT + 1.06 * GBR - 0.03 * USA \quad 5.4$$

Where *Y* is the total number of TEUs handled in the Portuguese port system and *BRA, FRA, DEU, ITA, NED, PRT, GBR* and *USA* represent the GDP of the respective nation on any given year.

Even though the MLR and the simple linear regression generate similar results, the former breaks a couple of rules of statistics. The first rule is that correlated independent variables shall not be used, the second rule, is that independent variables must be significant, that is, their p-values must be under 0.05.

The simple linear regression model using the Portuguese GDP as the explanatory variable is the better method in this study. Thus it is applied to the remainder of the forecast study whenever possible. Figure 5.2 shows the evolution of the Portuguese GDP as well as a forecast until 2030 according to IMF [64].

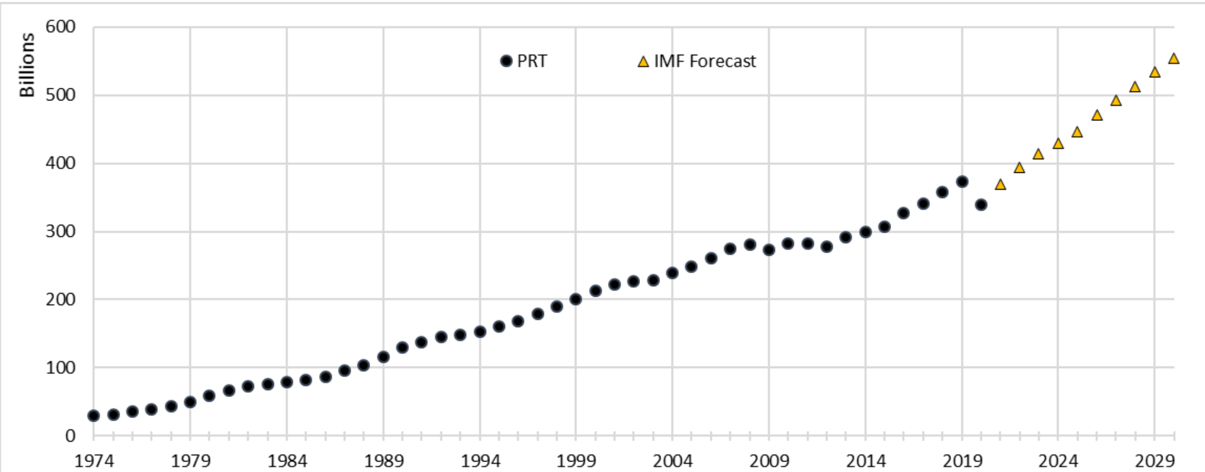

Figure 5.2 – Portuguese GDP and its forecast up to 2030

It is interesting to project an optimistic and conservative scenarios. As such, Figure 5.3 shows the possible outcomes of the different scenarios regarding the domestic containerized cargo. The optimistic scenario is generated through a linear regression using the Portuguese GDP (as forecasted by IMF) and has very high R coefficient of 0.97. However, this extreme rate of growth is very unlikely when considering the negative effects of the pandemic. The conservative scenario (probably more likely one) is generated by extending the cargo trend seen in the last 4 years. To note that the drop of the linear regression seen in 2020 is due to the fall of the Portuguese GDP for the same year.

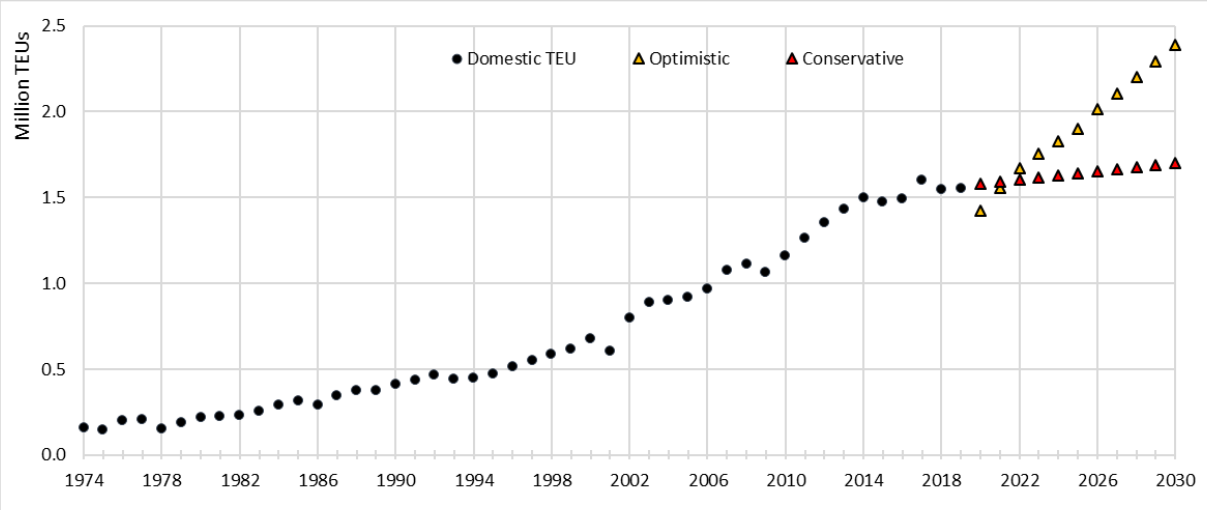

Figure 5.3 – Optimistic and conservative scenarios of the domestic containerized cargo forecast

5.3.2 Containerized transhipment cargo

The objective of the second forecast is to find a correlation between the transhipped containerized cargo in the port of Sines and the world's GDP. Figure 5.4 shows the nearly linear growth of the world GDP and its forecast up to 2030 published by IMF [64].

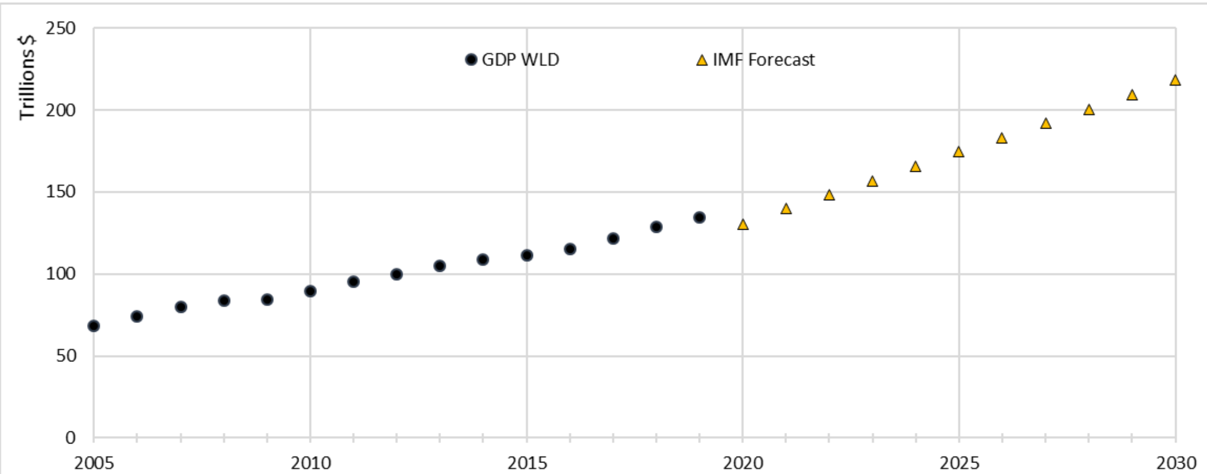

Figure 5.4 – World GDP and its forecast until 2030

Figure 5.5 shows the simple extrapolation of the trend of containerized cargo transhipped in the port of Sines as well as the forecast with a linear regression based on the world's combined GDP. Three cases are presented, a very optimistic case generated by a linear regression with a high R value of 0.94. An optimistic case generated by an extrapolation which extends the trend seen between 2013 and 2019. This scenario could be justified by the ongoing plans of expanding the container terminal as well as the current recovering trend of the global economies. And lastly a conservative scenario generated by extending the trend seen between 2016 and 2019. An argument for this scenario could be that the Chinese exports will likely begin to slow down in the next years.

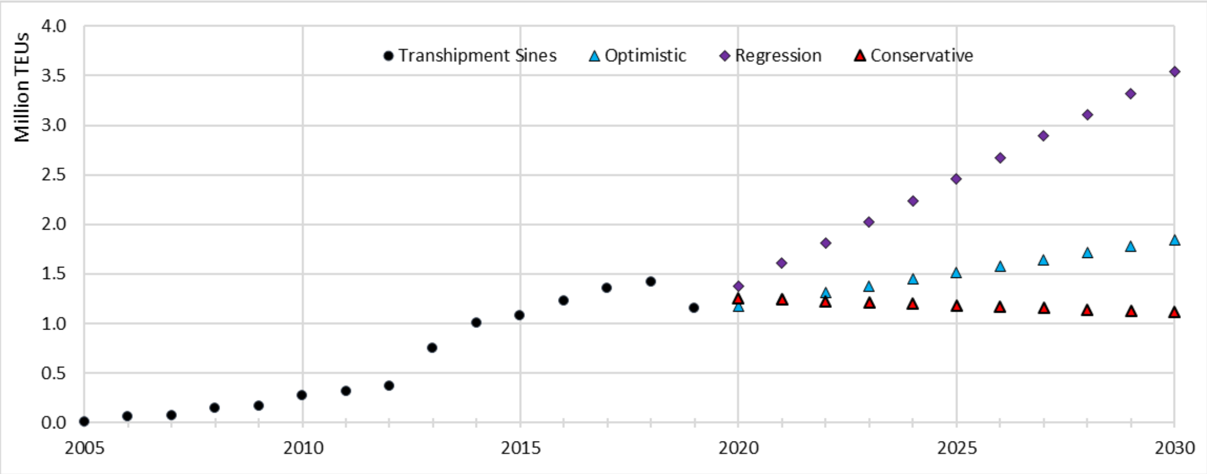

Figure 5.5 – Transshipped containerized cargo in the port of Sines

5.3.3 Containerized cargo in Leixões

Using the GDP Portugal as the explanatory variable, the linear regression method was applied to this cargo sector in Leixões. Figure 5.6 shows the resulting values of this forecast. With such a strong correlation coefficient R of 0.95, given the positive upwards trend of the GDP, the unloaded containerized cargo is expected to grow alongside. More recently, there has been a nearly stagnating trend seen since 2012. This is a classical behaviour whenever a port approaches its maximum handling capacity due to the physical restrictions. However, the optimistic case generated by the linear regression is still possible given the ongoing plans of expanding the container handling terminal in the next few years [65]. Otherwise, the cargo handling volume is expected to hover around the levels seen in the most recent years, as shown by the extrapolation. The drop seen in 2020 is partly due to the fall of the Portuguese GDP in that year.

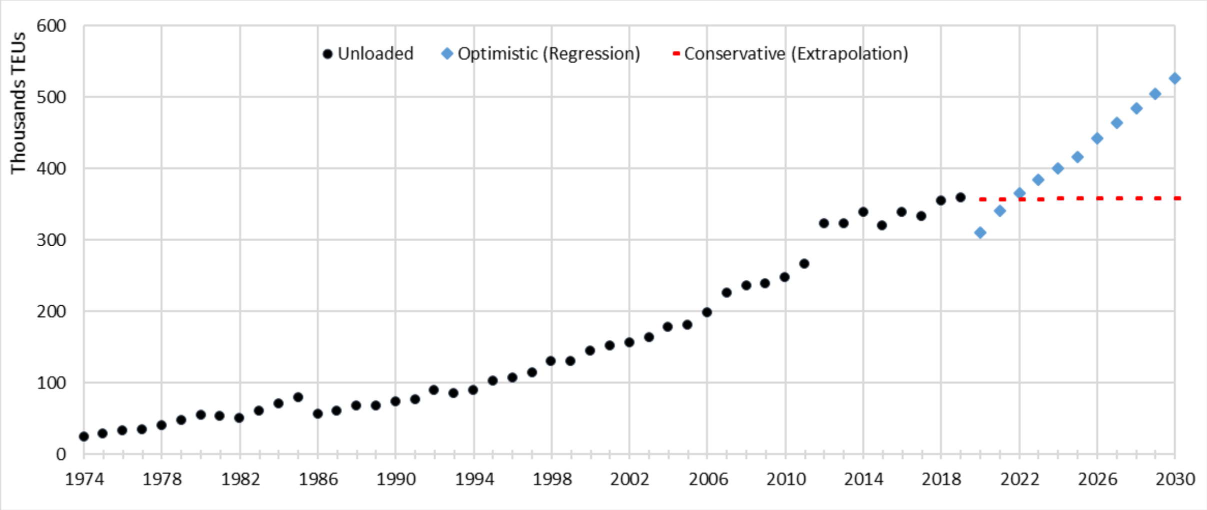

Figure 5.6 - Unloaded containerized cargo in the port of Leixões

As for the loaded containerized cargo, near identical results were obtained as seen in Figure 5.7. If the expansion of the terminal goes as planned, growth is once again expected for the following 10 years when using the linear regression. With a high R coefficient of 0.94. The drop seen in 2020 is partly due to the fall of the Portuguese GDP in that year. This forecast strengthens the idea that the port has potential to grow and is in need of a timely expansion of its container handling terminal.

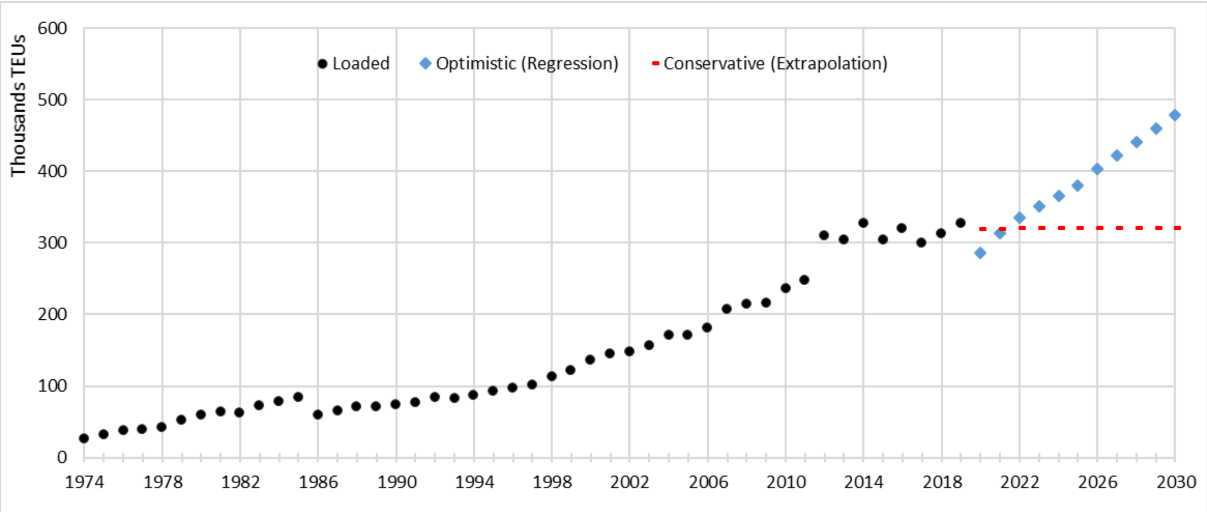

Figure 5.7 – Loaded containerized cargo in the port of Leixões

5.3.4 Containerized cargo in Lisbon

Figure 5.8 shows the resulting values of this forecast. With such a strong correlation, given the positive upwards trend of the GDP, the unloaded containerized cargo is expected to grow alongside according to the linear regression model. With a high R coefficient of 0.92. This can be described as extremely optimistic given the stagnation in cargo volumes handled since 2002 due to MSC having moved to Sines. As for a more conservative scenario, the extrapolation shown in red may be more realistic, especially when considering the instability seen from the influence of the union of stevedores through their frequent strikes [66].

