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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

EVALUATION OF THE EU AVIATION SECTOR'S PROGRESS TOWARDS NET-ZERO CO_2 EMISSION BY 2050

AB HAVACILIK SEKTÖRÜNÜN 2050 YILINA KADAR NET SIFIR CO_2 EMİSYONUNA YÖNELİK İLERLEMESİNİN DEĞERLENDİRİLMESİ

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ABSTRACT

The study examines 31 years of aviation-related CO_2 emission data from 1990 to 2021, utilizing advanced modeling techniques such as linear regression and Prophet to anticipate CO_2 emissions for the critical years 2030 and 2050. The report digs into each country's performance, assessing their promises to cut or even eliminate carbon emissions in line with the ambitious targets of the European Green Deal. Romania emerges as a noteworthy pioneer, demonstrating a remarkable commitment to decreasing emissions by an average of 47.22% by 2030 and 56.54% by 2050, establishing itself as a vital contributor to carbon neutrality. On the other hand, Luxembourg, Poland, and Spain are recognized as countries that deviate considerably from the established targets, raising worries about their capacity to reach the ambitious goals set by the European Green Deal. The study not only gives insights into expected CO_2 emission trajectories but also helps our knowledge of the obstacles and possibilities each nation has in achieving the carbon-neutral ambitions described in the European Green Deal.

Keywords: Aviation, European Green Deal, Linear Regression, Prophet, Sustainability.

JEL Classification Codes: O38, O47, M10.

ÖZ

Bu makale, 2030 ve 2050 yıllarına yönelik CO_2 emisyon tahminlerini yapmak amacıyla, 1990'dan 2021'e kadar olan 31 yıllık havacılık kaynaklı CO_2 emisyon verilerini incelemekte ve doğrusal regresyon ile Prophet gibi ileri modelleme tekniklerini kullanmaktadır. Çalışma, her bir ülkenin performansını değerlendirerek, emisyon azaltma taahhütlerini incelemektedir. Avrupa Yeşil Mutabakatının iddialı hedefleri doğrultusunda karbon emisyonlarının azaltılması hedeflenmektedir. Romanya, emisyonlarını 2030 yılına kadar ortalama %47,22 ve 2050 yılına kadar %56,54 oranında azaltma konusundaki kararlılığı ile öne çıkarak, karbon nötrlüğüne ciddi katkılar sunan bir ülke olarak kendini kanıtlamaktadır. Buna karşılık, Lüksemburg, Polonya ve İspanya, belirlenen hedeflerden önemli ölçüde sapmakta olup, bu ülkelerin Avrupa Yeşil Mutabakatının iddialı hedeflerine ulaşma kapasiteleri hakkında endişeler artmaktadır. Bu çalışma, sadece beklenen CO_2 emisyon trendleri hakkında bilgi sağlamakla kalmamakta, aynı zamanda her ülkenin Avrupa Yeşil Mutabakatı çerçevesinde karbon nötr hedeflerine ulaşmada karşılaştığı engeller ve sahip olduğu fırsatlar konusunda da derinlemesine içgörüler sunmaktadır.

Anahtar Kelimeler: Havacılık, Avrupa Yeşil Mutabakatı, Doğrusal Regresyon, Prophet, Sürdürülebilirlik.

JEL Sınıflandırma Kodları: O38, O47, M10

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GENİŞLETİLMİŞ ÖZET

Amaç ve Kapsam:

Sürdürülebilirlik kavramı yüzyıllar öncesine dayansa da modern önemi 20. yüzyılın sonlarındaki artan çevresel sorunlarla önem kazanmıştır. Küresel olarak dijital dönüşümü benimseyen toplumlar ve artan enerji talepleriyle birlikte, bu duruma bağlı olarak artan emisyonlar sürdürülebilir uygulamaların aciliyetini vurgulamıştır (Dincer ve Abu-Rayash, 2020). Havacılık, modern küresel bağlantı ve ekonomik faaliyetin temel taşlarından biri olarak, fosil yakıtlara dayalı bağımlılığı ile hem faydaları hem de zorlukları simgeler. Sektörün kerosen bağımlılığı, özellikle karbon dioksit (CO_2) emisyonları yoluyla çevresel izini önemli ölçüde artırmıştır. Son yıllarda hava trafiğindeki belirgin artış, buna paralel olarak uçak motorlarından kaynaklanan yakıt tüketimi ve emisyonlarda bir artışı beraberinde getirmiştir (Masiol ve Harrison, 2014; Kurniawan ve Khardi, 2011). Havacılık emisyonlarının büyük çoğunluğunu oluşturan karbon dioksit (CO_2), sera gazlarının birikimine ve yerel hava kalitesinin bozulmasına katkıda bulunmaktadır (Schmitt & Gollnick, 2016). Bu emisyonlar, özellikle kalkış ve iniş sırasında belirgin olup, sera gazı birikimine katkıda bulunmanın yanı sıra, yerel hava kalitesi sorunlarını ve gürültü kirliliğini kötüleştirerek havaalanlarına yakın toplulukları etkilemektedir (Schmitt & Gollnick, 2016). Havacılıkta kullanılan enerji kaynakları, uçak tipine, yakıt üretim süreçlerine ve motor özelliklerine bağlı olarak değişiklik göstermekte ve bu da sektörün genel çevresel izini etkilemektedir (Undavalli & Khandelwal, 2021). Yakıt verimliliğinde ve operasyonel uygulamalarda yaşanan ilerlemelere rağmen, havacılık endüstrisinin hızlı genişlemesi, diğer sektörlerde elde edilen emisyon azaltmalarını geride bırakmıştır. Uluslararası Sivil Havacılık Örgütü (ICAO) tarafından yayımlanan 2022 Çevre Raporu'na göre, küresel havacılık emisyonları 2010-2019 yılları arasında yıllık %3,3 artmıştır (ICAO Çevre Raporu 2022, 2022). COVID-19 pandemisi döneminde yaşanan seyahat kısıtlamaları ve ekonomik durgunluklar, 2020 yılında küresel CO2 emisyonlarında %5,8'lik bir düşüşe neden olmuştur (Lee et al., 2009). Ancak, önümüzdeki dönemde havacılık sektöründeki büyüme trendlerinin devam etmesi halinde, 2040 yılına kadar küresel uçak sayısının ikiye katlanması ve buna paralel olarak sera gazı emisyonlarının artması beklenmektedir (Lee et al., 2009). Uluslararası Sivil Havacılık Örgütü (ICAO) ve Avrupa Birliği (AB) gibi uluslararası kuruluşlar, havacılık emisyonlarını azaltmaya yönelik çeşitli girişimlerde bulunmuştur. Karbon Dışı ve Azaltma Uluslararası Havacılık Şeması (CORSIA) gibi programlar ve Paris İklim Anlaşması ile Avrupa Yeşil Anlaşması gibi anlaşmalar, havacılık sektörünü sürdürülebilir uygulamalara ve 2050'ye kadar karbonsuzluğa yönlendirmeyi amaçlamaktadır (European Commission, 2021). Bu çalışma, 27 AB ülkesinin havacılık sektöründeki karbon dioksit (CO_2) emisyon verilerini analiz ederek, Avrupa Yeşil Anlaşması'nda belirtilen 2030 ve 2050 hedeflerine doğru ilerleme trendlerini ve projeksiyonları değerlendirmektedir. Her ülkenin karbonsuzluk hedeflerine ne kadar yakın olduğunu değerlendirerek, mevcut politikaların ve uygulamaların sürdürülebilir havacılık hedeflerini gerçekleştirmedeki etkinliğini ortaya koymayı amaçlamaktadır. Bu çalışma, 31 yılı kapsayan havacılık kaynaklı CO_2 emisyon verilerini kullanarak, lineer regresyon ve Prophet gibi ileri modelleme tekniklerini gelecekteki emisyonları tahmin etmek için uygulamaktadır. Araştırma, Avrupa Yeşil Anlaşması tarafından belirlenen karbon azaltma hedeflerine AB üyesi her ülkenin ilerlemesini ve taahhüdünü değerlendirmeyi amaçlamaktadır. Beklenen ve hedeflenen emisyon azaltımları arasındaki farklılıkları inceleyerek, her ülkenin karbon nötr olma hedefine ulaşma yolunda karşılaştığı zorluklar ve fırsatlar hakkında içgörüler sunmaktadır.

