Unraveling Air Pollution Dynamics Under the Influence of Fossil Fuel Subsidies: The Cases of Slovenia and North Macedonia

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Purpose – Addressing the imperative of sustainable development and environmental conservation, this study investigates the intricate relationship between carbon dioxide emissions and annual fossil fuel subsidies in Slovenia and North Macedonia. Methodology/Approach – Utilizing regression analysis aligned with the indicators of the twelfth Sustainable Development Goal (SDG), we discern trends in sulfur dioxide, carbon monoxide, nitrogen monoxide, and total suspended particulate matter emissions. Findings – For every billion dollars in subsidies, North Macedonia experiences an average annual reduction of 40.073 kilotons in carbon dioxide emissions, while Slovenia sees an increase of 6.999.431 kilotons per year. The results point out the negative impact fossil fuel subsidies have on the environment by making fossil fuels more affordable, thus warranting further regulation by lowering or eliminating this type of subsidy. Implications – The implications address the need for research advancement and enhanced SDG reporting in North Macedonia, coupled with a demand for improved environmental indicators in Slovenia. Policymakers can leverage these findings for air pollution regulation, and managers can champion socially responsible practices for a green economy. Originality/Value – This study fills a critical gap in the literature regarding cross-country comparisons in this area, identified through a Scopus database search.

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1 Introduction

It has been a decades-long challenge for policymakers and societies to control and reduce carbon dioxide emissions to curb the effects of climate change and protect the environment (Osobajo et al., 2020). This challenge garners increasing interest with the rising emphasis on sustainable development, environmental conservation, and corporate social responsibility practices. Illustratively, the quality of the air in North Macedonia represents one of the most serious concerns in the country (Meisner et al., 2015).

When it comes to this scientific topic, organizational and economic sciences tend to connect air pollution restrictions with monetary stimulants or punishments. One of the pillar instruments in this regard is fossil fuel subsidies (Arzaghi & Squalli, 2023). Fossil fuel subsidies, along with the associated external costs, are expected to steadily rise in the following decade. Implementing fuel pricing reforms worldwide could result in a decrease in carbon dioxide (CO_2) emissions, potentially helping to limit global warming to acceptable thresholds (Black et al., 2023). On the other hand, researchers have pointed out that environmentally harmful subsidies, such as fossil fuel subsidy reforms alone, would not suffice to eliminate energy inefficiencies (Kicia & Rosenstock, 2015). This highlights the importance of further exploration in this research niche and provides additional motivation for conducting the research.

Furthermore, research in the field of air pollution is becoming increasingly important in the Balkans as Europe's most polluted area (Belis et al., 2023). While most scholars so far have primarily analyzed the impact of fossil fuel subsidies on carbon dioxide emissions in global terms, others have focused on air pollution or subsidies within separate countries (Verkuijl et al., 2018). The underexplored research context of Slovenia and North Macedonia, as demonstrated through a detailed search in the Scopus database, reaffirms the existence of a critical research gap regarding cross-country comparisons in this area.

As a result, the objective of this research is to address this gap and investigate the intricate relationship between carbon dioxide emissions and annual fossil fuel subsidies in Slovenia and North Macedonia. Using regression analysis aligned with the indicators of the twelfth Sustainable Development Goal (SDG), we aim to identify trends in sulfur dioxide, carbon monoxide, nitrogen monoxide, and total

suspended particulate matter emissions, and analyze the impact of fossil fuel subsidies on the environment. The structure of this paper is organized as follows: Section two presents the literature review, followed by an explanation of the methodology and the key findings in sections three and four, respectively. We will then conclude with a discussion of the findings in section five and present a set of conclusions and recommendations in the final segment.

2 Literature Review

One of the aspects of our analysis focuses on carbon dioxide emissions, which can be defined as stemming from the burning of fossil fuels and machinery-based productions (Solomon et al., 2009). These emissions are recognized for their role in causing irreversible climate changes and negative disruptions to well-being (Solomon et al., 2009). In this sense, researchers offer perspectives on the rationalization of inefficient fossil fuel subsidies, a pivotal objective in attaining SDG 12 (Van de Graaf & van Asselt, 2017).