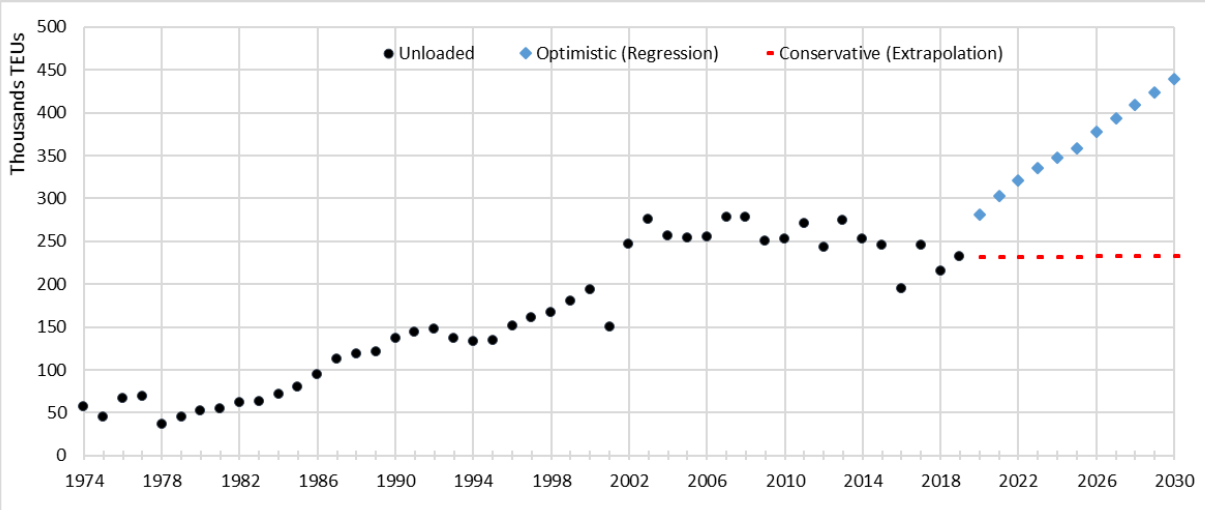

Figure 5.8 - Unloaded containerized cargo in the port of Lisbon

As for the loaded containerized cargo, near identical results were obtained as seen in Figure 5.9. Growth is once again expected for the following 10 years through the linear regression model. With a high R coefficient of 0.92. Yet the most likely scenario is the conservative one shown with the extrapolation method which uses the trend seen in the last 6 years, similarly to the unloaded cargo sector.

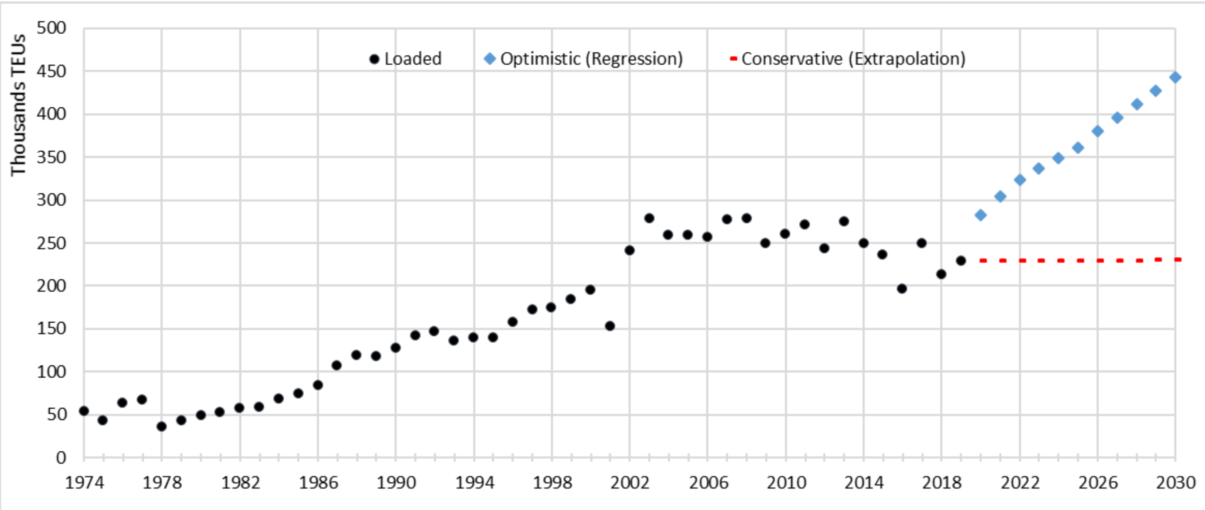

Figure 5.9 – Loaded containerized cargo in the port of Lisbon

5.3.5 Containerized cargo in Setúbal

Once again, using the Portuguese GDP as the explanatory variable, the linear regression method was applied to this cargo sector in Setúbal. Figure 5.10 shows the resulting values of this forecast. With such a strong correlation coefficient R of 0.85, given the positive upwards trend of the GDP, the unloaded containerized cargo is expected to grow alongside, similarly to the other two ports, this is a very optimistic scenario and an unlikely one. On the other hand, a more conservative scenario is presented, which has been generated by extending the trend seen in the last 5 years.

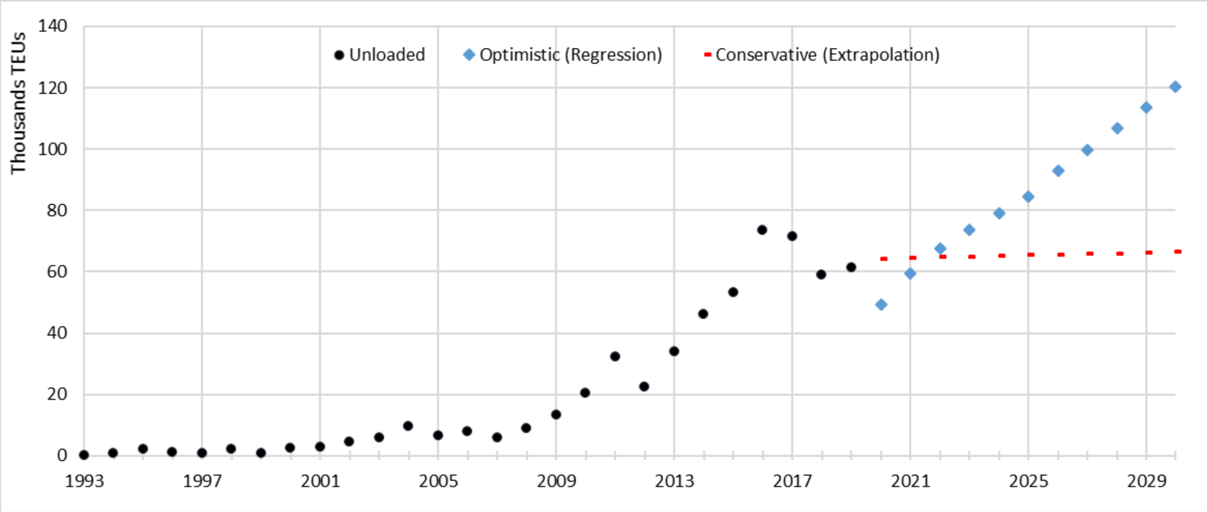

Figure 5.10 – Unloaded containerized cargo in the port of Setúbal

As for the loaded containerized cargo, near identical results were obtained as seen in Figure 5.11. High level of growth is expected for the following 10 years if the linear regression method is used. Which has a high R coefficient of 0.86. A more conservative and more likely scenario is the one obtained with the extrapolation of the more recent trend similarly to the unloaded cargo.

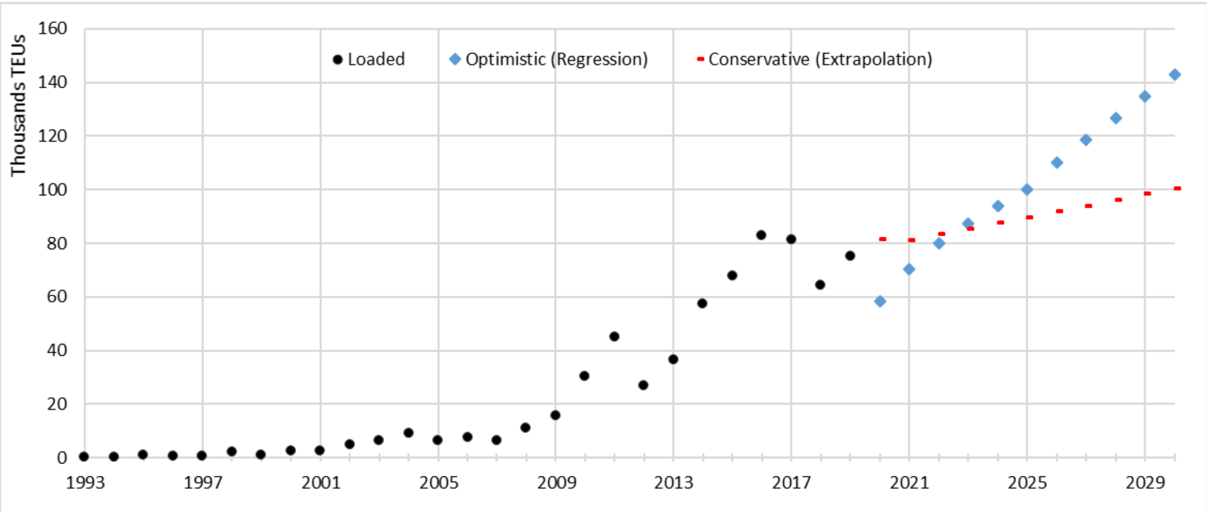

Figure 5.11 – Loaded containerized cargo in the port of Setúbal

5.3.6 Containerized cargo in Sines

Once again, using the same GDP as explanatory variable, linear regression method was applied to this cargo sector in Sines. Figure 5.12 shows the resulting values of this forecast. With such a strong correlation, given the positive upwards trend of the GDP, the unloaded containerized cargo is expected to grow alongside in a very optimistic scenario generated by the linear regression which has a high R coefficient of 0.91. A more conservative and realistic scenario is obtained by extrapolating the trend seen in the last 5 years.

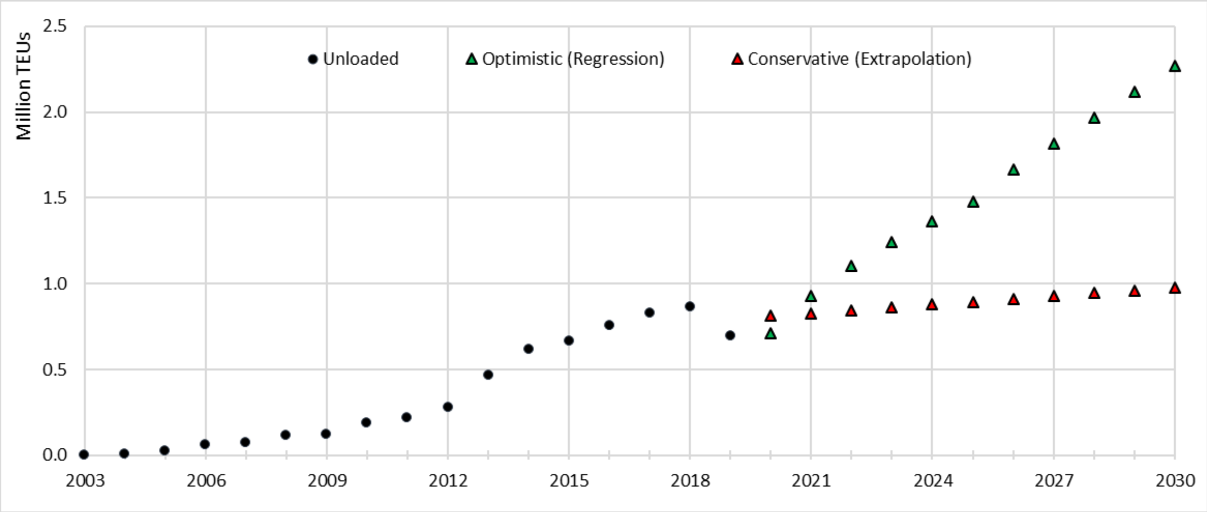

Figure 5.12 – Unloaded containerized cargo in the port of Sines

As for the loaded containerized cargo, near identical results were obtained as seen in Figure 5.13. In an optimistic scenario, a high level of growth is expected for the following 10 years when using the linear regression method which has a high R coefficient of 0.92. Once again, a more realistic and conservative scenario is obtained by extrapolating the trend seen in the last 5 years.

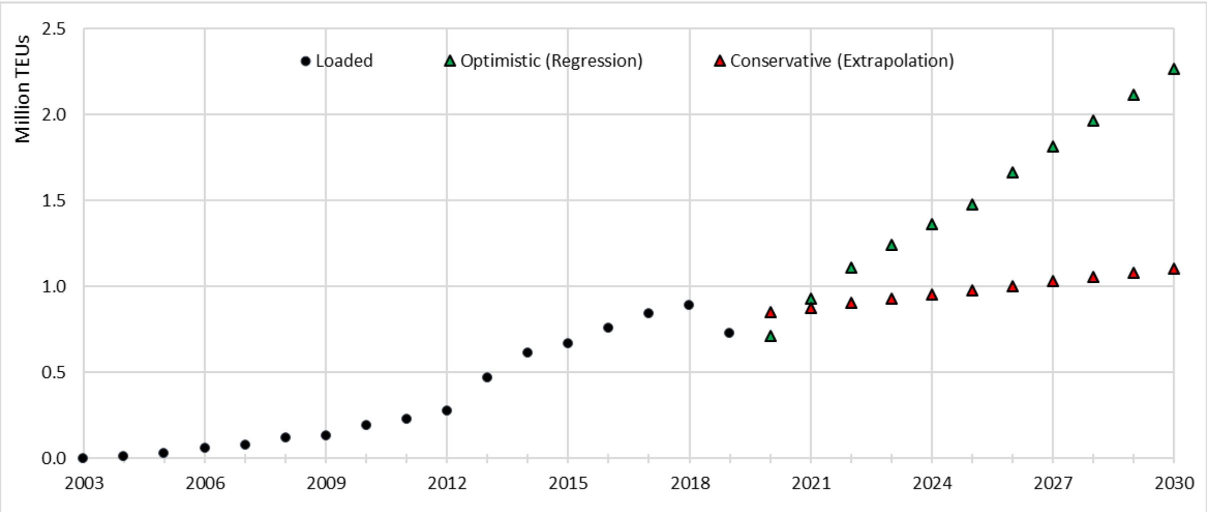

Figure 5.13 – Loaded containerized cargo in the port of Sines

An argument for the optimistic scenario could be made by justifying the growth of the total containerized cargo to 5 million TEUs by 2030 due to the ongoing expansion process of the Terminal XXI [67]. As for the conservative scenario, one could justify it by taking into account that the large majority of this cargo is transshipped, and that the Chinese economy which is one of the main sources of exports has been slowing down, alongside the world GDP in the recent years.

5.3.7 Containerized cargo in Portugal

In order to better compare the containerized cargo evolution between the ports being studied, the previous forecasts are grouped into two charts, one for the optimistic scenario and another for the conservative scenario. Figure 5.14 summarizes the performance of the main Portuguese ports in terms of containerized cargo throughput and their respective optimistic forecast. Overall in this forecast, this type of cargo is expected to return to the growth rates seen between 2013 and 2018 if the infrastructure expansion plans of the major ports goes as planned.

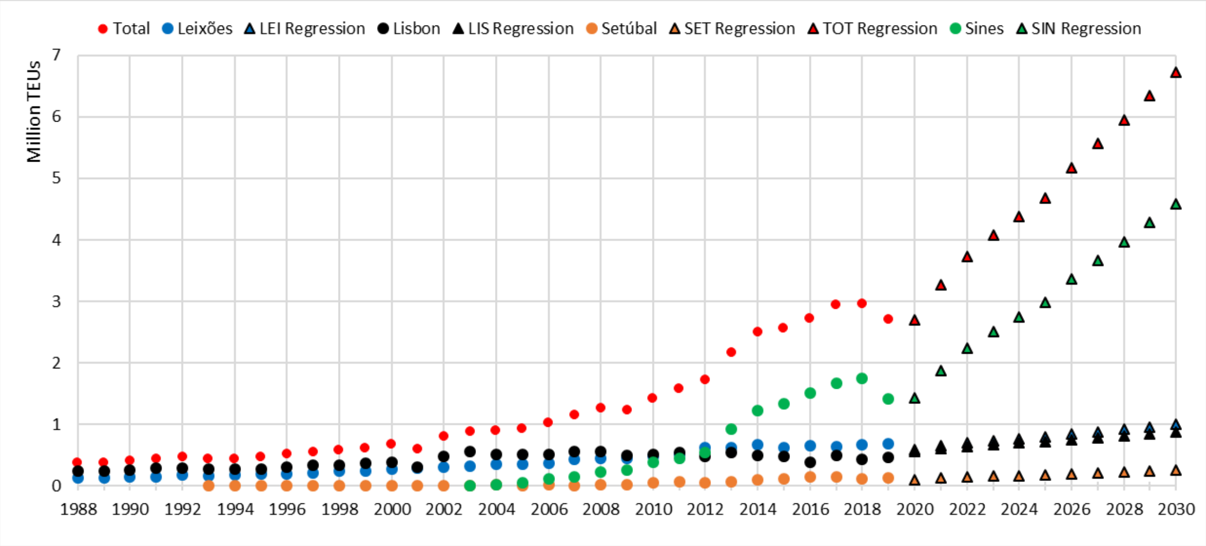

Figure 5.14 – Optimistic scenario of the containerized cargo evolution of main Portuguese ports

Figure 5.15 summarizes the performance of the main Portuguese ports in terms of containerized cargo throughput and their respective conservative forecast. Overall a slight increase is forecasted for this type of cargo in this scenario.