Yöntem:

Çalışma, havacılık kaynaklı CO_2 emisyon verilerini üç on yılı aşkın bir süre boyunca incelemekte ve gelecekteki emisyonları tahmin etmek için ileri modelleme teknikleri olan lineer regresyon ve Prophet'i kullanmaktadır. Bu analiz, uzun vadeli eğilimleri ve değişiklikleri anlamak için kapsamlı bir veri setine dayanmaktadır. Araştırma, Avrupa Yeşil Anlaşması kapsamında belirlenen 2030 ve 2050 yılı karbon azaltma hedeflerine her AB üyesi ülkenin ilerlemesini ve taahhüdünü değerlendirmektedir. Bu bağlamda, her ülkenin mevcut politikalarını, stratejilerini ve taahhütlerini analiz ederek, sürdürülebilirlik hedeflerine ulaşma yolundaki performanslarını ölçmektedir. Beklenen ve hedeflenen emisyon azaltımları arasındaki farklılıkları analiz ederek, araştırma her ülkenin sürdürülebilirlik hedeflerine ulaşmak için karşılaştığı engelleri ve sunulan fırsatları ortaya koymaktadır. Özellikle, ülkelerin ekonomik, sosyal ve teknolojik durumu göz önünde bulundurularak, karşılaşılan zorluklar ve bunların üstesinden gelmek için atılabilecek adımlar detaylandırılmaktadır.

Bulgular:

Araştırma sonuçları, Avrupa Yeşil Anlaşması kapsamında belirlenen 2050 yılına kadar karbon nötr olma hedeflerine yönelik AB üyesi ülkeler arasındaki farklılıkları göstermektedir. Her ülkenin karbon azaltma hedeflerine ulaşma konusundaki farklı derecelerdeki taahhüdünü vurgulamaktadır. Bu çerçevede, Romanya gibi belirli ülkelerin sürdürülebilirlik konusundaki kararlılığı öne çıkmakta, diğer yandan Lüksemburg, Polonya ve İspanya gibi ülkelerin belirlenen hedeflerin gerisinde kaldığı belirtilmektedir. Bu farklılıklar, Avrupa'nın karbon nötr olma hedefine ulaşma sürecindeki zorlukları ve fırsatları anlamamıza yardımcı olmaktadır.

Sonuç ve Tartışma:

Sonuç olarak, çalışma Avrupa Yeşil Anlaşması'nın hedeflerine ulaşma sürecindeki önemli noktaları vurgulamaktadır. Sürdürülebilirlik çabalarının etkin bir şekilde yönetilmesi ve uluslararası işbirliğinin önemi üzerinde durmaktadır. Her ülkenin özel durumunu göz önünde bulundurarak politika geliştirme ve uygulama süreçlerinin güçlendirilmesi gerektiği vurgulanmaktadır. Bu çalışma, Avrupa'nın sürdürülebilirlik hedeflerine ulaşma yolunda atılacak adımlar konusunda değerli içgörüler sunmaktadır. Sonuçların, AB üyesi ülkelerin sürdürülebilir performanslarını göstererek, farkındalık oluşturması beklenmektedir. Bu ülkelerin detaylı olarak incelenmesi, Avrupa Yeşil Anlaşma hedeflerine doğru ilerlemelerini veya onlardan sapmalarını derinlemesine anlamamızı sağlıyor. Her ülkenin yolculuğunu bağlamak için ekonomik koşullar, yasal çerçeveler ve teknik manzaraları incelemek, politika yapıcıları ve çevre savunucuları için faydalı içgörüler sağlayabilir.

1. INTRODUCTION

Although the concept of sustainability is not new, it gained importance with the emergence of environmental issues in the late 20th century, and goals based on this concept began to be presented. This concept is closely related to energy consumption. As modern societies transition to digital transformation and a need for more energy supply, there has been an increase in emissions depending on the type of energy used, and the idea of sustainable transformation has been asserted due to the environmental impact of the opinion of sustainable transformation promoted (Dincer & Abu-Rayash, 2020).

Journal In recent years, apart from some crises, with the continuous increase in the number of flights, there has been an increase in fuel consumption, mostly kerosene, and accordingly, the emission values of airplanes have increased (Masiol & Harrison, 2014). Aircraft engine emissions include approximately 70% carbon dioxide (CO_2), less than 30% water vapor, and less than 1% other pollutants such as carbon monoxide (CO) and nitrogen oxide (NO) (Kurniawan & Khardi, 2011). In addition, the noise emissions emitted by the aircraft, especially during landing and take-off, and greenhouse gas emissions adversely affect the local population due to the deterioration in the regional air (Schmitt & Gollnick, 2016).

This energy source for the aviation industry varies according to the industry in which the aircraft is utilized, the process of fuel production, and the kind of engine employed (Undavalli & Khandelwal, 2021). Due to the rapid growth of supply in the aviation sector, emissions from the same category tend to expand on an aviation basis. In contrast, emission levels in other industries tend to decline. According to the ICAO's Environmental Report for 2022 (ICAO Environmental Report 2022, 2022), it increased by 3.3% each year between 2010 and 2019. Because of the COVID-19 pandemic that began in 2020, there was a 5.8% drop in worldwide CO_2 emissions in 2020 compared to 2019. Due to the lockdown during the pandemic, airplane emissions have been reduced by 45%. However, assuming pre-pandemic growth rates in the aviation sector continue, it is anticipated that at least twice as many aircraft will be in the sky in 2040, and greenhouse gas emissions will rise in proportion (Lee et al., 2009).

Aviation is one of the utmost global economic activities in the modern world, and because of these extensive activities of the aviation sector, emissions of CO_2 and non-CO_2 effects result in environmental changes (Lee et al., 2021). Because of their immediate impact on the environment and human life, most chemicals produced during airplane combustion operations are categorized as hazardous air pollutants (Undavalli et al., 2023). To prevent these emissions, sustainable aviation fuels and other non-emission fuel choices have been suggested to meet the net zero CO_2 emissions goal in aviation by 2050. To achieve these objectives, the International Civil Aviation Organization (ICAO) and the European Union (EU) have attempted to diversify through programs such as the Carbon Offset and Reduction Scheme for International Aviation (CORSIA) and agreements that prioritize sustainability, such as the Paris Climate Agreement and the European Green Deal. In this way, the main goal is to achieve net zero by 2050, together with the countries included in the European Union.

When examining the ICAO's aviation targets, it is estimated that 2% energy efficiency each year should be attained by 2050 (ICAO Environmental Report 2022, 2022). Examining the emissions from aviation has been the focus of countries' attention, and the sustainability reports of the firms are produced every year in this context when today's conditions are analyzed, taking into account the research carried out to reduce aviation emissions (Zeydan & Yıldız Şekertekin, 2022).

This study used carbon dioxide (CO_2) emission statistics from the aviation industry, which included 27 EU nations, to undertake a time-dependent projection analysis. The research was based on the 2030 and 2050 objectives of the European Green Deal. The results of this research were used to evaluate how near or far countries are to meet the net-zero emission objective.