The term 'fossil fuel subsidies' refers to government support for consumers and producers of fossil fuels (Van de Graaf & van Asselt, 2017). Fossil fuel subsidies can be considered as part of a broader classification of environmentally harmful subsidies (Kicia & Rosenstock, 2015), encompassing consumer subsidies, which reduce the price of fossil fuels for consumers and are generally used in developing countries, and producer subsidies, which are used to lower costs of production (Zatti, 2020). Subsidies have sizable fiscal consequences, can encourage pollution, and promote inefficient resource allocation that particularly affects individuals with lower incomes (Black et al., 2023). Consequently, there has been growing concern regarding the need for fossil fuel subsidy reform recently (Chepeliev & van der Mensbrugghe, 2020).

Changes in fossil fuel subsidy policies would show great improvements regarding climate change (Zatti, 2020) The current research landscape indicates that linking fossil fuel subsidies to pollution and climate change, enacting proper reforms on a national and international level, as well as keeping close track of as many indicators for sustainable development as possible is imperative to reaching SDG 12 and achieving sustainable development globally (Coxhead & Grainger, 2018). Based on this, we develop four distinct hypotheses:

H1: There is a positive relationship between fossil fuel subsidies and CO2 emissions in North Macedonia.

H2: There is a positive relationship between fossil fuel subsidies and CO2 emissions in Slovenia.

H3: Sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NOx), and the total amount of suspended particles (TSP) emissions in North Macedonia have a defined trend.

H4: Slovenia has demonstrated measurable improvements in achieving the targets outlined in SDG 12 in comparison to North Macedonia over time.

3 Methodology

For this article, we opted for a secondary data collection method spanning from December 2023 to January 2024. We gathered data from global datasets of the World Bank and the International Monetary Fund, as well as governmental portals in Slovenia and North Macedonia (State Statistical Office of the Republic of North Macedonia, n.d.; Statistical Office of the Republic of Slovenia, n.d.). Our focus was on utilizing regression analysis to investigate the relationship between variables and predict the value of the dependent variable (y) in relation to the independent variable(s) (x). The dependent variable is also known as the response variable, while the independent variable is known as the predictor or explanatory variable. Simple regression is used when there is one dependent and one independent variable, while multiple regression is employed in the case of one dependent and two or more independent variables.

The linear regression includes multiple independent variables and can be represented by the following equation:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots. + \beta_n + \varepsilon \quad (1)$$

where:
y is the dependent variable; x is the independent variable; β_0 is a constant; βn is the slope coefficient for x_n; ε is the residual.

To fulfill the objective of comparing air pollution levels between North Macedonia and Slovenia, we considered carbon dioxide emissions, expressed in kilotons. To examine how the subsidies issued in each country affected carbon emission, we

conducted a regression analysis. During the data collection process, we observed that there is significantly more available data for the indicators of SDG 12 for Slovenia compared to North Macedonia (United Nations Department of Economic and Social Affairs, 2023). This discrepancy necessitated including a larger number of indicators in the comparative analysis, given the relatively small number of indicators included in the general report for North Macedonia (United Nations in North Macedonia, 2023)

Most of the information presented in the profiles of both countries in terms of SDG reports is based on measurements from 2018 and 2019. Despite the quantitative presentation of the indicators, there is a lack of information on trend movements in North Macedonia for most indicators within SDG 12. However, alternative sources provide more recent information regarding the indicators of the goal for responsible consumption and production (World Bank, 2024; International Monetary Fund, 2022).

Through the developed model and the explained methodology, our aim was to gather and compare indicator data for the given countries that have not been sufficiently explored. Additionally, we sought to examine the impact of subsidies for fossil fuels on the quantity of emissions of key greenhouse gases, namely CO_2 equivalents. The data encompassed total CO_2 emissions, excluding the burning of biomass with a short-term impact, while including other forms of biomass burning (such as forest fires, decay after logging, fires on drained peatlands, and decay of drained peatlands), and all anthropogenic sources of CH_4, sources of N_2O, and F-gases.

4 Results

4.1 Analyzing the Impact of Carbon Dioxide Emissions on Fossil Fuel Subsidies in North Macedonia and Slovenia

The carbon dioxide emissions in kilotons for North Macedonia and Slovenia represent the dependent variables for the period 2010-2020. In the regression analysis for both countries, the independent variable is the square value (North Macedonia) and quadratic and cubed value (Slovenia) of the nominal amounts of

subsidies for fossil fuels in U.S. dollars, along with the assessment of the slope of the movement of emissions in relation to subsidies (see Picture 1).