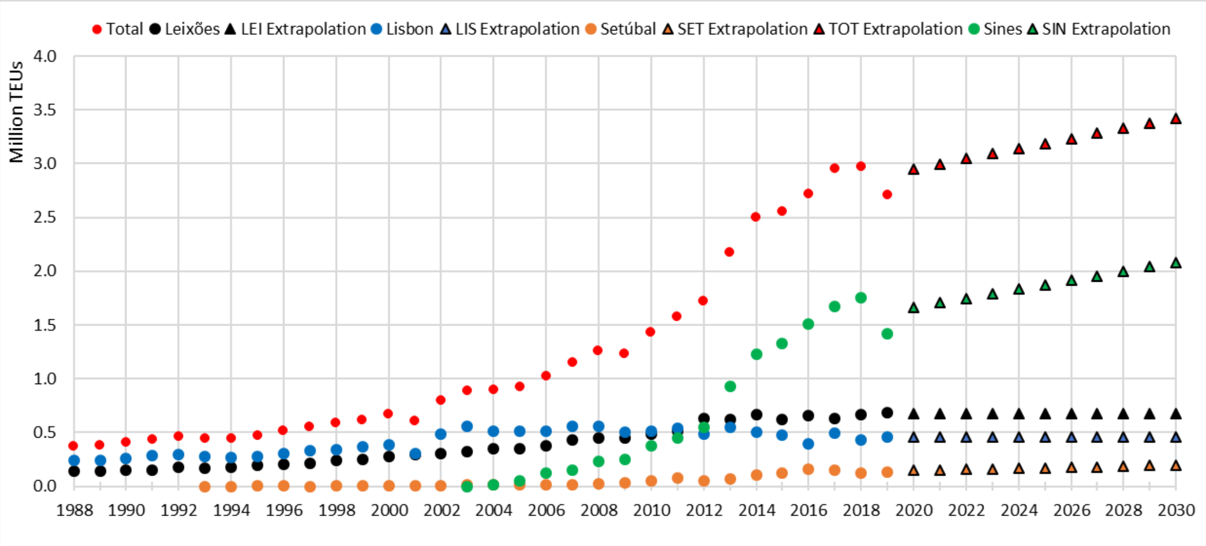

Figure 5.15 – Conservative scenario of the containerized cargo evolution of main Portuguese ports

For 2030, the optimistic scenario forecasts that the Portuguese ports will handle nearly 7 million TEUs, a growth of 200% over what was seen in 2019. This seems unlikely and not realistic, especially when taking into consideration the recent global pandemic. As such, the most likely scenario is the conservative one as it proposes a more reasonable growth rate over the next decade.

5.4 Linear Regression applied to General Cargo

5.4.1 Loaded general cargo in Leixões

The unloaded general cargo in Leixões reaches low values per year, as such it was discarded from this analysis. The loaded general cargo in the port of Leixões has had a peculiar evolution along the years. As seen in Figure 5.16 there has been a downwards trend in the period of 1988-2010 and especially between 1988 and 1996. In 2011 however, due to increase of steel and iron demand, general cargo had a sudden surge which stabilized up until 2019.

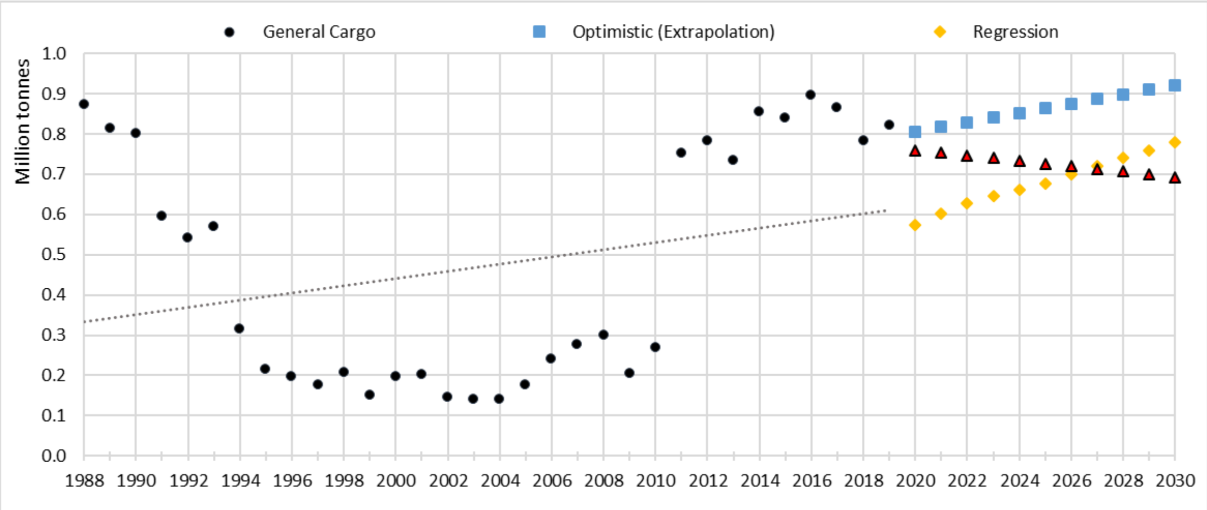

Figure 5.16 – Loaded general cargo in the port of Leixões

Such events and sudden changes make it hard to generate a good forecast, as the historical data becomes less reliable when trying to predict the future. A simple linear regression with a low R coefficient of 0.24 suggests that the cargo handling will grow at a steady pace in the following 10 years. However the drop from 2019 to 2020 (related to the regression) is perhaps too extreme even when taking into account the effects of the pandemic. On the other hand, a more optimistic scenario is generated by extrapolating the trend seen between 1988 and 2019. This scenario is most likely to take place, as the evolution is a compromise between the GDP growth and the trend of containerization. For a third and more conservative scenario, the trend seen between 1988 and 2014 was extrapolated. This scenario could take place if the general cargo suffers more intensely from the effects of containerization or the industries slow down.

5.4.2 General cargo in Aveiro (loaded and unloaded)

The general cargo unloaded in Aveiro, which consists mostly of metal products, has experienced growth from 1988 and peaking in 2004. A downhill trend was seen in the following years, up until the first couple of years of the last decade. Since then there has been once again a trend of growth. Similarly to what was seen in Leixões, a simple extrapolation of the overall generates a more realistic forecast. Figure 5.17 shows the extrapolation as well as an optimistic and a conservative scenarios. Even though highly unlikely, the optimistic takes into account the trend from 2009 to 2019, which may happen if new markets are attracted to the port. The conservative one takes into account the trend from 2001 to 2008, and goes along with the containerization trend.

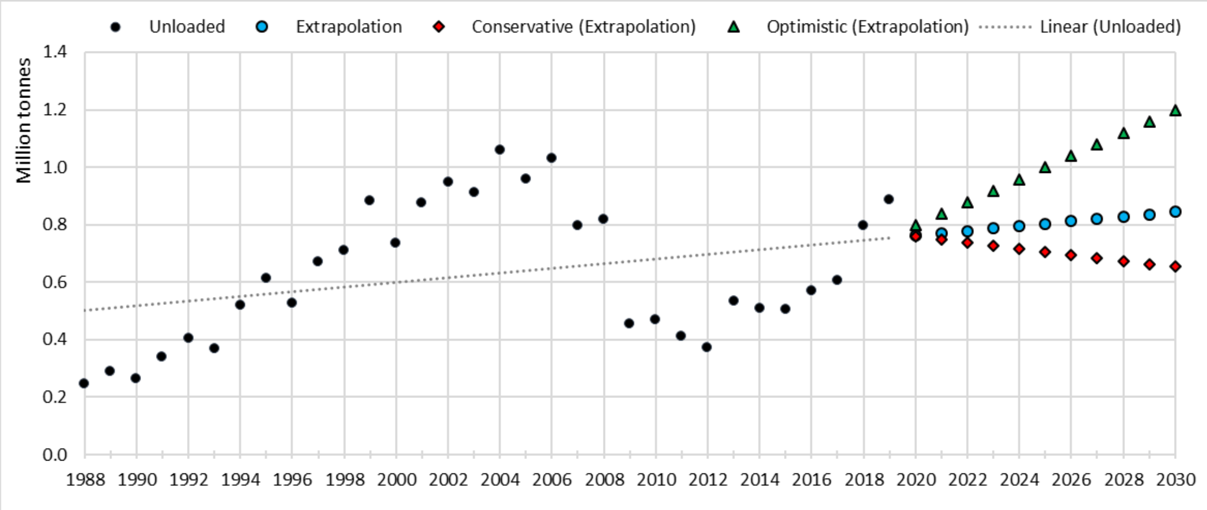

Figure 5.17 – Unloaded general cargo in the port of Aveiro

Even though the loaded general cargo in the same port, which consists mostly of cement, has a slightly more stable evolution, once again the extrapolation method was chosen as it is thought to be more fitting for the same reasons. An optimistic scenario was generated by taking into account the trend from 1994 to 2019 and a conservative one with a trend from 2011 to 2019. Figure 5.18 shows the resulting forecast for this cargo. The most likely outcome is thought to be between the extrapolation results and the conservative scenario.

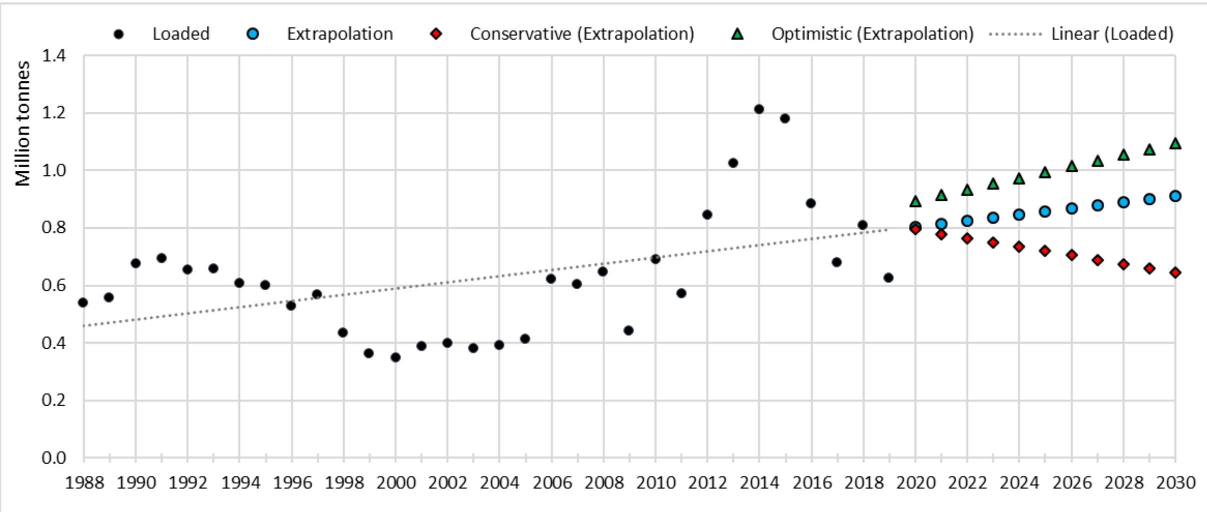

Figure 5.18 – Loaded general cargo in the port of Aveiro

5.4.3 General cargo in Setúbal (loaded and unloaded)

With a highly variable behaviour relatively to the other types of cargo, the MLR method had a R^2 of only 0.57, which is too low to be able to generate an accurate forecast. The unloaded general cargo in Setúbal, which consists mostly of metal products, is better forecasted with a simple extrapolation. With that said, the results of the extrapolation as well as a conservative scenario can be seen in Figure 5.19.

The forecast suggests that the cargo will keep its stable trend over the decade. However, if the phenomenon of containerization will have a stronger impact, the conservative scenario which is based on the trend seen between 2008 and 2019 is more likely to take place.

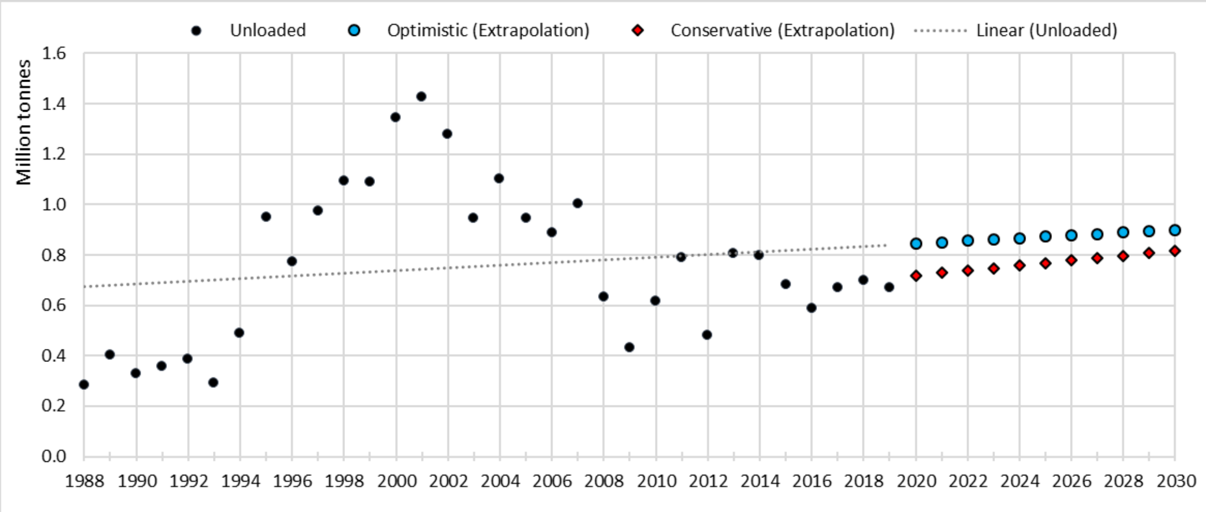

Figure 5.19 – Unloaded general cargo in the port of Setúbal

The loaded general cargo in the port of Setúbal, which consists of mostly cement and paper, has had a great peak after the world crisis of 2008. However it has had a downwards trend since 2015. As seen in Figure 5.20, the extrapolation suggests the sector will experience a high level of growth, and follow the overall positive trend. The most realistic scenario - obtained by extrapolating the trend seen between 1997 and 2003 - is most likely the conservative one, which suggests the general cargo will stabilize at the level seen in 2019, given the worldwide containerization trend.

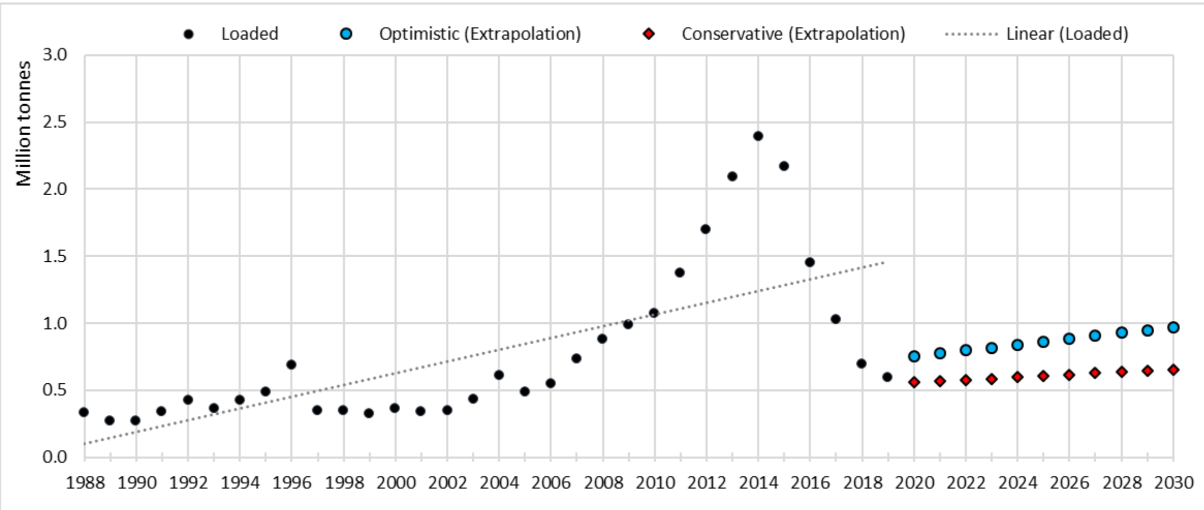

Figure 5.20 – Loaded general cargo in the port of Setúbal

5.4.4 General cargo in Portugal

In order to better compare the general cargo evolution between the ports being studied, the previous forecasts are grouped into two charts, one for the optimistic scenario and another for the conservative scenario. Figure 5.21 summarizes the performance of the main Portuguese ports in terms of general cargo throughput and their respective optimistic forecast. In this scenario, the cargo is expected to grow slightly as the decade passes, if the economy recovers well from the effects of the COVID-19 pandemic and finds new markets. To note that the total series takes into account the total Portuguese ports general cargo throughput.