2. BACKGROUND

There are many studies in the literature that estimate CO_2 levels. However, it becomes difficult to find studies with emission estimates in this field when it is classified as aviation. When the forecast approach is examined in general, according to Stefenon et al. (2023), to create security in the markets, it is necessary to determine the time series and future period forecasts well and create an effective model and forecasting approaches. Their study proposed combining seasonal and trend decomposition to make an accurate and robust time series analysis. They tested the accuracy of the prediction by comparing the results with MAPE. According to Primandari et al. (2022), the carbon dioxide (CO_2) level in the atmosphere is constantly increasing depending on the fuels used. The Prophet model, which can handle seasonality and determine change points, was used in the analysis to observe this increase. With the study's results, the model's performance was tested with error measurements and was found to have high performance. According to Rafferty (2021), a cross-validation technique was used to create a forecasting model. Various methodologies have been used to forecast CO_2 emissions in the near and long run. These approaches, which integrate regression models and machine learning methods with scenario analysis, primarily estimate future patterns based on historical data (Hosseini et al., 2019).

The study in Primandari et al. (2022) employs the Prophet Facebook model to assess and forecast changes in CO_2 concentrations over time, emphasizing seasonality and trends in the data. The paper discusses the problems caused by greenhouse gas emissions and the need for improved analytical and forecasting approaches to understand better and control the environmental effects of CO_2 emissions. Furthermore, the essay underlines the Prophet model's usefulness in capturing complex patterns and providing valuable insights into the dynamics of CO_2 emissions. This study adds to our understanding of the environmental repercussions of rising CO_2 levels and underscores the need for modern analytical approaches in resolving issues related to CO_2 emissions in the atmosphere.

2.1. European Green Deal

The European Union (EU) has often stated its commitment to lead global efforts to tackle climate change, actively participating in international climate negotiations and enacting policies to lower greenhouse gas emissions and support clean energy sources. However, the EU's success in efficiently reducing greenhouse gas emissions is not convincing, and insufficient steps to control emissions in many industries have been implemented. Greenhouse gas emissions have increased in transportation, and coal is essential in the energy environment. Despite attempts, advances in building energy efficiency have fallen short of expectations, and decarbonizing the industry has proven difficult. The Fridays For Future movement is mobilizing youngsters to push for a more proactive climate agenda, one of the current challenging issues within the EU. Furthermore, movements such as the Gilets Jaunes in France and elsewhere exemplify opposition to perceived unjust increases in fossil fuel prices. This highlights the complexities of EU climate policy and the varying emotions it provokes from different population groups. (Claeys et al., 2019).

After the climate crisis became a significant phenomenon, the European Union began to conduct studies to prevent it and to examine their targets under various headings to decide on where they set a target; as a result of these studies, the European Green Deal was proposed for Europe to be carbon neutral continent on Earth by 2050 (Claeys et al., 2019). Although the decisions taken are not taken only based on aviation, they can also be taken into consideration for aviation since the limitations cover all sectors.

If nothing has been done, the number of emissions attributed to aviation in Europe will rise as demand for travel is expected to increase and other polluting sectors decarbonize in line with their respective promises. Due to this situation, it seems necessary to transform into green energy sources in all transportation and all industries that cause carbon emissions, especially in the aviation sector. By the long-term climate targets of the EU and the Paris Agreement, stakeholders from the European aviation sector are cooperating through several projects to reach net zero CO_2 emissions and a 90% reduction of non-CO_2 impacts by 2050. The aviation industry is fully aware of its obligations and the difficulties that come with them with all three UN sustainability pillars. This vision lays the groundwork for overcoming these obstacles and ensuring that aviation contributes to Europe's economic and societal prosperity (The Advisory Council for Aviation Research and Innovation in Europe (ACARE), 2022).

ACARE outlines future European aircraft emissions development policies. This plan aims to reduce CO_2 emissions per passenger km by 75%, NO_x emissions by 90%, and perceived noise by 65% relative to a 2000 baseline. These goals will be achieved through aircraft and engine technology advancements, operational improvements, and alternative fuels. In addition, there is expected to be a decrease in the amount of fuel used with new materials, especially nanotechnology, especially in the aviation sector (Joint Research Centre (European Commission) et al., 2021). All users were considered while determining the targets. In this context, the necessity of employing the most competent people who can provide these services by considering the selection of a product and service without sacrificing quality was mentioned when setting the 2050 targets. In addition, it is among the targets to bring the entire European Aviation system to the air logistics chain in a fully interconnected manner by 2050. While establishing targets for environmental protection and energy supply, targets were determined within the framework of the fuels used and within the emissions framework (Directorate-General for Mobility and Transport (European Commission) & Directorate-General for Research and Innovation (European Commission), 2011).

A large part of the emissions from flight in aviation occurs depending on the type of fuel used and the amount of fuel consumed. Due to this situation, switching to sustainable fuel types is inevitable. Different fuel types are shown as alternatives to achieve this transformation. In particular, the conversion to electric air vehicles or the transition to hydrogen-based fuels that do not emit carbon dioxide as a result of their use will allow emission values to be considered (Siddiqui & Dincer, 2021). It has been determined to significantly reduce the carbon footprint, especially after introducing hydrogen-based and battery-powered aircraft. Thanks to the engine and technological developments, it is thought that both performance increase and noise emission will be reduced. In addition, it aims to make aircraft emission-free during taxiing. It aims to design and manufacture the aircraft using recyclable materials to contribute to the circular economy and the production targets. To realize all these flight activities, transforming Europe into a sustainable fuel base is also among the targets set (Directorate-General for Mobility and Transport (European Commission) & Directorate-General for Research and Innovation (European Commission, 2011).

2.2. Reducing CO_2 Emissions

The GHG Protocol establishes criteria and guidelines for businesses to quantify and report their GHG emissions voluntarily. The Kyoto Protocol's accounting and reporting coverage includes the six greenhouse gases listed below:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6) (Newmont Corporation, 2023).

When assessing emissions, a classification is applied by categorizing them according to their impact. When we talk about emissions, we often talk about carbon dioxide. The reason for this is directly related to the duration of the gases emitted to the atmosphere in the atmosphere. In the Table 1, information is given about how long these gases remain in the atmosphere. According to Table 1, carbon dioxide is thought to have more catastrophic effects because it takes a lot of time to disappear from the atmosphere. The other gases in Table 1 can be categorized as non-CO_2 under a single heading.

Table 1. The Lifetime of Emissions in the Atmosphere

Emission	Lifetime
Carbon dioxide (CO_2)	50-200 years
Nitrogen oxide (NO_x)	Some weeks
Water steam (H_20)	Some weeks
Methane (CH_4)	8-10 years
Ozone (O_3)	Some months
Cirrus, contrails	Up to some weeks

Source: (Schmitt & Gollnick, 2016; Fuglestvedt et al., 2008).