The regression's confidence level is 96.6%, which is statistically significant in relation to the usual significance level of 0.05 (Chatterjee & Hadi, 2013). Additionally, the independent variables show statistical significance, as confirmed by the t-statistic. From the results, it can be concluded that 57% of the variations of the dependent component are explained by the variations of the independent components, which is satisfactory enough to explain that there is some connection between these components (Seber & Lee, 2012). From here on, we observe that the carbon dioxide emissions for the given period average around 11,198 kilotons, without the influence of subsidies. On average, with each addition of a billion dollars of subsidies in North Macedonia, emissions decrease by an average of 40,073 kilotons per year.

In North Macedonia, the data exhibits more scattered patterns, with periods of slight decline and growth in the trend. Conversely, in the Slovenian case, the data shows significant oscillations in terms of how subsidies affect carbon dioxide emissions. The significance confidence of the regression is at a level of 92%, which can be considered as a high percentage of significance (Chatterjee & Hadi, 2013). The independent variables and the residual value also show statistical significance in addition to the t-statistic. Evidently, 59% of the variations of the dependent component can be attributed to the variation of the independent variables, which further justifies the connection between these variables (Seber & Lee, 2012).

Dependent Variable: MAK_CO2_KTONI
Method: Least Squares
Date: 12/22/23 Time: 14:26
Sample: 2010 2020
Included observations: 11

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	11198.02	234.6905	47.71401	0.0000
(MAK_NOM_IZNOSI_SU_BIL_$)^2	231781.7	82966.80	2.793669	0.0234
MAK_NOM_IZNOSI_SU_BIL_$	-40073.60	13046.31	-3.071642	0.0153

R-squared	0.572385	Mean dependent var	10697.89
Adjusted R-squared	0.465481	S.D. dependent var	749.6633
S.E. of regression	548.0848	Akaike info criterion	15.67774
Sum squared resid	2403176.	Schwarz criterion	15.78625
Log likelihood	-83.22756	Hannan-Quinn criter.	15.60933
F-statistic	5.354208	Durbin-Watson stat	1.394653
Prob(F-statistic)	0.033436		

Dependent Variable: SLO_CO2_K_TONI
Method: Least Squares
Date: 12/22/23 Time: 14:30
Sample (adjusted): 2010 2020
Included observations: 11 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-347164.0	127315.8	-2.726795	0.0295
(SLO__NOM__IZ_NOSI_SU_BIL$)^3	93166257	33864475	2.751150	0.0285
(SLO__NOM__IZ_NOSI_SU_BIL$)^2	-44419194	15954439	-2.784128	0.0271
SLO__NOM__IZ_NOSI_SU_BIL$	6999431.	2481407.	2.820751	0.0257

R-squared	0.597713	Mean dependent var	17101.02
Adjusted R-squared	0.425305	S.D. dependent var	1127.273
S.E. of regression	854.5707	Akaike info criterion	16.61436
Sum squared resid	5112038.	Schwarz criterion	16.75905
Log likelihood	-87.37900	Hannan-Quinn criter.	16.52316
F-statistic	3.466841	Durbin-Watson stat	1.645820
Prob(F-statistic)	0.079588		

Figure 1: Results of the regression analysis for North Macedonia (left) and Slovenia (right)
Source: Authors' analysis

On average, each addition of a billion dollars of subsidies in Slovenia results in an increase of emissions by an average of 6,999,431 kilotons per year. This indicates that Slovenian subsidies have a positive effect on the amount of CO_2 emissions, suggesting that they are effectively used to boost the use of fossil fuels. In North Macedonia, conversely, subsidies hinder the amount of CO_2 emissions, suggesting that they are either not being effectively used or that their effect on the environment is detectable after more than a year. This result may also suggest insufficient reporting and data collection. Subsequently, H1 is rejected, and H2 is accepted, due to the negative and positive relationships between the analyzed variables, respectively.