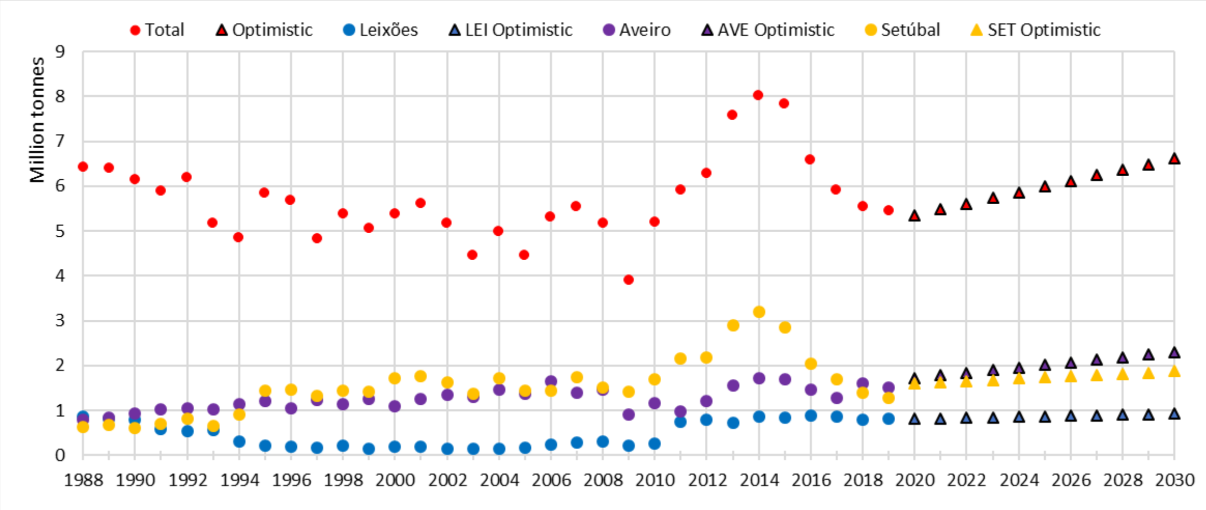

Figure 5.21 – Optimistic scenario of the general cargo evolution of main Portuguese ports

Figure 5.22 summarizes the performance of the main Portuguese ports in terms of general cargo throughput and their respective conservative forecast. In this scenario, the cargo is expected to either stagnate or to go through a slight decrease as the decade passes, following the trend of containerization.

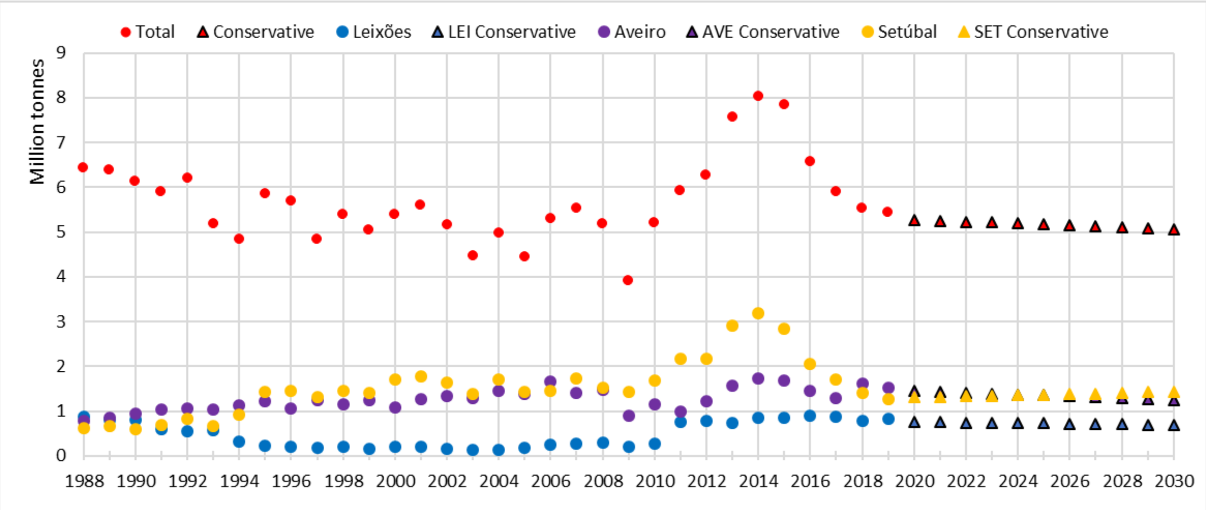

Figure 5.22 – Conservative scenario of the general cargo evolution of main Portuguese ports

Overall, given the global trend of containerization, the conservative scenario is the more likely one.

5.5 Linear Regression applied to Roll-on/Roll-off Cargo

5.5.1 Unloaded roll-on/roll-off cargo in Setúbal and Lisbon

In this forecast it is of interest to pair the volume of ro-ro cargo imported by the Portugal through its main ports in this sector with the Portuguese GDP, since the main consumers of this cargo is the country's own population. The two important ports for this type of cargo, and for unloading, are Setúbal and, for some years, Lisbon. As seen in Figure 5.23, overall the unloaded roll-on/roll-off cargo in these two ports has been decreasing, with the exception of the last 8 years, where it is seen to have bounced back.

An optimistic scenario is also presented, using only the last 11 years of data in the regression, this case might be justified if the country's demand for vehicles rises. A conservative scenario seen in the same figure is also likely to take place if the markets demand slows down.

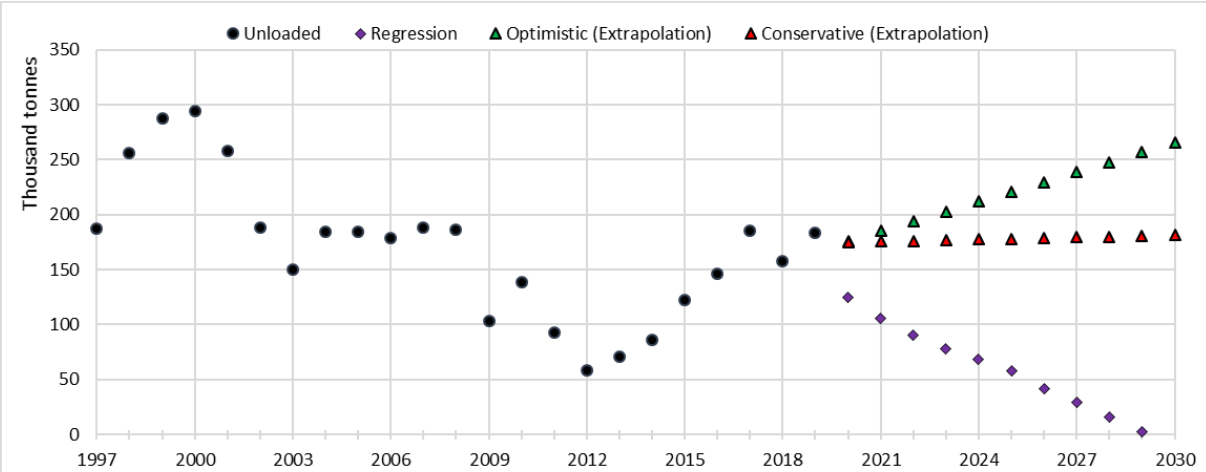

Figure 5.23 – Unloaded Ro-Ro cargo in the ports of Setúbal and Lisbon

The linear regression suggests that these two ports will no longer import roll-on/roll-off cargo starting from mid-2029. This phenomenon has to do with the inverted relation which is seen between the GDP and the unloaded ro-ro cargo, intensified by the increase of the GDP's growth rate in the more recent years. However this doesn't seem realistic, based on the simple logical thought that the Portuguese automotive market will always show some level of demand. In modern days people need vehicles for transportation purposes and industries need them in order to properly function.

Even though the Portuguese GDP is expected to recover in 2022, given the inverted correlation seen between it and the evolution of this cargo, whenever the GDP grows, the linear regression forecasts that the cargo will fall.

5.5.2 Loaded roll-on/roll-off cargo in Setúbal and Lisbon

In this forecast it is also of interest to pair the volume of ro-ro cargo exported by the Portugal through its main ports in this sector with the Portuguese GDP, since the main producer is the Autoeuropa factory, which exports their cars through both ports. As seen in Figure 5.24, overall the loaded roll-on/roll-off cargo in these two ports has been decreasing, with the exception of the last 3 years, where it is seen to have bounced back.

An optimistic scenario is also presented, using only the last 11 years of data in the regression, this case might be justified if the Autoeuropa has the capacity to produce more vehicles and if there is a market for them [68]. A conservative scenario seen in the same figure is also likely to take place if the factory is forced to scale down production due to lack of demand.

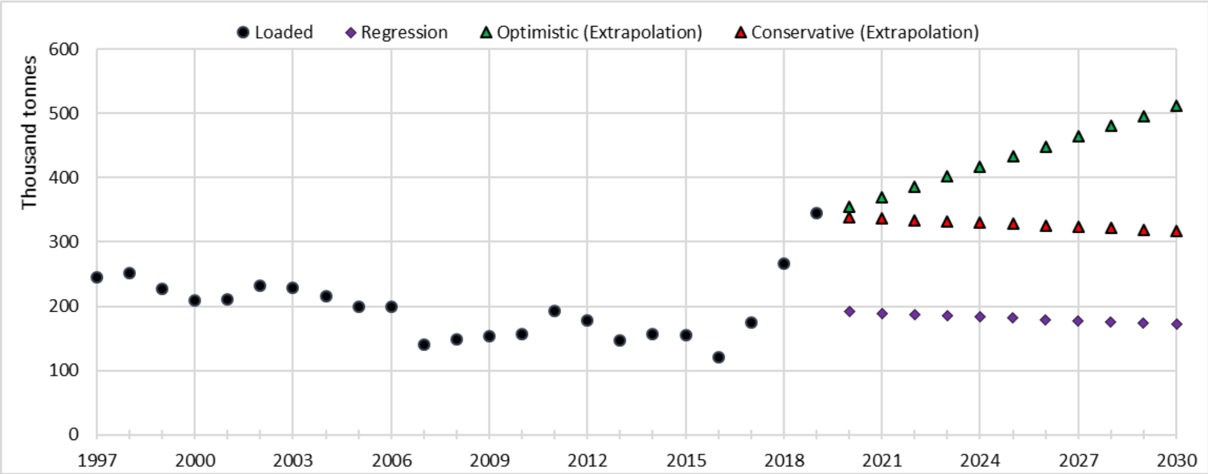

Figure 5.24 - Loaded Ro-Ro cargo in the ports of Setúbal and Lisbon

The linear regression generated a fairly similar trend to the conservative one, however due to the method's nature, it has trouble when dealing with local peaks such as the ones seen between 2016 and 2019. Thus the severe drop which was forecasted in the following year.

5.5.3 Roll-on/Roll-off cargo in Leixões (loaded and unloaded)

The available data for ro-ro in the port of Leixões goes back to 1997. However, as shown in Chapter 4, the period between 1997 and 2014 the values are negligible, thus being excluded from the forecast. Only in November of 2013 a regular line began operations with significant volumes.

With the small number of observations of only 6, the linear regression doesn't produce reliable results. The general rule of thumb according to [53] is that in order to be able to detect reasonable-size effects, a higher number of observations are needed.

Figure 5.25 shows the forecast through extrapolation of the trend seen between 2014 and 2019 for the ro-ro cargo unloaded in the port of Leixões until 2030. A more conservative scenario was built by extrapolating the trend seen between 2017 and 2018. One can argue this case is more likely to happen due to the port's lacking infrastructure.

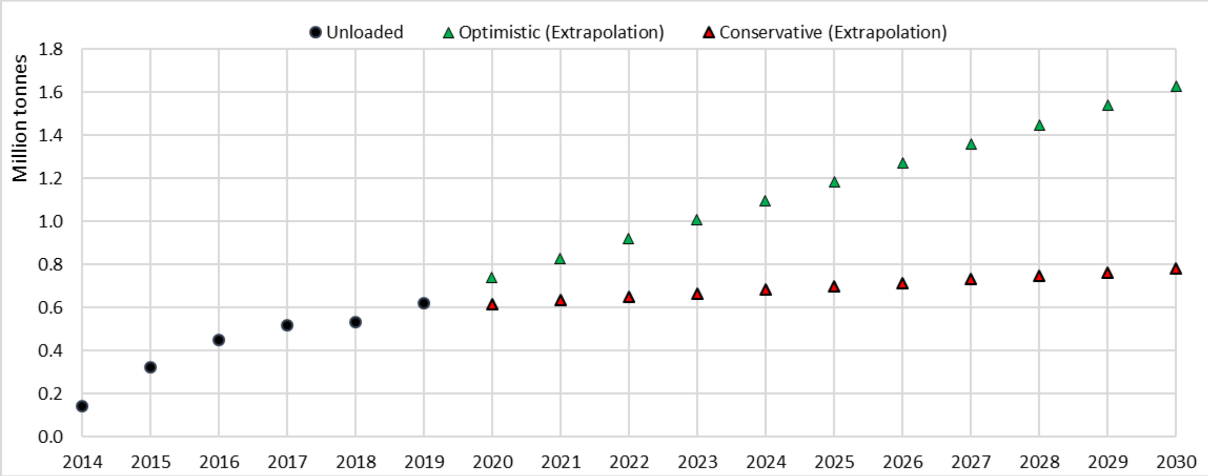

Figure 5.25 – Forecast of unloaded ro-ro cargo in the port of Leixões

As for the loaded ro-ro cargo in the port of Leixões, Figure 5.26 shows the forecast through extrapolation of the trend seen between 2014 and 2019 until 2030. A more conservative scenario was built by extrapolating the trend seen between 2017 and 2018. Once again, one can argue this case is more likely to happen due to the port's lacking infrastructure.

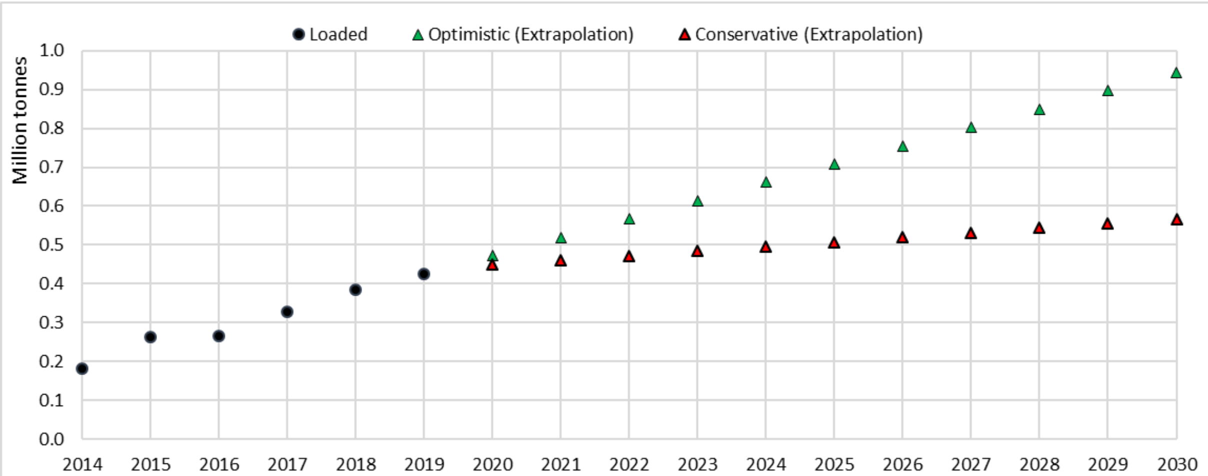

Figure 5.26 – Forecast of loaded ro-ro cargo in the port of Leixões

5.5.1 Roll-on/Roll-off cargo in Portugal

Between 2005 and 2013 there can be seen a stable output from the ro-ro cargo. Since then however, there has been a substantial, near linear growth. The resulting linear regression for the next 10 years suggest a reasonable rate of growth.