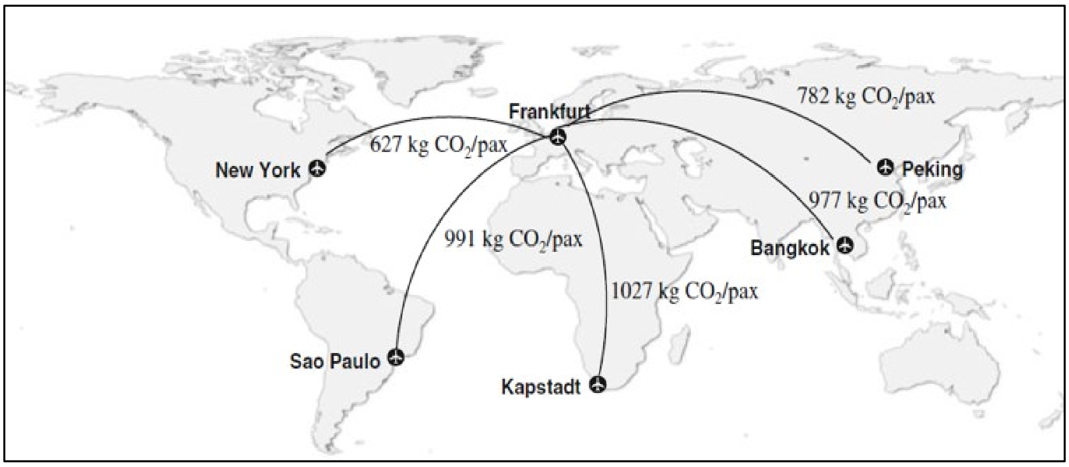
Greenhouse gas emission sources are divided into three areas or scopes: emissions directly attributable to a business and those indirectly attributable. These are as follows:

Scope 1: Several reliable public sources calculate the scope one emission factors. These sources usually include CO_2, CH_4, and N_2O emission factors that may be multiplied by the corresponding GWP and combined to get the total CO_2e.

Scope 2: Sources for the site's electrical product suppliers or published regional average factors for the electricity mix are used to calculate the scope 2 emission factors. Depending on the data source, these components may already be represented as CO_2e or may be broken down into contributing gas.

Scope 3: The most common representation of scope three emission factors is CO_2e, and they frequently use generic factors from paid databases, reliable public sources, and sources particular to customers and suppliers (Newmont Corporation, 2023).

Figure 1. Average CO_2 Emissions per Flight



Source: (Schmitt & Gollnick, 2016).

3. FORECASTING METHODS

Two primary analytical methods, Prophet and linear regression, were used for this analysis. Prophet, a time series data analysis tool, was used to forecast future patterns based on a 31-year dataset of CO_2 emissions. Prophet's adaptability, durability, and ability to handle complex datasets and resolve seasonal effects were major factors in selecting this analysis technique.

Linear regression analysis, on the other hand, was employed to analyze the relationship between prior CO_2 emission data and future emission estimates. This method is helpful for discovering patterns and correlations in a dataset. Linear regression is a simple mathematical modeling tool that permits building a linear model based on previous data to anticipate future CO_2 emissions.

By combining both of these analytic approaches, the work establishes a foundation for understanding the dynamics of time series data and projecting future CO_2 emissions, ensuring the integrity of the research aims.

Both analyses are mentioned below:

3.1. Prophet

Prophet is a Facebook-developed open-source time-series forecasting library. For time series forecasting, it employs multiple distinct approaches. It also supports modeling seasonality and holiday effects, which can be helpful to in high-frequency datasets such as daily or weekly data. However, seasonality and holiday effects are less relevant in this study, where annual data was used. The nature of annual data does not require the consideration of short-term seasonal fluctuations or holiday impacts; thus, these components were not utilized in the model. Instead, the focus was on the long-term trend in aviation-related CO_2 emissions, which is the most significant aspect when working with annual time series data.

When the studies on the Prophet are examined, it is seen that they were worked on, especially between 2019 and 2021. (Aguilera et al., 2019) In the study, water level estimation was made using Prophet, and it was understood to perform better than other estimation methods.

When the time series analyses using the Prophet method were examined, it was thought that this method did not pose a problem regarding applicability. Since Prophet is an R and Python-supported estimation application, R 4.3.1 software was used in this study.

The prophet is made up of three primary parts. The first component, termed trend, is used to define the trend in time series data. The second component is seasonality, and the third component is holidays. The following equation describes these three components:

$$Y_t = g_t + s_t + h_t + \varepsilon_t \tag{1}$$

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where, $g_t$represents trend, s_t represents seasonality and h_t represents holidays. Again, ε_t is an error term which takes into consideration any irregular changes that the model may not accommodate (Arslan, 2022).

Since the dataset used in this study is based on annual observations, both seasonality and holiday influences have been excluded from the analytical model. This decision was based on the understanding that these factors are unimportant in yearly data, for which long-term trends are more important than short-term seasonal or holiday fluctuations. Consequently, the trend component $g_t$the Prophet model's primary focus in this research was capturing the overall upward or downward movement in aviation-related CO_2 emissions over time.

Prophet is a procedure for forecasting time series data created by Facebook's Core Data Science team. It aims to be able to forecast 'at scale', meaning PROPHET wants to be the forecasting tool that is automated in nature, giving more ease of use in tuning time series methods and enabling analysts from any background or people with little to no prior knowledge in forecasting to be able to forecast successfully (Satrio et al., 2021).

3.2. Linear Regression

Linear regression is a powerful statistical technique for predicting numerical values based on the relationship between independent and dependent variables. It is commonly adopted in various fields, including project management, data science, real estate analysis, urban growth modeling, and education. In project management, linear regression is frequently applied to assess and understand the factors contributing to delays in construction projects. For example, in Korea, researchers utilized linear regression to investigate the reasons driving delays in construction projects in India and to compare different construction cost estimating models. Linear regression is a popular predictive modeling approach in data science. Author age, facial recognition, electricity consumption, cancer occurrence, and fatality rates, the surface tension of vegetable oils, and concrete compressive strength have all been predicted using linear regression (Primandari et al., 2022). Linear regression enables us to construct a mathematical equation that depicts the relationship between the independent variables (predictors) and the dependent variable (goal). We can create reliable predictions about the target variable based on the values of the predictors by analyzing historical data and applying the principles of linear regression analysis. In real estate analysis, linear regression can be used to predict property prices by considering variables such as location, size, and amenities.

The equation expresses the simple linear regression:

$$Y = \beta_0 + \beta_1 X + \varepsilon \tag{2}$$

where Y represents the response variable, X is the predictor variable, β_0 and β_1 denote the regression coefficients or parameters, and ε accounts for the error between the predicted values derived from Equation (2) and the actual observations. The expected value formulation of Equation (2) is

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X \tag{3}$$

where $\hat{Y}$ represents the estimated or predicted value, and $\widehat{\beta}$ are estimates of the regression coefficients. It is essential to note that the distinction between fitted and predicted values lies in that the fitted value pertains to instances where the values for the predictor variable correspond to one of the n observations used to determine $\widehat{\beta}$, whereas predicted. In contrast, predictedfor any set of predictor variable values different from the observed data (Fumo & Rafe Biswas, 2015).

The current study's linear regression predictions were based on a dataset that included 31 years of CO_2 emissions by the aviation industry. This study used an autoregressive model to increase the accuracy of long-term predictions. Specifically, the autoregressive model used included lag periods; three lags were chosen based on the autocorrelation function of the data. This approach meant that the temporal relationships of the dataset could be easily incorporated, further enhancing the predictive accuracy for 2030 and 2050. Moreover, while generating the forecast for the year 2050, there was re-forecasting over previously forecasted data points to consider the accumulated emissions growth over time.

Within the scope of this study, the Linear Regression method was selected in addition to the Prophet to make comparisons. The primary purpose of choosing this method is that the dataset shows a regular upward trend except for minor deviations outside the pandemic.

When the standard linear regression model was used, a smooth result could not be obtained due to sudden changes in the data. Therefore, during the analysis, a more complex model was created around linear regression with transformations and quadratic equations affecting independent variables in the linear model.