Dependent Variable: LOG(TOTAL GHG MKD)
Method: Least Squares
Date: 12/24/23 Time: 17:45
Sample: 2002 2019
Included observations: 18

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	90.48719	17.15840	5.273639	0.0001
YEAR	-0.038837	0.008534	-4.550608	0.0003

R-squared	0.564128	Mean dependent var	12.40631
Adjusted R-squared	0.536886	S.D. dependent var	0.276041
S.E. of regression	0.187853	Akaike info criterion	-0.401875
Sum squared resid	0.564620	Schwarz criterion	-0.302945
Log likelihood	5.616874	Hannan-Quinn criter.	-0.388234
F-statistic	20.70803	Durbin-Watson stat	1.106806
Prob(F-statistic)	0.000327		

Figure 2: Regression results of logarithmic emissions of SO_2, CO, NOx, and TSP
Source: Authors' analysis

An additional regression analysis was conducted on the annual sums of emitted gases SO_2, CO, NOx, and TSP, estimating the percentage movement of the emission of these gases annually in North Macedonia for the period from 2002 to 2019. The statistically significant model (see Picture 3) indicates that 56% of the variations are explained by the variations of the independent components, which satisfactorily explains the connections between the variables. On average, the level of these gases decreases by 3.88% per year. This trend of reducing emissions of the above-mentioned gases, with SO2 being the most prominent, confirms H3 and serves as an important indicator of the SDG 12 progress in North Macedonia.

4.2 Comparison of Indicators Between North Macedonia and Slovenia

The quantity of SO_2 from 2002 showed an intensive upward trend over the next 3 years, reaching approximately 160,000 kilotons, followed by a steep downward trend, only to experience a significant increase again in 2019. Similar patterns can be observed with NOx, and CO, which reached about 50,000 tons in recent years, as did TSP. On the other hand, total non-CO_2 gases noted an upward trend, which continued until 2019 when available data ended. The data shows that the level of CO_2 emissions in kilotons ranged from 16,000 to 20,000 over the past two decades in Slovenia, contrasting with North Macedonia, where this figure ranged from about 10,000 to 12,000 during the same period. No significant oscillations causing drastic changes were observed.

Regarding subsidies presented as a percentage of the gross domestic product (GDP), the observations in Slovenia predate those in North Macedonia. In the former, there was an increase in the percentage share of subsidies in GDP from 2008 to 2010, followed by stagnation and a slight decrease in 2020/1. However, in North Macedonia, the indicator remained at zero until 2014, then increased to 1.5% in 2020. Additionally, the lowest number of subsidies per capita in Slovenia is approximately equal to the highest in North Macedonia. Similarly, North Macedonia, experienced a significant increase in subsidies in the period 2017-2019, whereas the data for Slovenia demonstrates a constant subsidy level between 350-450 million until 2018, after which it decreased.

From the findings of a simple comparative analysis of select time series data from the targets (Figure 1), it becomes apparent that Slovenia has not shown improvements over time across all targets when compared to the progress seen in North Macedonia. This is particularly evident in the areas of plastic exports and nitrogen emissions. Although Slovenia ranks thirteenth and North Macedonia ranks sixtieth according to their SDG index scores, both countries exhibit a combination of advancements and setbacks concerning SDG 12. Consequently, H4 is subject to rejection.