In order to better compare evolution between the ports being studied for this sector, the previous forecasts are grouped into two charts, one for the optimistic scenario and another for the optimistic scenario. Figure 5.27 summarizes the performance of the two main Portuguese ports in terms of ro-ro cargo throughput and their respective optimistic forecast. In this scenario, the cargo is expected to grow at a significant pace as the decade passes, if the economy recovers well from the effects of the COVID-

19 pandemic and finds new markets. It is also evident how the operation of a single service (Ro-Ro) changes completely the performance of a port in this specific cargo type.

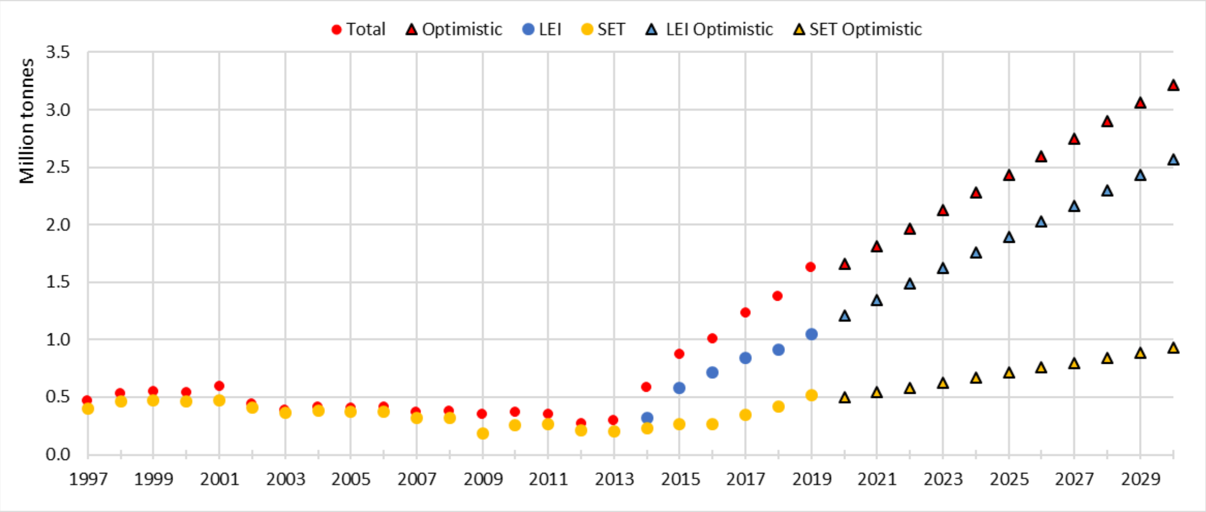

Figure 5.27 – Optimistic scenario of the ro-ro cargo evolution of main Portuguese ports

Figure 5.28 summarizes the performance of the main Portuguese ports in terms of ro-ro cargo throughput and their respective conservative forecast. In this scenario, the cargo is expected to stagnate as the decade passes given the lack of port infrastructure in Leixões.

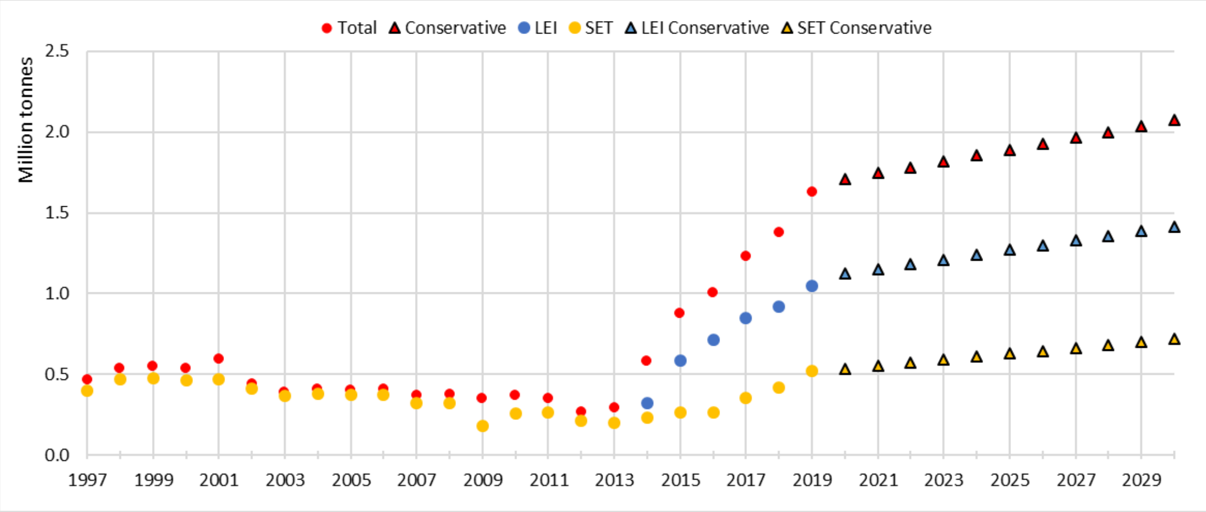

Figure 5.28 – Conservative scenario of the ro-ro cargo evolution of main Portuguese ports

Overall, one could argue the most likely scenario is perhaps the conservative one as the terminals approach their cargo handling capacity.

5.6 Qualitative forecasting applied to Solid and Liquid Bulks

5.6.1 Forecasting of Liquid bulk cargo

As mentioned in Chapter 4, the Galp refineries in Sines and Leixões play an extremely important role in their respective ports. The large volumes of crude oil required by these refineries have granted them a great level of stability along the last decades. However, in December of 2020 Galp announced that it will focus its refining activities and future projects on the Sines complex and discontinue refining in Matosinhos. This means that the port of Leixões is going through a phase where it is looking to attract new clients in order to keep the port running as it was.

With the refinery recently using between 5 and 5.5 million tonnes of crude oil per year [69], the volume of unloaded liquid bulk handled in the port of Leixões is expected to drop near completely from the current 5.2 million tonnes. The crude oil processing capacity is split into three units, the aromatics and solvents unit, lubricants unit and last but not least the main oil factory [70].

As for the exported liquid bulks, these are also expected to drop nearly entirely from the yearly 2.4 million tonnes when the refinery concludes its shutting down process in the end of 2021 [71]. There is a project of using the space of the refinery to install a lithium refinery, idea which is supported by the Minister for the Environment [72]. However, it has not been established a concrete plan yet. Meaning that any repurposing will take at least a couple of years in order to get approved and executed. If the repurposing plans go through successfully, secondary products present in the lithium refinement process such as hydrochloric acid and hydrogen chloride will be required, meaning they would most likely have to be imported through the port in large volumes.

In Leixões the unloaded liquid bulk is expected to drop nearly entirely as seen in Figure 5.29. This has to do with the fact that the vast majority of this cargo consists of oil products for the refinery, which has recently shutdown. With that said, the linear regression method doesn't generate a realistic forecast. As such, a qualitative analysis is carried out based on the ongoing plans of establishing a lithium extraction and refining operation in the northern region of Portugal. The expected extraction capacity of the mine is of over 20 million tonnes per year and the operating company Savannah Resources plans to refine the ore in China for the initial phase as a safer approach [73]. However, in 3 or 4 years, a refinery with a production capacity of approximately 175 thousand tonnes of lithium concentrate will most likely be built in Matosinhos in order to process the minerals in the same country. The volume of sulphuric acid was calculated with the help of an article explaining the different lithium production methods step by step [74].

Two scenarios are presented, an optimistic one where the refinery process starts in 2024, with the port handling sulphuric acid as well as other chemicals required for the refining process. As well as a conservative scenario where the refining operation is delayed or cancelled completely.

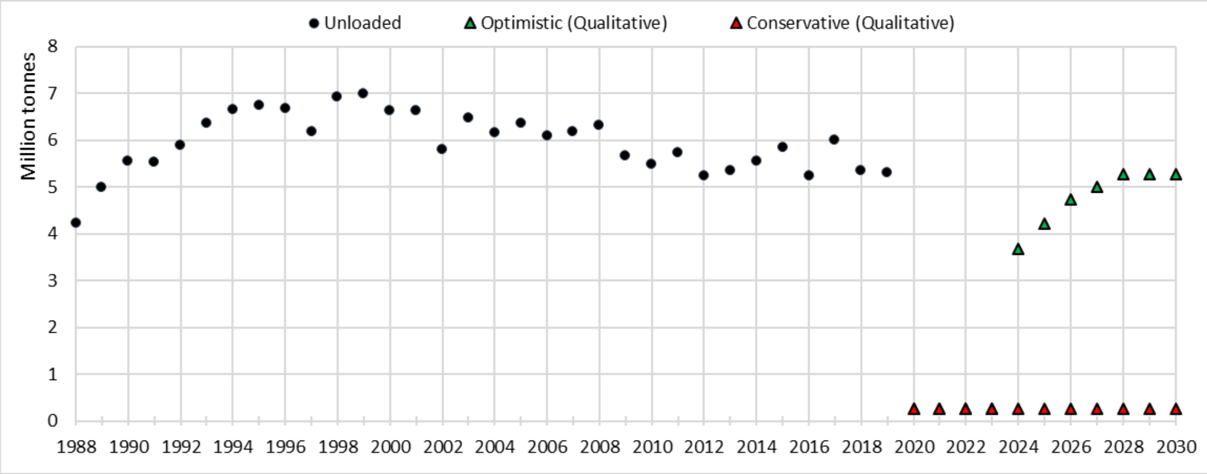

Figure 5.29 – Forecast of unloaded liquid bulk in Leixões

As for the loaded liquid bulk in Leixões, Figure 5.30 suggests it will keep growing, however this sector is also expected to fall as it was heavily dependent on the refinery processed products. Two scenarios are presented, an optimistic one where the refinery process starts in 2024, with the port handling the lithium concentrate and other forms of lithium. As well as a conservative scenario where the refining operation is delayed or cancelled completely.

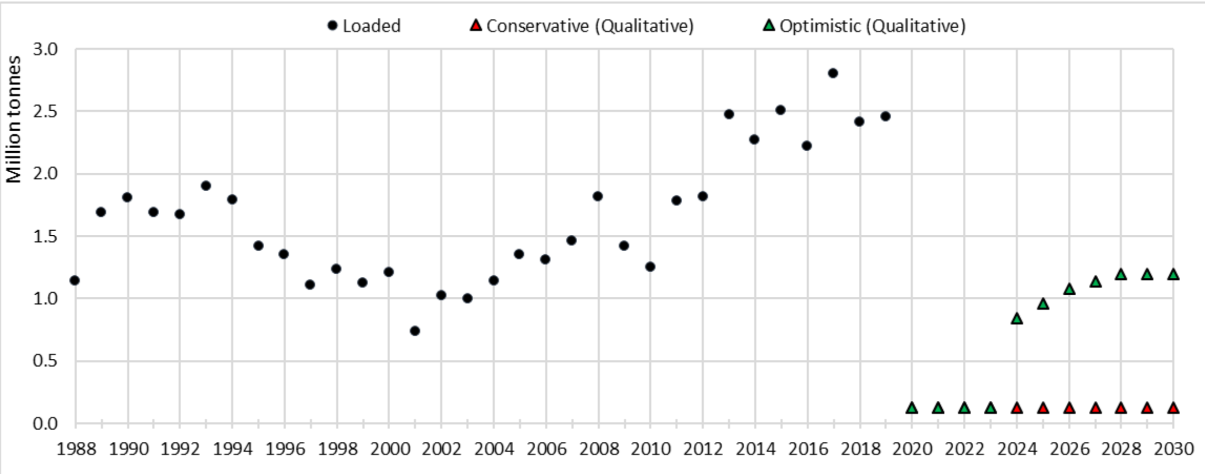

Figure 5.30 – Forecast of loaded liquid bulk in Leixões

In Aveiro the unloaded liquid bulk which consists largely of oil products is expected to have a highly positive evolution over the decade, as suggested by the linear regression forecast in Figure 5.31. The R coefficient for the linear regression is 0.89, a relatively high value. However two points make this forecast unreliable. First, the drop from 2019 and 2020 is too drastic and unlikely, and second, the growth rate is too steep. As such two alternative scenarios are presented. A conservative one which is generated by extrapolating the trend seen between 2011 and 2015. And a more optimistic one which is an extrapolation of the trend seen between 2001 and 2019. It is very likely that the next years will show a growth level somewhere between the optimistic scenario and the conservative one.

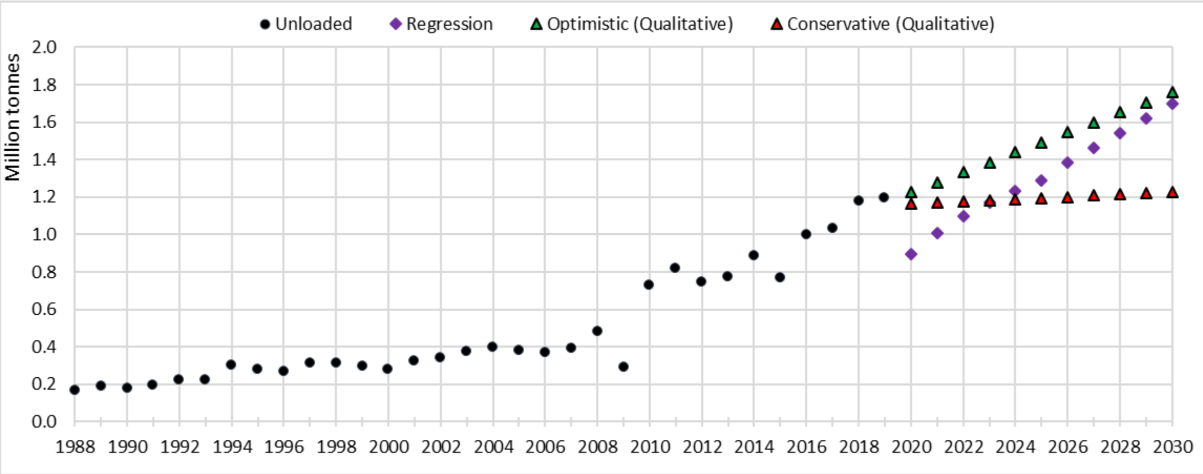

Figure 5.31 – Forecast of unloaded liquid bulk in Aveiro

As for the unloaded liquid bulk in Lisbon which consists largely of oil products and fuel, is expected to have a relatively stable behaviour in the following years, as seen in Figure 5.32. The drop seen in the linear regression scenario is however unlikely. The R coefficient for the linear regression is 0.81, a relatively high value. As such two alternatives are presented. A conservative and very likely scenario which extrapolates the trend seen between 2012 and 2019 where the cargo remains stable and a more optimistic scenario which extrapolates the trend seen between 2012 and 2015.