An advanced model was used when it was impossible to explain the data with the help of only linear regression since there was a nonlinear trend, described by Equation (4). Additional elements in the advanced model involved the squared term and the logarithmic transformation. In this new procedure, both the original and transformed forms of the same independent variable are used to express different features of the behavior of the data. This type of approach allows managing the rising and falling trends more successfully.

The new model was created differently from the equation given in Equation 3;

$$\hat{Y} = \hat{\beta}_0 + \hat{\beta}_1 X + \hat{\beta}_2 X^2 + \hat{\beta}_3 \log X \quad (4)$$

It has been reconstructed to be more complex than linear regression. In this way, unlike linear regression, it is aimed to prevent inconsistent and erroneous results that may occur in future estimates by creating a model that can be affected by increase and decrease.

4. METHODOLOGY

This study aims to anticipate CO_2 emissions using two different modeling techniques: the Prophet time series forecasting model and linear regression. The procedures used to prepare, examine, and evaluate the data utilizing these approaches are described in this section.

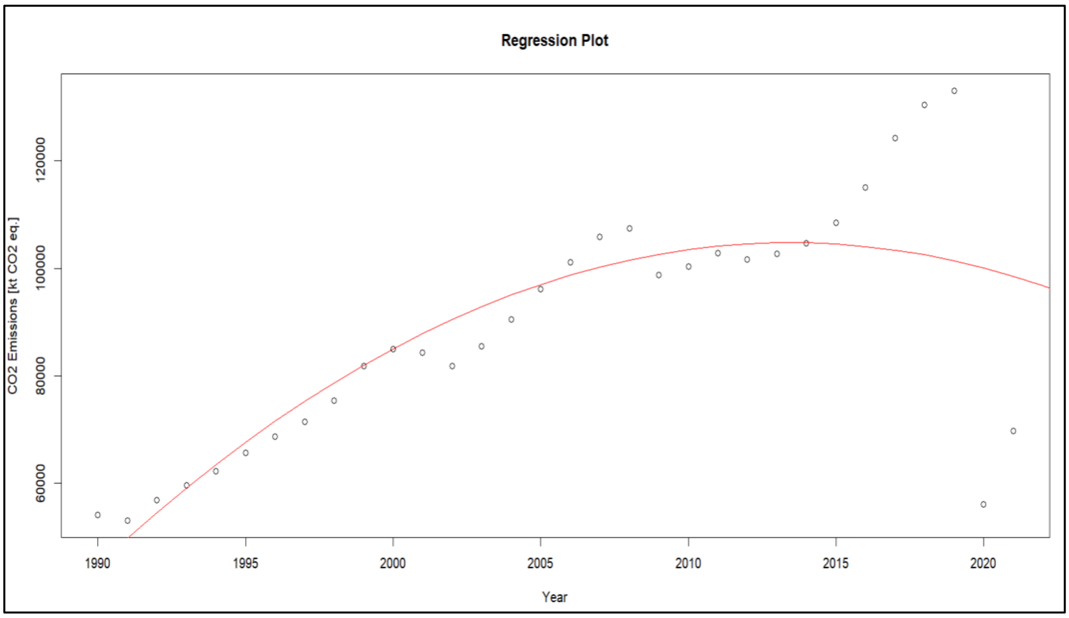
4.1. Data Collection

Historical data on aviation-related CO_2 emissions of EU Countries were obtained to provide a comprehensive dataset covering relevant periods. The table for the data used is included in Appendix 1.

4.2. Data Analysis

Our examination of CO_2 emitted by the aviation industry between 1990 and 2021 shows a quasi-steady increase until 2020, suggesting ongoing expansion. However, in 2020, a notable divergence appeared, ascribed to the COVID-19 pandemic's worldwide effects. The significant impact of lockdowns and limitations on industrial and transportation operations brought on by the pandemic is reflected in the sharp decline in CO_2 emissions during this time. This anomaly demonstrates how susceptible emissions are to outside influences. Comprehending these anomalies is crucial for effective environmental governance and provides insight for the following forecasts and strategies

Figure 1. Temporal Trends in CO_2 Emissions of EU-Countries between 1990-2021



The graph in Figure 2 depicts the temporal patterns of CO_2 emissions from 1990 to 2021, demonstrating a consistent increase in emissions during this period. Notably, the global consequences of the COVID-19 pandemic are being blamed for the significant drop in 2020. Examining these temporal trends allows us to understand the dynamic nature of CO_2 emissions across time. In the graph given in Figure 2, the dots show the actual values. The red logarithmic curve also shows the estimated values calculated as a result of the regression. As can be seen, a severe decline will be visible in 2020. This decline applies to all EU countries. Due to a severe decline in 2020, estimation by making a linear approach affects the accuracy of the results and causes the estimated values to be surprising in the coming years. Therefore, based on the examination of the dataset, two different estimation methods were used to analyze it.

This paper uses R programming language to examine CO_2 emissions thoroughly. The first step was to import and clean our dataset of CO_2 emissions. After sorting the data, a year-by-year time series was created.

Most importantly, we created distinct linear regression models for each country and used them to forecast CO_2 emissions in 2030 and 2050.

Throughout our investigation, CO_2 emissions are calculated for each nation in 2030 and 2050 using linear regression analysis. Customized linear regression models are employed based on historical CO_2 data from 1990 to 2021, adapted to each country's specific emission trends. The models were then used to forecast CO_2 levels for the coming decades. A comprehensive table has been created based on projections for 2030 and 2050, illustrating the expected CO_2 emissions for each country. The tabular representation enables easy comparison of predicted emissions and provides valuable insight into the likely trends in CO_2 levels in different geographical locations. Readers can identify and evaluate the differences in anticipated emissions across the countries under consideration using the tabulated data as a crucial reference point.

Table 2. Error Measurements for the Two Analyses of the Chosen Countries

Country	Model	R-squared (R^2)	MSE	RMSE	MAPE	MAE
Austria	Linear Regression	0.721408	974.6143	31.21881	10.31935	157.8625
Austria	Prophet	0.642576	0.000288	0.016983	10.73649	183.9627
Belgium	Linear Regression	0.598007	3.91E-09	6.25E-05	9.934498	376.5749
Belgium	Prophet	0.854467	0.000129	0.011344	4.620717	184.0358
France	Linear Regression	0.664139	975.977	31.24063	10.08781	1234.359
France	Prophet	0.740821	86.03049	9.275262	8.364278	1096.23
Germany	Linear Regression	0.71436	1.63E-07	0.000403	9.324512	1833.309
Germany	Prophet	0.765134	0.012448	0.111572	7.978173	1697.657
Luxembourg	Linear Regression	0.889281	0.000351	0.018747	11.42634	117.8747
Luxembourg	Prophet	0.978409	2.44E-05	1.56E-05	3.575542	44.21529
Ireland	Linear Regression	0.558284	4.31E-05	0.006563	21.25524	384.5
Ireland	Prophet	0.661467	0.001528	0.039087	15.43362	298.1609

Chosen as examples, certain countries have been subjected to error measurements. Upon comparing the outcomes, it becomes apparent that the Prophet algorithm performs nearly as well as the Linear Regression. Looking at the R-squared values to decide which model is better, it is seen that Prophet gives better results. When the specific values of some countries shown in Table 2 are compared, it can be seen that all of them have valid rates. This leads to the conclusion that both models are valid and their outputs can be interpreted.

After deciding whether the model is valid or not, the 2030 and 2050 targets of the EU countries, which are calculated as a result of two different forecast models, are shown in Table 3 and Table 4.