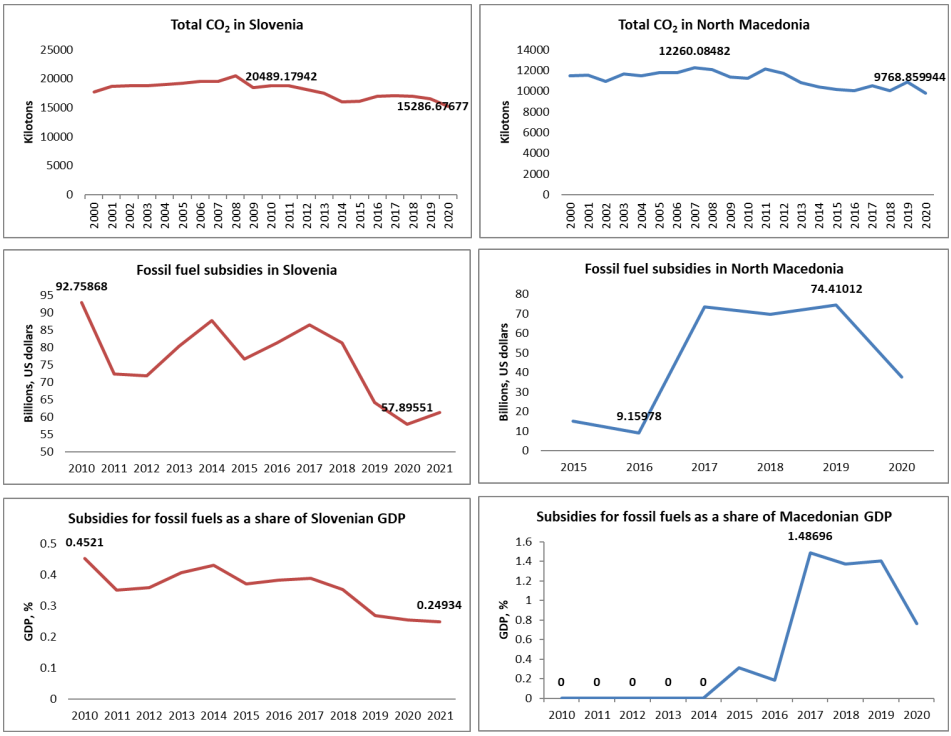

Figure 4: Comparative analysis of Slovenian and Macedonian indicators
Source: Authors' analysis

5 Discussion

Fossil fuel subsidies are positively correlated with greenhouse gas emissions in Slovenia, which is consistent with most contemporary research heavily pointing to the connection between fossil fuel subsidies and air pollution globally (Couharde & Mouhoud, 2020). According to the data on the Macedonian fossil fuel subsidies, they appear negatively correlated to the CO_2 emissions in the country, contrasting the common view of the positive correlation between the two variables. It is noteworthy that SO2, CO, TSP, and NOx are more prevalent pollutants in Macedonia, and their data is subject to closer monitoring. This data reveals a negative trend. The scarcity of reliable data on fossil fuel subsidies and overall pollution indicators leads to inaccurate or erroneous conclusions, such as the estimation of air pollution costs in the Macedonian capital Skopje, ranging between 0.5 and 1.5 billion euros (Niranjan, 2023). Slovenia, on the other hand, demonstrates a better track

record in implementing sustainable development measures in the context of responsible consumption and production (Hojnik et al., 2020). However, challenges persist in areas such as plastic exports, where recycling is lacking, and nitrogen emissions (Lavtizar et al., 2021). While Macedonia shows promise in reducing greenhouse gas emissions, it falls behind in other aspects (Ćosić et al., 2011).

In this sense, researchers are adamant that adequate monitoring and data collection can boost future research of SDG 12-related targets and make prospective reforms in inefficient subsidies considerably better informed and more precise (Black et al., 2023). Furthermore, including alternative solutions to fossil fuel subsidy reforms, such as carbon pricing models, to the targets for achieving SDG 12 would further improve the discussion regarding the efficiency of fossil fuel subsidy reforms and carbon pricing models.

6 Conclusions

The objective of our research endeavor was to investigate the intricate relationship between carbon dioxide emissions and annual fossil fuel subsidies and compare the indicators related to SDG 12 in Slovenia and North Macedonia. We found that there is a positive relationship between fossil fuel subsidies and CO_2 emissions in Slovenia and a negative one in North Macedonia. Furthermore, the results indicated that SO_2, CO, NOx, and TSP emissions in North Macedonia have a defined trend, yet a space for improvement regarding the achievement of the targets outline in SDG 12 in the cases of both countries was noted. For every billion dollars in subsidies, North Macedonia experiences an average annual reduction of 40.073 kilotons in carbon dioxide emissions, while Slovenia sees an increase of 6.999.431 kilotons per year. This underscores the need for regulatory measures to lower or eliminate such subsidies. There are also several implications from the analysis where, compared to Slovenia, North Macedonia has a greater need for monitoring strategies to achieve sustainable development. Despite Slovenia's implementation of numerous measures and higher sustainability rankings, challenges remain in areas such as plastic exports rather than recycling, as well as nitrogen emissions. The connection between fossil fuel subsidies and air pollution remains insufficiently explored across most countries. Further research on this connection would greatly assist in the financing of environmentally and economically sustainable projects and in the gradual elimination of unsustainable fossil fuel subsidies.

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