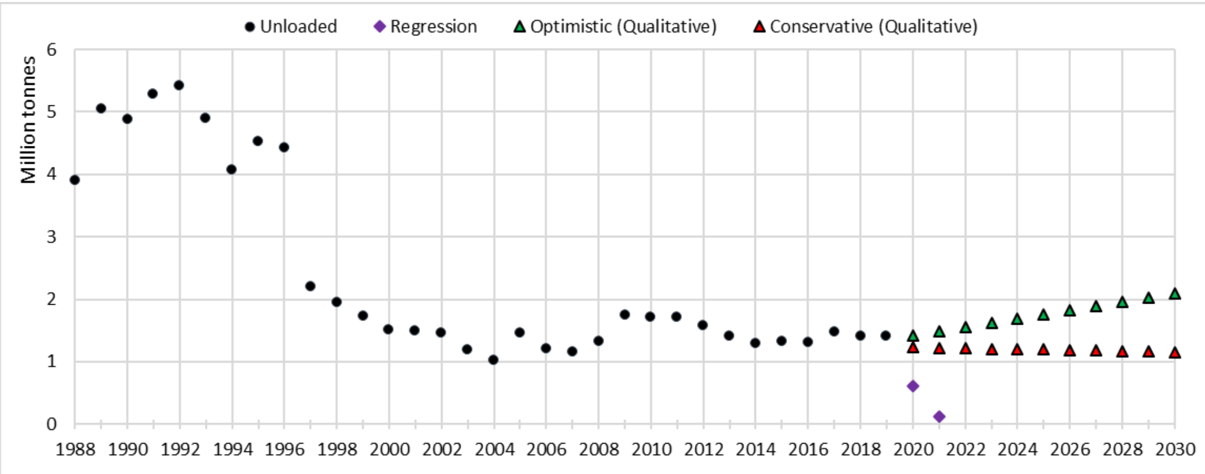

Figure 5.32 – Forecast of unloaded liquid bulk in Lisbon

The unloaded liquid bulk in Setúbal which consists largely of oil products is forecasted to cease activity by the year of 2026 through the linear regression method as seen in Figure 5.33. The R coefficient for the linear regression is 0.62, a relatively low value. However two alternative scenarios which are more likely to happen are also presented. First a conservative one generated by extrapolating the trend seen between 2014 and 2019 where the cargo remains somewhat stable. Second, an optimistic scenario which extrapolates the more recent upward trend seen between 2016 and 2019.

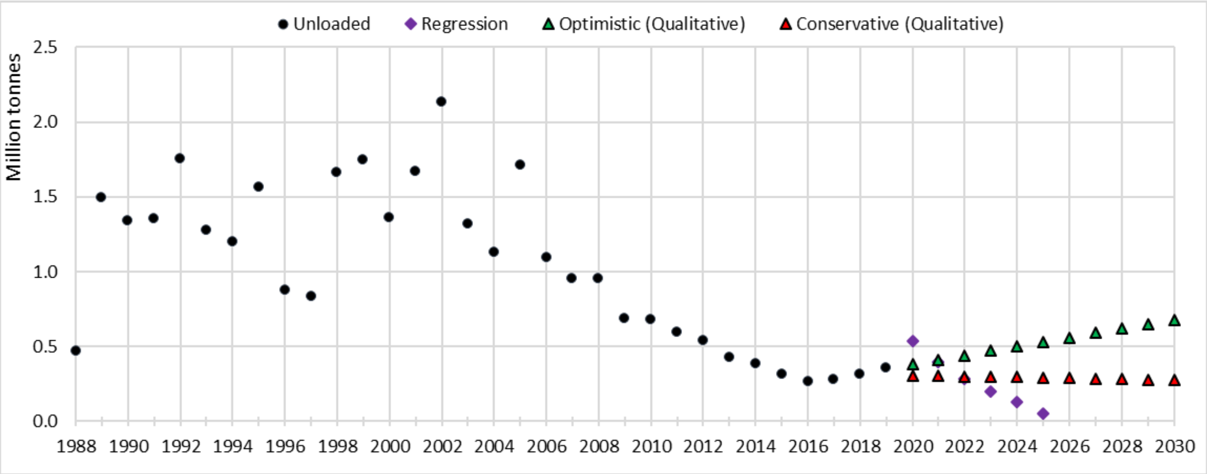

Figure 5.33 – Forecast of unloaded liquid bulk in Setúbal

On the other hand, Sines will likely experience an increase in terms of unloaded liquid bulk as suggested by the forecast seen in Figure 5.34. The R coefficient for the linear regression is 0.88, a very high value. The majority of this cargo consists of oil products which will grow in volume in this port due to the shutdown of the Matosinhos refinery. A more conservative forecast generated by extrapolating the trend seen between 2006 and 2019 suggests this cargo will grow at a slower rate in case if the Sines refinery won't try to compensate for the loss seen in Matosinhos.

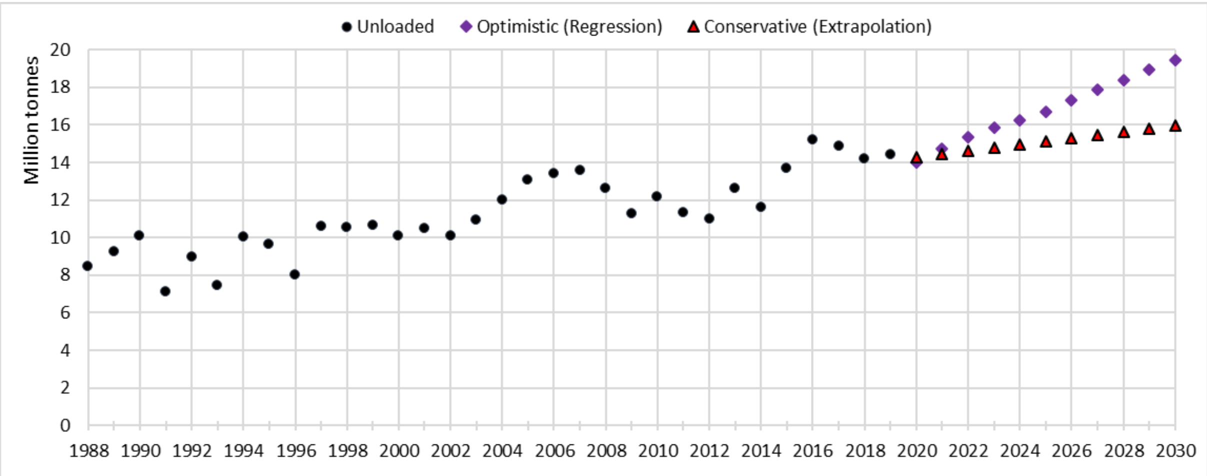

Figure 5.34 – Forecast of unloaded liquid bulk in Sines

The loaded liquid bulk in Sines is predicted to have a comeback in terms of volume handled as shown by the extrapolation of the trend seen between 2011 and 2019 in Figure 5.35. Once again due to the shutdown of the refinery in Matosinhos. The majority of this cargo consists of oil processed products. The scenario generated by the linear regression is considered too conservative. The R coefficient for the linear regression is 0.13, an extremely low value.

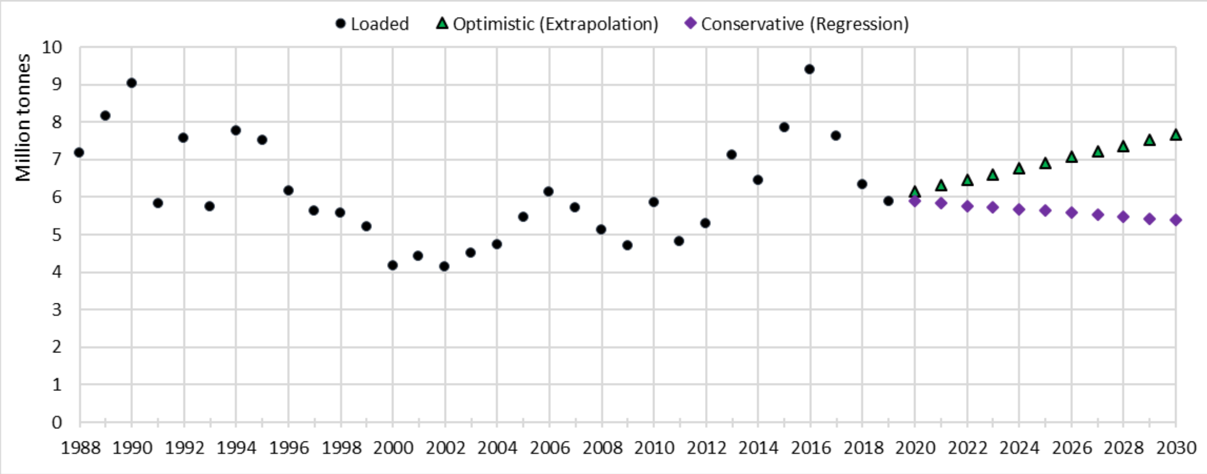

Figure 5.35 – Forecast of loaded liquid bulk in Sines

A conservative forecast of total liquid bulk handled in Portugal as well as in the five main ports is presented in Figure 5.36. Due to the shutdown of the refinery in Leixões, the total volume handled is expected to drop and stabilize in case if the shift of volumes from Leixões to Sines isn't significant.

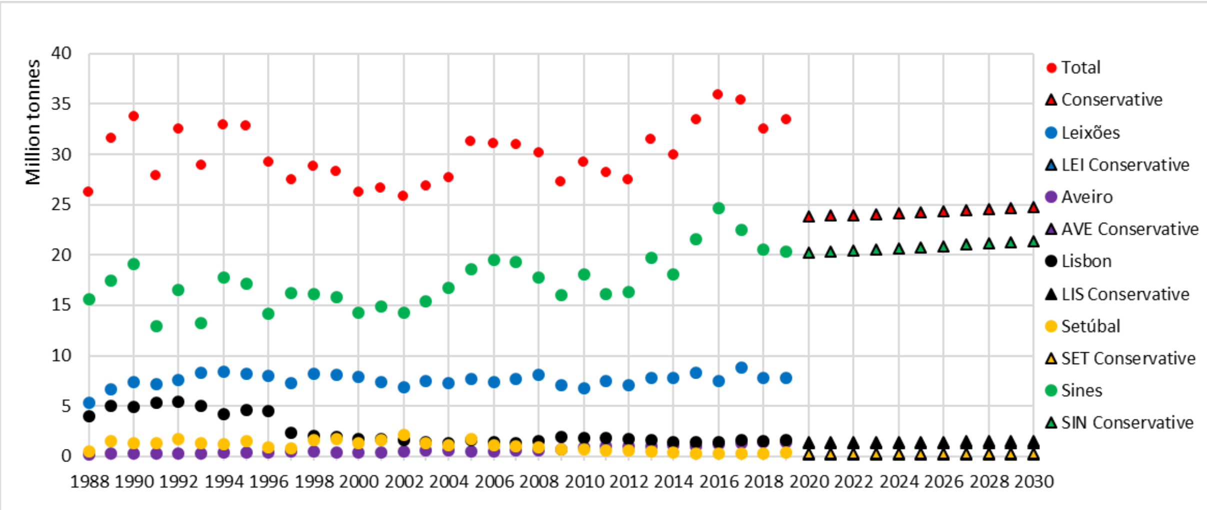

Figure 5.36 – Conservative forecast of total liquid bulk handled in Portugal

An optimistic forecast of total liquid bulk handled in Portugal as well as in the five main ports is presented in Figure 5.37. Due to the shutdown of the refinery in Leixões, the total volume handled is expected to drop but to follow a positive trend which is led by the port of Sines.

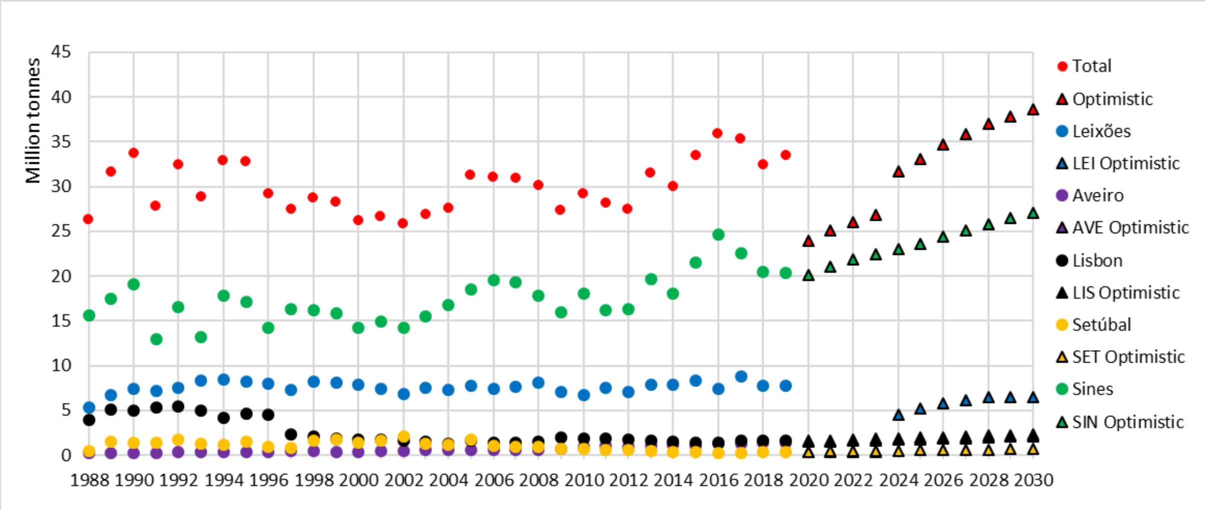

Figure 5.37 – Optimistic forecast of total liquid bulk handled in Portugal

Overall, one could argue the most likely scenario of the two is perhaps the optimistic one given the ongoing plans of establishing different industries in this sector in the country.

5.6.2 Forecasting of Dry bulk cargo

The forecast for the unloaded dry bulk in Sines has a positive trend, as such it would be expected to keep increasing over the next years as well as seen in Figure 5.38. However it is known that the large majority – over 97% – of this cargo consists of coal intended to fuel the power plant. And with the shutdown of the power plant this year, the activity of unloading dry bulk in this port will cease. As for a more optimistic scenario, it is somewhat likely for the port to begin handling soya beans in significant quantities in the near future, most likely in the second half of the decade in volumes similar to the ones seen in the port of Lisbon. As for the volumes such cargo, it is too early and there is no sufficient data to attempt a forecast with any reasonable accuracy.

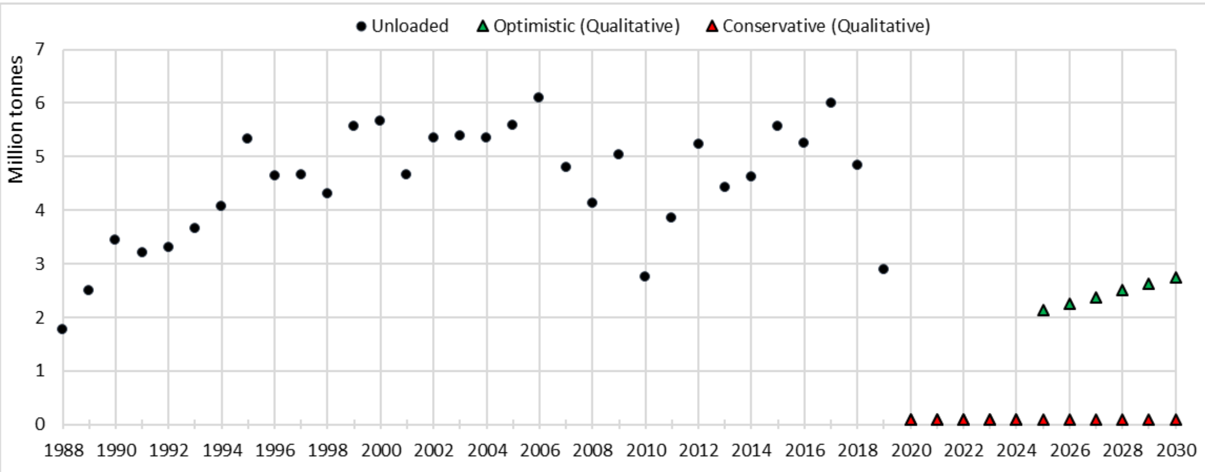

Figure 5.38 – Forecast of unloaded dry bulk in Sines

The evolution of the unloaded dry bulk in Leixões has been relatively steady, demonstrating a stable growth rate over the years. The majority of this cargo consists of agro-food products. Shown in Figure 5.39, the linear regression method with the Portuguese GDP as the independent variable suggests the positive trend will continue, this can be considered as a very optimistic scenario. The R coefficient for the linear regression is 0.94, a very high value. As for a more conservative scenario, an extrapolation of the trend seen between 1999 and 2009 generates a more likely outcome for the next decade.