Table 3. Predictions of the CO_2 Emission Values for the Years 2030-2050 according to Linear Regression Analysis

EU Countries	LR2030	LR2050	EU Countries	LR2030	LR2050
Austria	1317.92	-1462.30	Italy	5524.15	-7378.57
Belgium	4204.85	2337.18	Latvia	606.06	1145.57
Bulgaria	1112.48	2772.00	Lithuania	640.62	1756.79
Crotia	618.65	1185.39	Luxembourg	1915.75	2049.31
Cyprus	467.38	-500.08	Malta	390.98	461.95
Czechia	677.06	-312.45	Netherlands	4190.03	-16814.1
Denmark	1231.81	-2574.07	Poland	4146.84	8809.70
Estonia	206.76	278.86	Portugal	3820.87	4846.65
Finland	1802.24	1060.37	Romania	809.19	1786.54
France	6465.17	-23605.10	Slovakia	119.72	5.62
Germany	18122.20	-9210.96	Slovenia	0.68	-2201.24
Greece	2768.83	2073.43	Spain	11663.85	-1062.33
Hungary	75.33	-1554.40	Sweden	1196.95	-2123.98
Ireland	1189.72	-3214.10	Switzerland	3211.21	-759.85

The values in Table 3 show the estimates of the 2030 and 2050 targets on a country basis, which emerged due to the complex linear regression model. As can be understood from the data, it is predicted that many countries are getting closer to the target every year, and many of them will reach the net zero emission target by 2050 in the aviation industry.

A systematic set of procedures was used to conduct the Prophet analysis. To fulfill the Prophet model's input criteria, the CO_2 emission dataset for each nation was first preprocessed. Prophet is designed to carry out the training process on its own. During training, the model automatically recognizes annual changes and possible holiday impacts, using its innate ability to adjust to temporal patterns and manage missing data. The next stage was to fit the model to the historical CO_2 data so that Prophet could figure out the underlying patterns on its own. The model produced projections for 2030 and 2050 after training. After that, the data were carefully arranged to be compared with the original linear regression models' conclusions. This strategic strategy sought to use the advantages of both analytical approaches and provide a more thorough picture of the future paths of CO_2 emissions for each nation.

Table 4. Predictions of the CO_2 Emission Values for the Years 2030-2050 according to Prophet Model

EU Countries	P2030	P2050	EU Countries	P2030	P2050
Austria	1217.12	-105.46	Italy	4619.187	-2452.82
Belgium	5227.84	6281.03	Latvia	242.81	51.76
Bulgaria	695.42	850.58	Lithuania	273.11	300.48
Crotia	444.14	508.87	Luxembourg	2777.80	4590.75
Cyprus	485.68	-15.82	Malta	314.72	234.06
Czechia	419.60	-305.93	Netherlands	5234.23	-3160.73
Denmark	690.47	-2023.13	Poland	3643.47	5801.50
Estonia	153.21	152.48	Portugal	2518.30	1535.76
Finland	592.74	-1385.57	Romania	-147.22	-1223.92
France	4292.15	-13305.00	Slovakia	87.70	21.19
Germany	15515.15	745.13	Slovenia	18.95	-52.68
Greece	3078.72	3276.41	Spain	8200.13	-1223.75
Hungary	462.30	252.76	Sweden	600.91	-1832.48
Ireland	2100.15	1647.22	Switzerland	1244.80	-3890.52

Similar to the values in Table 3, Table 4 shows the model outputs of the same countries calculated using the Prophet model. Similarly, in the values here, it is estimated that countries are approaching the net-zero target and that most countries will achieve this target.

5. FINDINGS

Analyzing aviation-related CO_2 emissions from 1990 to 2021 using Linear Regression and Prophet models yields similar results. The closeness in performance between these two models shows an excellent match to the dataset's underlying patterns. Both models demonstrate an admirable capacity to capture and anticipate the complex patterns of CO_2 emissions across time. This convergence of results not only emphasizes the dependability of the chosen models but also suggests that the linear character of the regression and the extra complexity given by the Prophet model provide similarly compelling insights into the dynamics of CO_2 emissions.

The findings were examined, and the 31 years of CO_2 emissions from the aviation industry across nations provided valuable insights into future projections for 2030 and 2050. However, the primary goal of this research was to establish if these nations share the vision of the European Green Deal pledge to decrease, if not eliminate, carbon emissions. To answer this question, a simple mathematical method was used to compute the decrease in aviation CO_2 emissions or rise rates for nations from 1990 to 2030.

$$Growth\ Rate = \left(\frac{Old\ Value - New\ Value}{Old\ Value}\right) \times 100 \tag{5}$$

The same technique was used to calculate these rates for the year 2050 based on the 1990 numbers. Using this method, we determined each nation's percentage decrease or increase in CO_2 emissions between 2030 and 2050. This research contributes to understanding how nations are nearing or diverging from the ambitious carbon neutrality target established in the European Green Deal.

Table 5 compares the projected CO_2 emissions in the aviation sector of different EU countries for 2030 and 2050. The percentage changes are expected to occur from a clearly defined base year, indicating what paths various countries are likely to take in terms of enhancing or curtailing aviation-related CO_2 emissions over the years.

The decision to compare 2030 projections to 2021 and 2050 projections to 1990 was made to align with international standards and climate policy frameworks. The 2021 comparison is an immediate baseline for assessing short-term efforts, while the 1990 comparison is a globally recognized reference for long-term emission reduction goals. This approach allows for a more comprehensive evaluation of both short- and long-term trends in aviation CO_2 emissions.

Table 5. Percent Change Rates of CO2 Emissions of the EU Countries from 1990 to 2030 and 2050

EU Countries	1990	2021	% of Increase (1990-2021)	% of Increase (2021-2030) Prophet	% of Increase (2021-2030) LR	% of Increase (1990-2050) Prophet	% of Increase (1990-2050) LR
Austria	889	1237	39.145	-1.607	6.542	-108.525	-218.213
Belgium	3149	4576	45.316	14.245	-8.111	37.260	-48.925
Bulgaria	718.7	494.3	-31.223	40.688	125.062	72.078	460.793
Crotia	500.4	300.6	-39.928	47.751	105.805	69.285	294.341
Cyprus	723.6	559.1	-22.734	-13.132	-16.405	-102.830	-189.444
Czechia	674.6	377.6	-44.026	11.123	79.306	-181.020	-182.746
Denmark	1769	1269	-28.265	-45.589	-2.931	-259.427	-302.842
Estonia	107.6	130.2	21.004	17.673	58.802	17.112	114.178
Finland	1015	830	-18.227	-28.586	117.137	-266.936	27.755
France	8877	8418	-5.171	-49.012	-23.198	-258.054	-380.412
Germany	12179	18298	50.242	-15.208	-0.961	-95.928	-150.339
Greece	2494	2531	1.484	21.640	9.397	29.451	-18.079
Hungary	508.8	377.5	-25.806	22.464	-80.045	-33.044	-511.762
Ireland	1081	1325	22.572	58.502	-10.210	24.318	-342.574
Italy	4317	5000	15.821	-7.616	10.483	-149.056	-247.571

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EU Countries	1990	2021	% of Increase (1990-2021)	% of Increase (2021-2030) Prophet	% of Increase (2021-2030) LR	% of Increase (1990-2050) Prophet	% of Increase (1990-2050) LR
Latvia	222.8	240.8	8.079	0.835	151.686	-78.505	375.735
Lithuania	401.9	186.9	-53.496	46.126	242.761	60.770	839.963
Luxembourg	398	1881	372.613	47.677	1.847	144.059	8.948
Malta	198.2	249.4	25.832	26.191	56.768	-6.151	85.225
Netherlands	4639	7348	58.396	-28.767	-42.977	-143.015	-328.826
Poland	645	2453	280.310	48.531	69.052	136.506	259.140
Portugal	1548	2012	29.974	25.164	89.904	-23.670	140.887
Romania	796.2	249.1	-68.714	-159.101	224.845	-591.337	617.198
Slovakia	67.6	65.7	-2.811	33.486	82.222	-67.747	-91.446
Slovenia	49.25	26.78	-45.624	-29.238	-97.461	-296.714	-8319.716
Spain	4776	8320	74.204	-1.441	40.191	-114.709	-112.768
Sweden	1352	998	-26.183	-39.789	19.935	-283.615	-312.824
Switzerland	3089	2336	-24.377	-46.712	37.466	-266.546	-132.528