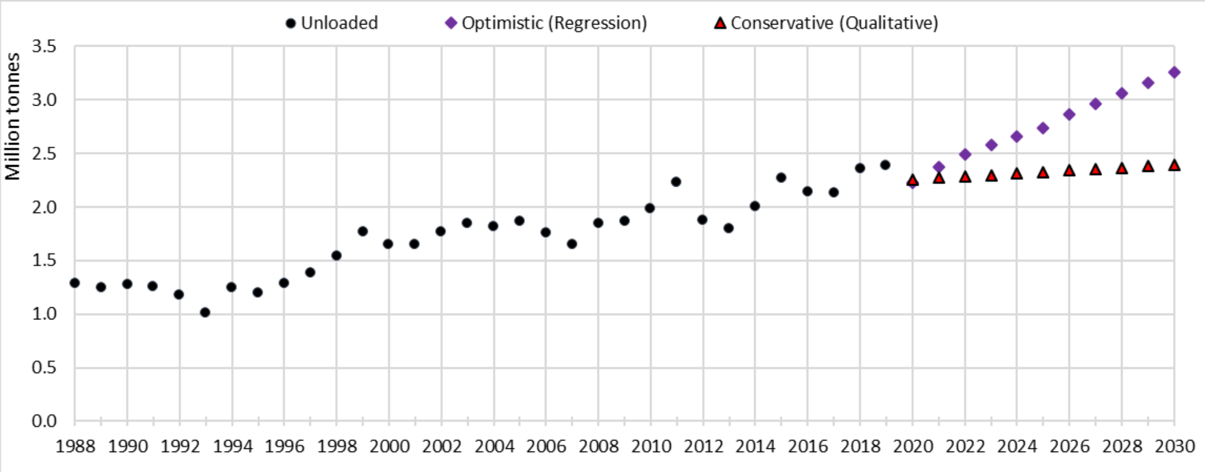

Figure 5.39 – Forecast of unloaded dry bulk in Leixões

The unloaded dry bulk in Aveiro which consists mainly of agro-food products has had some ups and downs over the years. However an overall positive trend is noticeable. As seen in Figure 5.40, once again the linear regression suggests the positive trend will continue over the current decade. The R coefficient for the linear regression is 0.78, a relatively high value. Although two points make this forecast unreliable. The first one is the drop from 2019 to 2020 is too drastic, even in pandemic conditions. Second, the gradient or rate of growth for the next 10 years is too steep and perhaps not very likely to happen. As such a simple extrapolation of the trend seen between 1998 and 2017. This conservative scenario is the more likely one given the pre-pandemic stagnation of this sector. Lastly, an optimistic scenario where the economy bounced back is also presented which was generated by extrapolating the trend seen between 2003 and 2019.

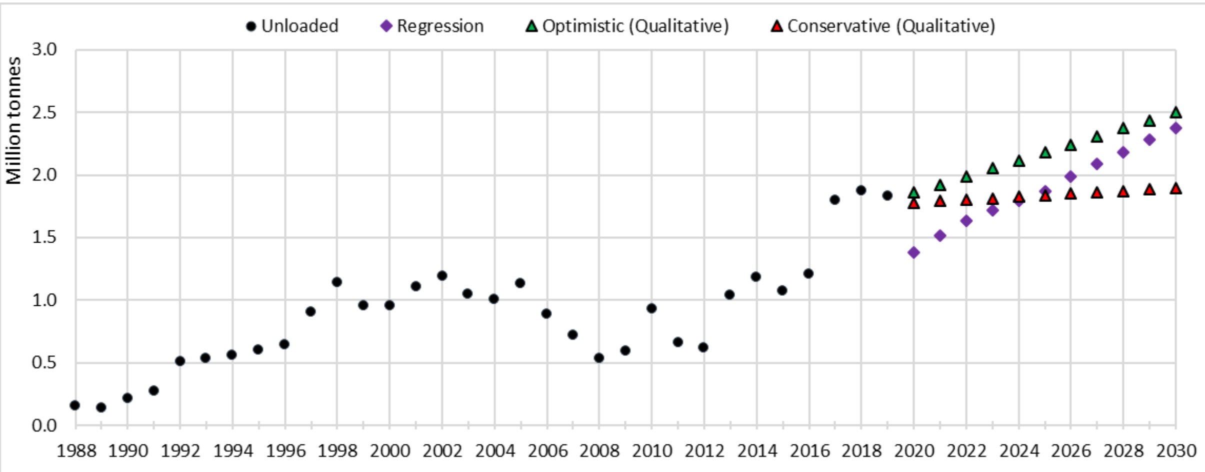

Figure 5.40 – Forecast of unloaded dry bulk in Aveiro

The loaded dry bulk in Aveiro consists largely of cement product. Figure 5.41 shows there have been a couple peaks in terms of this cargo's evolution. However an overall positive trend stands out. Once again the linear regression has generated a growth rate which can be considered too steep and unlikely. The R coefficient for the linear regression is 0.81, a relatively high value.Two alternative scenarios were created. A fairly optimistic one which is the extrapolation of the trend seen between 1988 and 2019 and another more conservative one which uses the trend seen between 2007 and 2019.

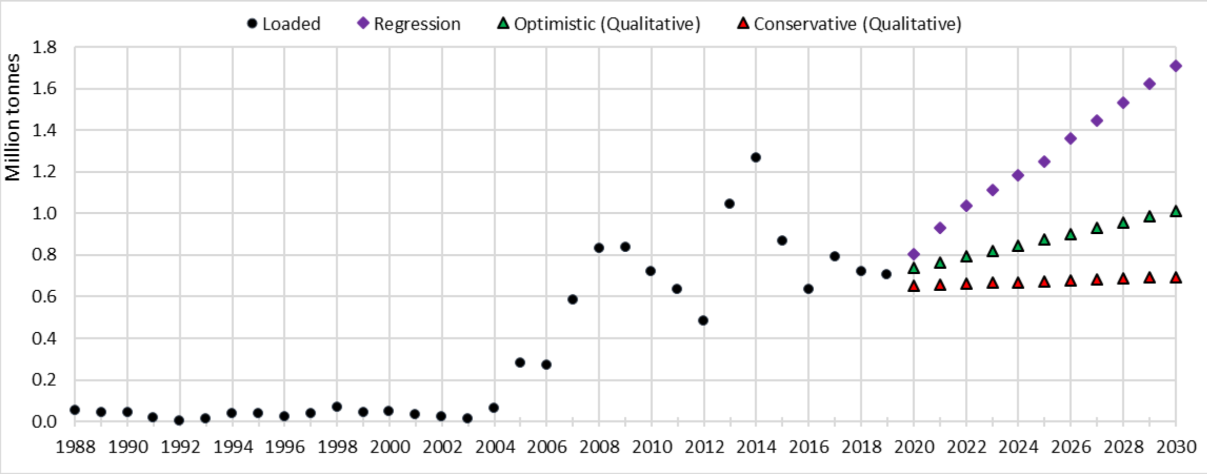

Figure 5.41 – Forecast of loaded dry bulk in Aveiro

The unloaded dry bulk in Lisbon which consists mainly of agro-food products has been showing a slight negative trend. Figure 5.42 depicts the three scenarios for this sector. The forecast of the linear regression method is too negative and too unlikely to take place. The R coefficient for the linear regression is 0.84, a relatively high value. As such two alternative scenarios are proposed. A conservative one which uses the extrapolation of the trend seen between 1988 and 2019, and a more optimistic one which uses the extrapolation of the trend seen between 2012 and 2015. The conservative case is perhaps the most likely one given the instability of the ports caused by the regular strikes of the stevedores.

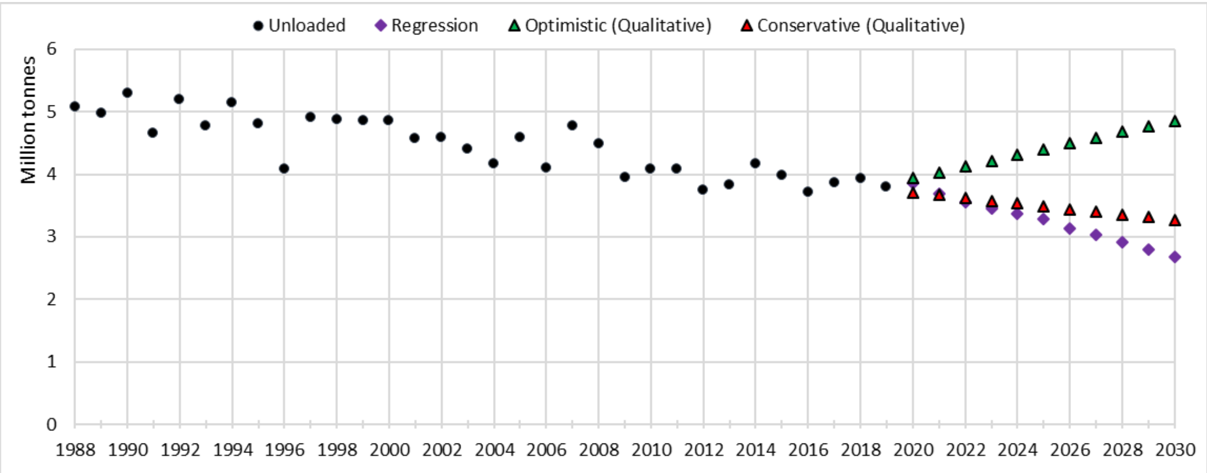

Figure 5.42 – Forecast of unloaded dry bulk in Lisbon

On the other hand, the loaded dry bulk in Lisbon which consists largely of cement products has a more promising evolution. Figure 5.43 shows the positive forecasts for the upcoming years. The scenario generated by the linear regression shows a growth rate which is too steep and unlikely. The R coefficient for the linear regression is 0.78, a fairly high value. As such two alternative scenarios are presented. A conservative one generated by the extrapolation of the trend seen between 2006 and 2016. And a slightly more optimistic one which was generated by extrapolating the trend seen between 2006 and 2019. The conservative scenario is perhaps the most likely one to take place once again given the instability of the port and the negative global pandemic effects on the economies.

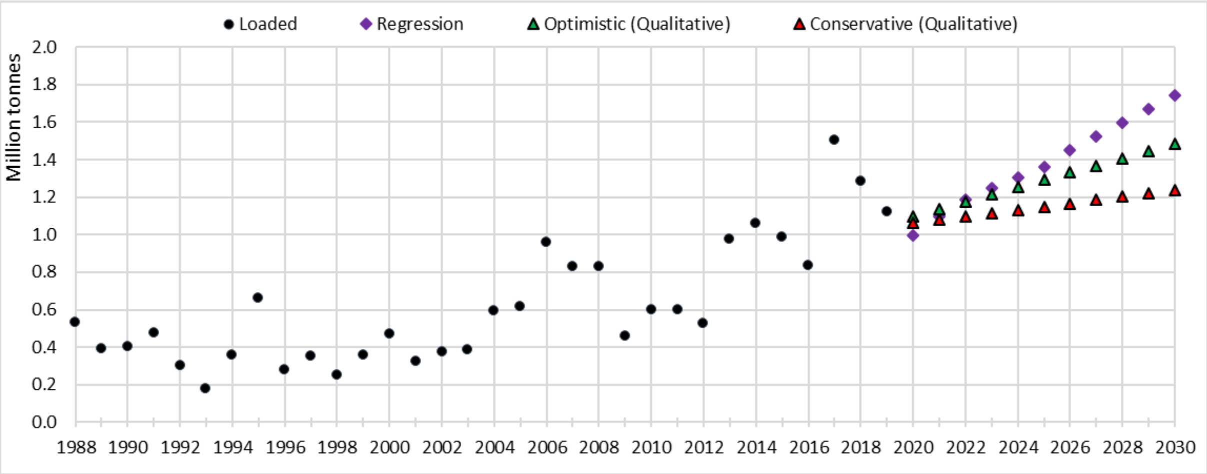

Figure 5.43 – Forecast of loaded dry bulk in Lisbon

In Setúbal the unloaded dry bulk which consists largely of cement products is expected to keep growing as the linear regression forecast suggests in Figure 5.44. The R coefficient for the linear regression is 0.56, a relatively low value. However the drops between 2019 and 2020 is too drastic. As such two alternatives are presented. A conservative scenario which was generated by extrapolating the trend seen between 2001 and 2019 and a more optimistic and likely one which uses the extrapolation of the trend seen between 2008 and 2019.

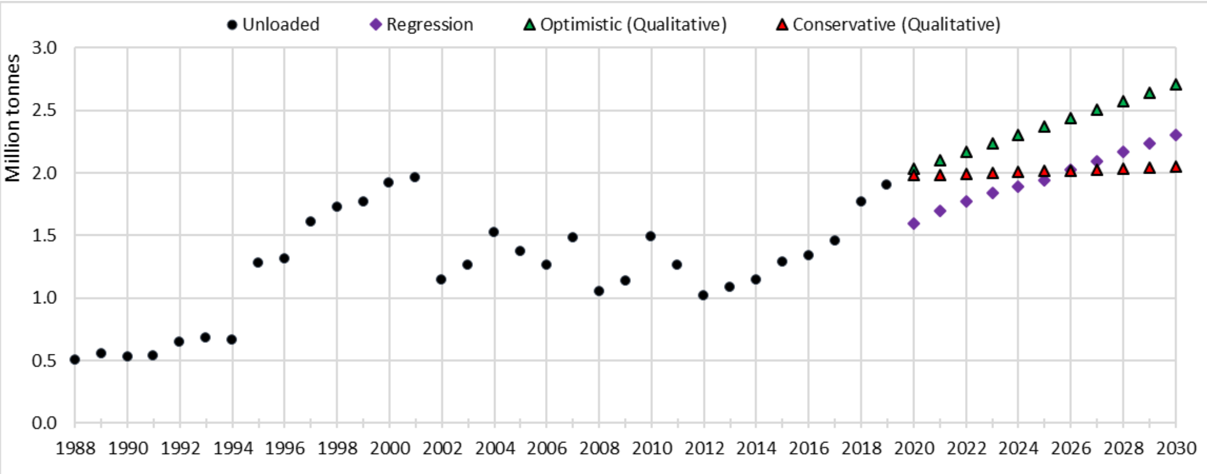

Figure 5.44 – Forecast of unloaded dry bulk in Setúbal

Similarly, the loaded dry bulk in the same port which consists largely of wood products is also expected to keep growing as seen in Figure 5.45. The forecast of the linear regression once again generated a growth rate which is too steep and optimistic. The R coefficient for the linear regression is 0.68, a somewhat low value. As such two alternatives are presented. A conservative scenario generated by extrapolating the trend seen between 2001 and 2019 and a slightly more optimistic one which was generated by extrapolating the trend seen between 1988 and 2010. Either of these two are likely to happen depending on the post-pandemic recovery rate of the global economies.

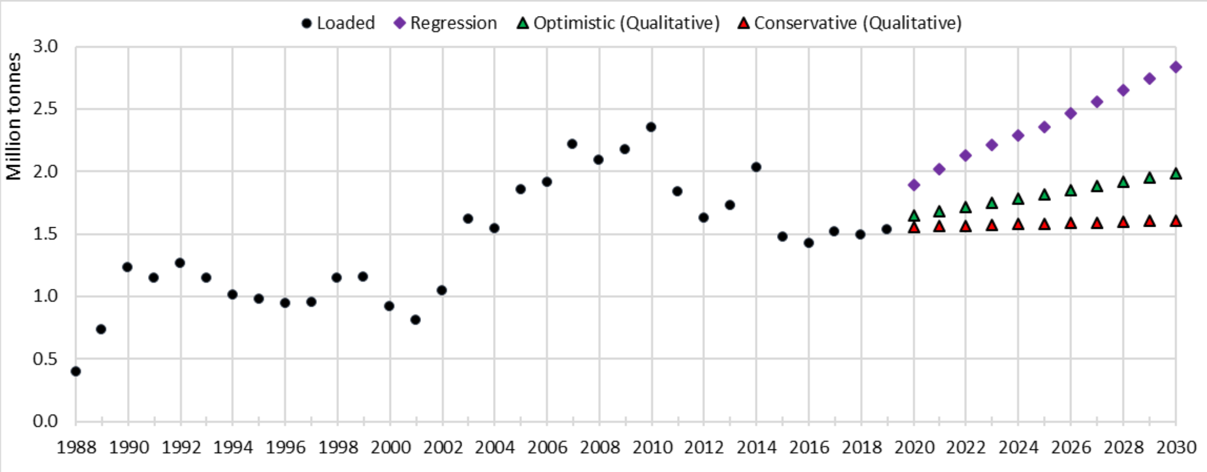

Figure 5.45 – Forecast of loaded dry bulk in Setúbal

A conservative forecast of the total dry bulk handled in Portugal as well as in the five main ports is presented in Figure 5.46 . Due to the shutdown of the power plant in Sines, the total volume handled is expected to drop and stabilize.