Figure 2. Time Projection Histogram for Romania until 2050

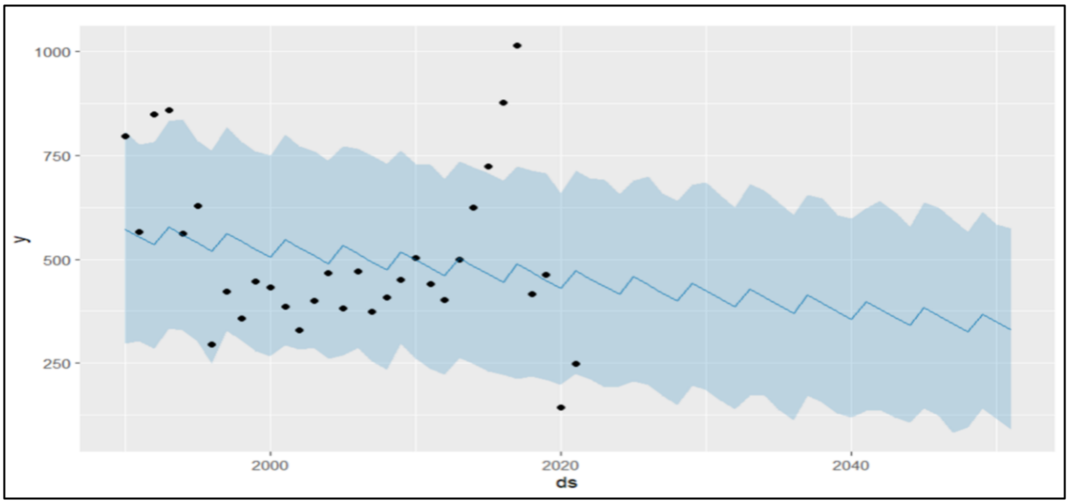
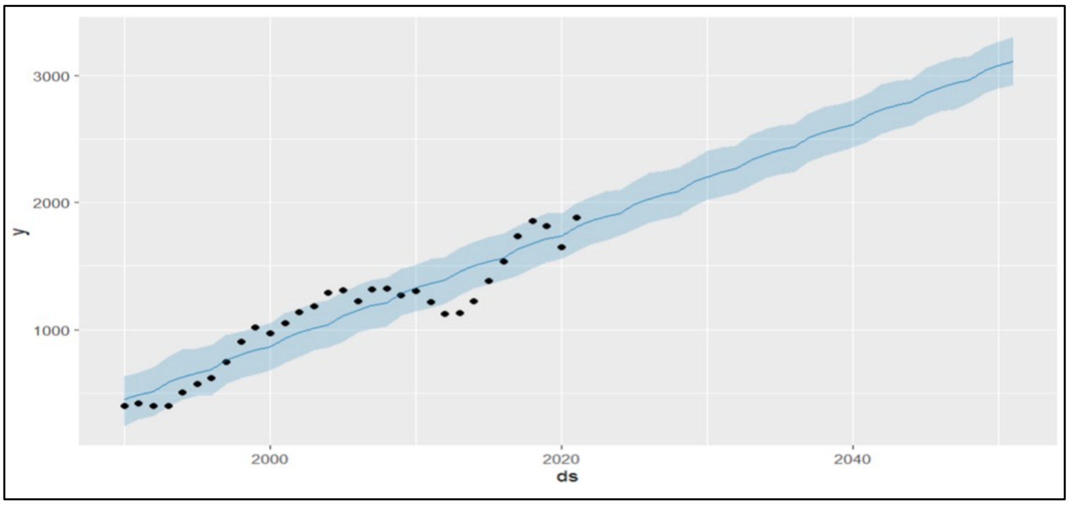


Figure 4. Time Projection Histogram for Luxembourg until 2050



The black dots in the graphs in Figure 3 and Figure 4 show the actual values, the blue lines show the model's predictions, and the light blue areas show the model's prediction range. When we look at the outputs of Prophet, as can be seen from Figure 3 and Figure 4, the best country model was Romania, and the country with the highest emissions was estimated for Luxembourg.

According to projections for 2030 and 2050, Lithuania is the second-closest country to the objective, with Bulgaria coming in third. Luxembourg, Poland, and Spain are countries that are far from the aim.

These techniques helped us foresee future environmental effects and gave us a more excellent knowledge of changes in CO_2 emissions by providing the framework for our investigation.

6. DISCUSSION AND RESULTS

The Prophet and linear regression analysis yielded diverse trends in aviation-CO_2 emissions for nations, including notable instances such as Romania and Luxembourg. Prophet's ability to distinguish subtle time series subtleties revealed a multidimensional emission pattern over 31 years. This research showed seasonal and cyclic patterns, allowing for a more detailed understanding of emission changes. Linear regression simultaneously established a quantifiable link between historical emissions and future estimates, providing a transparent predictive model.

When specific cases are examined, Romania emerges as a fascinating subject of study, showing a remarkable decline in emissions between 1990 and 2030. An in-depth examination of the potential driving forces behind Romania's success, such as the implementation of sustainable policies, advances in green technologies or economic developments, as well as examining the socio-economic factors affecting the increase in Luxembourg's emissions and potential areas for improvement, can be offered as suggestions for other studies.

This thorough examination of individual countries provides a deep insight into their progress toward or divergence from the European Green Deal targets. Economic circumstances, legislative frameworks, and technical landscapes will be examined to contextualize each nation's trajectory, providing policymakers and environmental campaigners with helpful insight.

DECLARATION OF THE AUTHORS

Declaration of Contribution Rate: The authors have equal contributions.

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Declaration of Conflict: There is no potential conflict of interest in the study.

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Appendix 1. 1990-2021 Aviation-Related CO_2 Emission Data of EU Countries