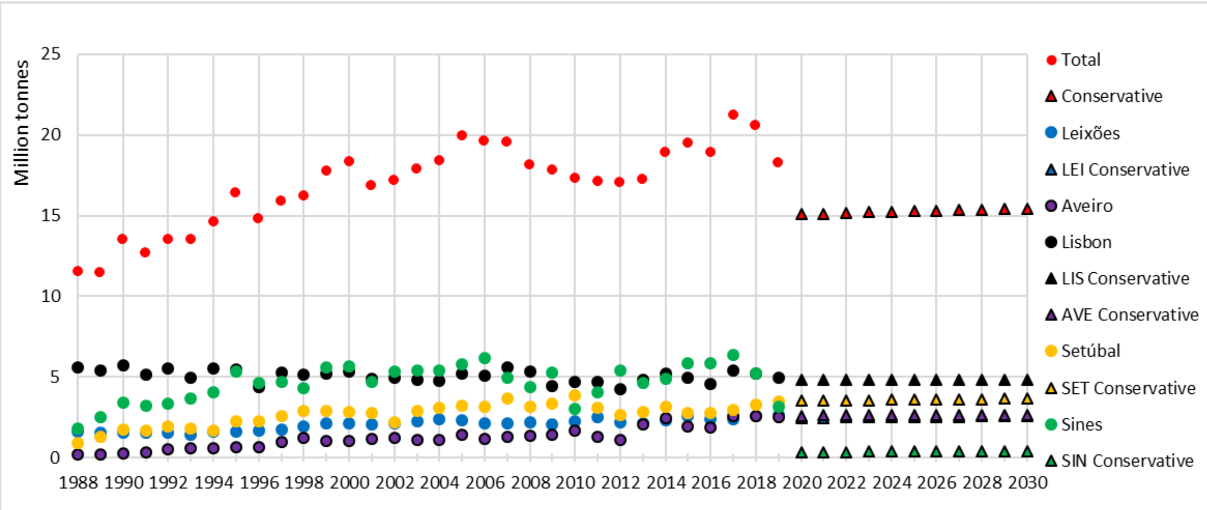

Figure 5.46 – Conservative forecast of dry bulk handled in Portugal

An optimistic forecast of the total dry bulk handled in Portugal as well as in the five main ports is presented in Figure 5.47. Due to the shutdown of the power plant in Sines, the total volume handled is expected to drop. Eventually the total volume is likely to surpass values seen in 2019, especially if an alternative to the coal handled in Sines is found.

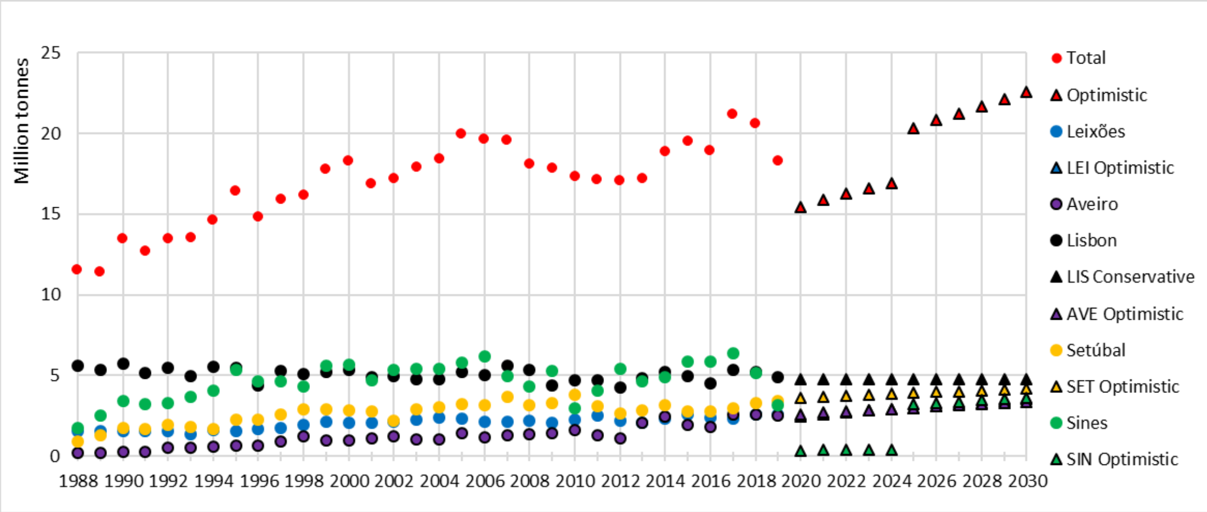

Figure 5.47 – Optimistic forecast of dry bulk handled in Portugal

Overall one could argue the most likely scenario is the optimistic one as it is likely that Sines will find a substitute cargo for the coal in the near future.

5.7 Aggregation of forecasts for the Portuguese port system

As for the Portuguese port system as a whole (considering only the five main ports under study), the aggregated total volume of cargo handled in the next years is expected to grow at a significant pace according to the optimistic scenario generated by the linear regression forecast seen in Figure 5.48. The R coefficient for the linear regression is 0.88. One could argue this is too optimistic given the negative trend that the country has entered in 2017 and to add up, the negative effects of the most recent global pandemic of COVID-19. As such, a more conservative and more likely scenario is presented. This one was generated by extrapolating the trend seen between the years of 2014 and 2019 (discounting the peak of 2017) and it forecasts a less steep rate of growth for the cargo handled in Portugal for the next decade. As may be seen in Figure 5.48 the forecasts for 2030 vary significantly. The optimistic scenario predicts 140M tonnes while the conservative scenario anticipates only about 80M in 2030. The first benefits from the very positive IMF growth rate forecast and the replacement of some dry and liquid bulks by other cargos (coal and crude oil and products, respectively in Sines and Leixões). The second scenario is based on very moderate growth rates and no replacement of mentioned dry and liquid bulks. This difference in forecasts is very significant and perhaps an intermediate scenario with some stronger economic growth in the wake of the ending of the pandemic coupled to some cargo replacing ceasing cargos in Sines and Leixões would lead to about 100M tonnes by 2030.

Overall, and although the general results of this exercise are fairly reasonable, forecasting cargo handling volumes for many types of cargo proved difficult. Generally, forecasting of containerized cargo based on the very optimistic growth rates predicted by IMF proved to lead to fairly realistic values. However, for many other cargos the extrapolation method proved to be more suitable in detriment to the linear regression due to high variability or lack of data points. Also, some types of cargo in some ports are highly dependent on specific industrial activities and their performance dictates the evolution of cargo handling in the future. These difficulties led to the need to develop optimistic and conservative scenarios.

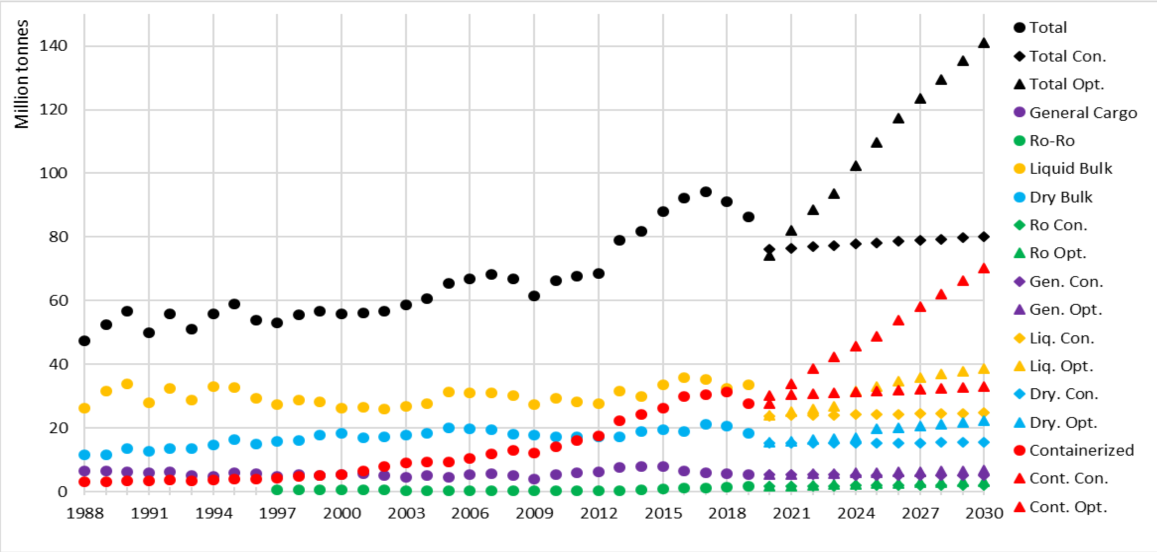

Figure 5.48 – Forecast of the total cargo handled in the Portuguese port system

The optimistic and conservative scenarios generated are in some cases subjective, as these were created based on the trends in which the cargo were found to be growing or receding at a more reasonable rate. These are to be interpreted with care, and are meant to serve as a general set of guidelines in terms of the most likely upper and lower boundaries for each of the cargoes' throughput evolution. One could argue that the most likely scenario is the optimistic one given the ongoing structural expansions which will increase the handling capacity of cargo and also due to the recovery which is expected from the global economies. It is also worth mentioning that in many of the ports, one cargo takes a large share of the volumes handled in the terminals. This leaves these ports vulnerable to significant changes whenever the company responsible for that one cargo moves or shuts down operation. Two examples of such scenarios are the cases of the unloaded coal in Sines and the unloaded crude oil in Leixões.

Finally, it is important to take any forecast as general guideline, taking into consideration the most likely lower and upper boundaries but not discarding completely the more extreme cases. One example of an unfulfilled forecast is one made by the Portuguese Minister of the Sea, Ana Paula Vitorino [75] which stated that the Portuguese port system was expected to grow and surpass the 100M tonnes of cargo handled in 2018. In fact, in 2017 the system had handled almost 96M tonnes so this expectation was a reasonable one. The numbers shown in Figure 5.48 are slightly smaller as these comprise only the five main ports in the Portuguese mainland and only the major cargos. However, the growth predicted by the minister didn't take place, in fact, the opposite happened. As seen in the statistics, see [52], the total cargo entered a period of decline in 2018 and even more in 2019. In 2019 ports handled only about 87M tonnes and, due to COVID pandemic, in 2020 handled even less: about 82M tonnes. Forecasting port cargo handling in the wake of this pandemic event remains a difficult task, but it seems that the goal of achieving 100M tonnes of cargo remains a challenging one even in 2030.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

One of the main contributions of this thesis has been the presentation of a detailed review of the development of cargo handling in the major Portuguese ports. Statistical data has been collected covering extensive periods of time, for the various types of cargo. Containerized cargo is now available for the period between 1974 and 2019. General cargo, liquid bulk and dry bulk data is available between 1988 and 2019. Ro-Ro cargo is available for the period between 1997 and 2019. This statistical data was merged with the time series previously available in the work of Mainardi [76] and largely expanded the initial period of 2001-2014 both to previous years and by updating the database for recent years.

This statistical data has been used to develop a database dedicated to cargo handling in Portuguese ports. An analysis of the data allows the conclusion that over the past three decades the Portuguese port system has been evolving with a positive trend. The volume of most of the cargo types handled have been increasing from year to year, especially in the containerized sector. A few exceptions are the unloaded liquid bulks in Leixões, Lisbon and Setúbal, as well as the unloaded dry bulk in Lisbon which have been experiencing a declining trend.

The database has allowed a forecasting exercise to be carried out, aiming at predicting the cargo throughput in the main Portuguese ports for the 2021-2030 period using mostly linear regressions but also extrapolations when the former do not provide reasonable results. The main drivers of the Portuguese economy are led by the agro-alimentary industry as well as industries which highly rely on imported raw goods. These are mainly the productions of cement, steel, paper, as well as chemical and oil products. The country is a highly open economy and this means that the country is easily influenced by global trends and crises. This translates into a more complex problem as the forecasts can be invalidated by wildcard events. Also, events such as the world crisis of 2008, the acquisition of the main Portuguese container handling terminals by the Turkish company Yilport, a large container terminal operator, or the current COVID pandemic, have significant consequences in the forecasting exercises. Overall, port forecasting remains a very hazardous task especially in today's uncertain world. The Portuguese GDP used as a basis for the majority of the forecasts has had a fairly stable growth period over the last decades. As such, this variable tends to allow positive forecasts for many different cargos.

One important outtake from this study is that non-containerized cargoes like liquid bulk or dry bulk are tightly interlinked with the evolution of industries related to the respective products. Meaning that extrapolation method of the trends of their evolution is more adequate when predicting their future. Another important conclusion is that multiple linear regressions aren't always the best forecasting method due to multi-collinearity which are inevitable when using data points such as the GDP of various nations. In those cases, the simpler method of linear regression can be used. With that said, one must still be critical and analytical regarding the results which are generated, as these may in some cases create forecasts which could be either too conservative or too optimistic. As is the case of the containerized cargo. It could be argued that due to the nature of the linear regression, there is a tendency to over accentuate the causal relation between the independent variable which is the GDP and the dependent variable which is the volume of containerized cargo.

Another challenge in using linear regression as a forecasting method is dealing with highly variable data sets such as the case of the general cargo. The method attempts to find mirroring trends between the two variables, however one can quickly understand that due to the erratic distribution of data points over the years it is highly difficult to find one. As such alternative methods like extrapolation of trends must be used in order to filter out and simplify the high level of variability. The cargoes where the linear regression proved to generate more realistic results were the dry and liquid bulks. Given the stable evolution of the volumes handled each year, it was possible to more easily create likely scenarios. As for the roll-on and roll-off cargo, the Setúbal and Lisbon ports had a somewhat unstable distribution of points which made the forecasting process more difficult. Regarding the remaining ports, due to the relative short number of data points, the resulting forecasts must be taken lightly even though the trend was found to be nearly linear, thus generated quite realistic results given the conditions.

In terms of extreme or wildcard events, the recent shutdown of both the fuel refinery in Leixões and the thermoelectric plant in Sines have caused (and will cause) a severe loss in terms of cargoes handled in both ports. In Leixões nearly 7.5 million tonnes of liquid bulk will no longer be handled in the next few years. In optimistic circumstances, if the lithium refining process is started successfully, the port may slowly once again begin to see more activity in both liquid and dry bulks. In the case of Sines, nearly 5 million tonnes of coal are no longer being imported to fuel the thermoelectric plant. However, there may be some alternative dry bulk cargos which may replace the coal such as soya intended for food processing, consumption or transshipment.

Overall the Portuguese port system had shown a promising growing trend up until 2017. The years of 2018 and 2019 showed already some worrying trends and this was further complicated by COVID pandemic. However, as the economies begin to recover and return to normality, the years following the pandemic will most likely give place to a boom in investments of industries which will lead the global shipping to bounce back and grow ever stronger and more active. As the decade unfolds, the previous target set by the Minister of Sea for the national port system to reach the 100M tonnes of total cargo handled may very well be achieved but only by 2030 given the conservative forecast predicting 80M tonnes and the optimistic forecast predicting 140M tonnes.

6.2 Recommendations for future work

One of the perhaps most interesting recommendations for future studies would be the application of more complex methods of forecasting. Methods such as Artificial Neural Networks may generate more plausible results, provided that enough data points are available in order to train and test the network with a satisfactory level of accuracy. In order to obtain such high number of data points, one could use statistics with a shorter interval of time. Using quarterly or even monthly values for example, instead of yearly cargo throughputs in any given port. Another recommendation is to develop or research a forecasting model for the Portuguese main manufacturing and production industries. And then attempt to use its results as foundation for a hypothetical linear regression model which would substitute the forecasts of GDP in Portugal as a basis for forecasting exercises for some types of cargo.

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APPENDIX 1 – CONTAINER CAPACITY CONVERSION

Table 1 contains the array of available ISO compliant container dimensions [77]. The TEU factors were applied to some of the data points presented in the statistics of ports chapter in order to convert the values into one standard unit of measure when speaking of container handling.

Table A.0.1 - ISO container dimensions

Length		Width		Height		Internal Volume		TEU
feet	metres	feet	metres	feet	metres	cubic feet	cubic metres	
20	6.058	8	2.44	8’6	2.59	1.172	33.2	1
40	12.192	8	2.44	8’6	2.59	2.389	67.6	2
45	13.716	8	2.44	8’6	2.59	3.040	86.0	2.25
48	14.630	8	2.44	8’6	2.59	3.264	92.4	2.4
53	16.154	8	2.44	8’6	2.59	3.604	102.1	2.65

The Figure A.1 illustrates the relative dimensions of the different types of containers used worldwide.

Figure A.0.1 – From bottom to top, (2x) 20', 40', 45', 48' and 53' containers