EU Countries	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Austria	889	999	1086	1152	1202	1346	1488	1551	1609	1576	1711
Belgium	3149	2520	2532	2547	2563	2929	3390	3654	4127	4653	4727
Bulgaria	718.7	616	844.8	1132.5	918.3	911.7	598.3	443	390.3	210.7	241.6
Crotia	500.4	95	72.8	183.7	266	247	224.9	237.5	256.5	247	202.7
Cyprus	723.6	859.7	836.4	711.3	730.8	802.9	770.1	758.8	800.2	820	833.6
Czechia	674.6	478	547.8	446.7	548.4	538.5	421.6	390.1	364.8	421.8	498
Denmark	1769	1632	1692	1659	1818	1864	1958	2001	2156	2288	2349
Estonia	107.6	110.1	36.2	53.9	44.3	50.9	47.1	65.8	46.7	66	64.1
Finland	1015	955	845	794	836	904	967	1005	1030	1102	1071
France	8877	8529	9979	10298	10687	10702	11352	11666	12406	13738	14233
Germany	12179	11988	12984	13930	14580	15074	15968	16554	17078	18470	19614
Greece	2494	2150	2243	2389	2834	2656	2545	2462	2583	2901	2545
Hungary	508.8	400.7	422.9	388	585	562.8	597.8	569.2	603.8	648.3	724.5
Iceland	221	223	205	197	215	238	273	294	340	366	410
Ireland	1081	1047	912	1351	1197	1163	1067	1290	1329	1573	1829
Italy	4317	5164	5107	5264	5439	5845	6200	6274	6822	7539	8021
Latvia	222.8	301.3	84.7	84.7	78.5	78.5	100.4	100.4	91	91	81.6
Lithuania	401.9	483.7	195.6	108.2	114.7	118.1	96.3	90.3	80.9	74.8	70.7
Luxembourg	398	416	402	398	504	572	621	743	901	1016	968
Malta	198.2	187.3	245.6	251.8	310.3	331.7	328.6	345.1	331.6	340.2	327.3
Netherlands	4639	4936	5760	6305	6639	7656	8224	8873	9376	9959	9953
Norway	4639	4936	5760	6305	6639	7656	8224	8873	9376	9959	9953
Poland	645	665	722	719	728	785	923	827	842	752	800
Portugal	1548	1568	1658	1571	1580	1646	1630	1682	1779	1963	2020
Romania	796.2	564.8	848.8	859.3	561.3	627.9	294.9	421.3	358.5	446	432.1
Slovakia	67.6	62.8	58.1	56.9	48	48.2	56.9	50.4	46.4	46.9	47.7
Slovenia	49.25	21.33	33.75	48.18	53.83	57.59	53.23	56.07	50.11	60.09	69.29
Spain	4776	5274	5819	5723	6105	6683	7242	7726	8216	8980	9633
Sweden	1352	1103	913	1246	1368	1456	1495	1581	1695	1904	1952
Switzerland	3089	3014	3208	3344	3454	3681	3833	3981	4174	4484	4696

EU Countries	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Austria	1667	1555	1467	1741	1978	2068	2196	2203	1911	2069	2189
Belgium	4276	3561	3877	3779	3597	3743	4047	4370	3989	4213	4476
Bulgaria	312.9	374.8	480.2	462.9	568.5	543.6	548.3	638.2	458.5	505	511.2
Crotia	202.7	190	183.7	212.2	259.7	266	278.7	319.9	272.4	297.7	313.5
Cyprus	978.1	942	1009	922.8	839.4	846.2	833.5	865.1	817.7	834.4	865.6
Czechia	501.4	517.2	625.1	894.9	977.4	1031.3	1059.9	1091.6	1044	961.5	952
Denmark	2380	2059	2139	2451	2571	2580	2646	2646	2311	2412	2483
Estonia	51.5	54.1	62.8	93.8	137.7	147.6	179.1	204.7	111.3	102.1	137.6
Finland	1098	1086	1122	1292	1300	1445	1668	1805	1582	1666	1971
France	14342	14445	14600	14609	15850	16720	17356	17570	16137	16215	17059
Germany	19109	19029	19365	20021	23204	24434	25337	25601	24919	24523	23344
Greece	2366	2367	3080	3165	2620	2801	2971	2953	2739	2604	2717
Hungary	680.1	642	629.3	718.3	829.8	839.3	871.1	857.3	731.3	725.9	732.6
Iceland	351	312	335	383	424	503	515	431	346	380	425
Ireland	2210	2349	2294	2173	2506	2888	3062	2846	2247	2324	2084

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EU Countries	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Italy	7925	6865	7978	8017	8548	9276	9841	9447	8333	8877	9278
Latvia	81.6	84.7	122.4	148.8	180.4	202.5	247	297.1	313.6	359.9	361
Lithuania	94.3	84.1	94.2	105.2	140	159.3	199.6	231.2	110.8	146.4	168.2
Luxembourg	1047	1135	1182	1286	1307	1223	1314	1323	1268	1301	1217
Malta	276.3	255.9	257	262.6	268.4	260.8	277	284.8	268.5	294	305.1
Netherlands	9695	10114	9972	10685	11000	11149	11218	11374	10539	10285	10706
Norway	9695	10114	9972	10685	11000	11149	11218	11374	10539	10285	10706
Poland	788	773	836	821	922	1239	1296	1570	1382	1448	1411
Portugal	968	1871	2056	2214	2299	2432	2566	2657	2416	2659	2755
Romania	386.1	329.9	400.1	467.5	381.9	470.4	374.4	407.2	449.9	502.5	439.4
Slovakia	44.9	46.6	61.5	82.9	140.5	167.4	174.9	196	144.3	133.2	136.1
Slovenia	78.46	80.88	77.11	57.68	61.35	71.04	93.58	103.95	77.91	73.8	68.8
Spain	9816	9442	9906	10982	11648	12125	12953	13046	12046	12702	13854
Sweden	1895	1633	1587	1795	1961	2032	2222	2487	2114	2137	2302
Switzerland	4431	4089	3669	3457	3514	3694	3946	4263	4071	4283	4584

EU Countries	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Austria	2092	1994	1996	2147	2342	2263	2549	2928	1052	1237
Belgium	4121	3898	4082	4426	4410	4835	5183	5214	3633	4576
Bulgaria	492.6	480.2	511.2	532.8	641.3	717.8	772.4	718.4	414.9	494.3
Crotia	332.5	369.3	370.9	356.7	378.6	452.4	563.8	610.4	165	300.6
Cyprus	837	780.8	871.7	756.6	883.8	1005.9	1045	1034.9	329.1	559.1
Czechia	901.2	869.5	898	904.4	971	1088.4	1256.6	1285.2	349.1	377.6
Denmark	2510	2486	2696	2641	2840	2924	3060	3128	985	1269
Estonia	180.8	144.3	144.4	151.4	138.9	180.7	210.2	211.9	72.7	130.2
Finland	1903	1964	1935	1978	1982	2113	2406	2593	876	830
France	16641	16540	16724	17690	17390	17668	18277	19192	8310	8418
Germany	25256	25763	24794	24701	26707	29438	30312	30001	13808	18298
Greece	2405	2485	2851	2891	3104	3461	3888	4019	1334	2531
Hungary	526.9	514.1	542.7	555.8	590.2	685.4	847.2	856.9	311.1	377.5
Iceland	445	502	585	679	924	1155	1295	964	263	415
Ireland	1751	2020	2240	2536	2601	3060	3307	3344	1187	1325
Italy	8991	8935	9088	9639	10368	11239	12047	12488	3817	5000
Latvia	365.5	377.1	336.6	330.3	375.9	430.5	471.4	485.7	179.7	240.8
Lithuania	191.7	212.7	235.9	246.9	289.1	320.1	280.9	372.8	163.8	186.9
Luxembourg	1123	1128	1225	1381	1532	1733	1853	1812	1649	1881
Malta	300.7	324.5	342.9	360.3	395.2	429.4	474	510.8	195.7	249.4
Netherlands	10289	10512	10909	11467	11765	12106	12251	11980	6682	7348
Norway	10289	10512	10909	11467	11765	12106	12251	11980	6682	7348
Poland	1524	1524	1709	1892	2020	2564	3047	3260	1382	2453
Portugal	2777	2849	3027	3167	3394	3867	4154	4402	1582	2012
Romania	402.5	499.7	624.4	722.8	877.6	1014.6	415.7	461.7	143.3	249.1
Slovakia	121.1	113	119.3	145.5	155.1	166.2	185.9	187	55.1	65.7
Slovenia	66.33	73.07	72.11	74.72	61.05	74.24	102.2	77.83	26.16	26.78
Spain	13417	13537	14117	14642	16303	17540	18478	19124	6471	8320
Sweden	2192	2268	2297	2195	2559	2787	2822	2677	938	998
Switzerland	4688	4746	4767	4938	5178	5341	5663	5735	2068	2336

Source: (European Environment Agency [EEA], 2023).