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# Examining the impact of high technology exports on environmental sustainability? An empirical insight

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**ABSTRACT**

Over the last few decades, countries have been highly dependent on exports leading to negative effects on environmental sustainability. Several studies have examined the link between exports and CO2 emissions. However, a huge gap exists in understanding the relationship between high technology exports (HTE) and environmental sustainability. Therefore, this study investigates the impact of HTE on environmental sustainability by providing deeper empirical insights. We controlled the effects of urbanization, industry, and economic growth (GDP). The present study extracted data from the World Development Indicators (WDI) database covering the period 2009 to 2018, with particular attention paid to 25 countries that are considered technologically advanced. The analysis is conducted using both ordinary least squares and robust tests. The results reveal a positive impact of HTE on the carbon intensity level. Additionally, a positive moderating effect of human capital is found. The findings present useful, practical implications to policymakers and academicians. This study enriches the existing research on technology exports and provides a theoretical framework for governments to implement in formulating policies.

**List of abbreviation:** ICT: Information and communication technology; ENVS: Environmental sustainability; HTE: High technology exports; URB: Urbanization; IND: Industry; HC: Human capital; CI: Carbon intensity; OLS: Ordinary least square; WDI: World development indicators

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## 1. Introduction

With the progression of globalization, the world economy has shown a rapid increase over the last two decades. Export development increases global output, significantly influencing energy consumption and environmental sustainability levels (Muhammad et al., 2022; Su et al., 2022). Past studies have shown that the trend of exports is often

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combined with significant environmental impacts, such as an increase in CO2 emission levels (Li et al., 2022; Su, Li et al., 2022). The government focuses on profit maximization in most technologically advanced countries, but energy consumption strategies are ignored (Kwakwa, 2022; Liang et al., 2022; Ning et al., 2022). Thus, this research aims to figure out the link between high technology exports and carbon intensity levels to provide deeper insight into the impact of exports on carbon emissions. Through this research, policymakers can formulate new policies that will ultimately help the government increase its profits and reduce energy consumption. Hence, this study will help researchers and academicians understand the significance of green growth in the economy.

It is undeniable that CO2 emissions increase the issue of global warming, which is more harmful to the sustainable development of the country (Rehman et al., 2022). Therefore, the issue of CO2 emissions has received much attention on a global level from academicians and policymakers. Considering the environmental sustainability issue, the export sector's importance is also worth discussing. High technology exports (HTE) improve the economy but are at risk of environmental deterioration because HTE depends on high technology and energy usage, leading to environmental degradation (Du et al., 2022; Khursheed et al., 2019). Moreover, some studies have provided evidence of the positive effect of exports on carbon dioxide emissions, while others have highlighted its negative impact (Z. Wang et al., 2021; Xu & Lin, 2018). For example, in the case of developed countries, exports are found to cause a decrease in carbon dioxide emissions (Shahzad et al., 2020). While in the case of developing countries, the studies claimed the opposite results of exports (Murshed & Dao, 2022). Therefore, considering the mixed results within the context of developing and developed countries, it is significant to investigate the impact of high technology exports on CO2 emissions. Along with high-technology exports, a country's economic and financial condition also plays an important role in understanding the link between exports and CO2 emissions (Hu et al., 2020). Such as trade liberalization also affects the export sector in low-income countries with lessor pollution control policies (Lu et al., 2022). Further, concerning the crucial factors linked to environmental sustainability, the moderating role of human capital (HC) in examining the influence of HTE on environmental sustainability is also significant (Jahanger et al., 2022).

Hence, this research focuses on analyzing the impact of high technology exports on environmental sustainability considering carbon intensity level and its alternative variable, PM2.5 intensity level. This study applies the ordinary least square (OLS) regression model to 25 technologically advanced countries. This strategy enables this research to reduce the risk of misspecification in the model and assists in understanding the complex relationship between high-technology sports and environmental sustainability. This research adds value to the existing literature through two specific approaches. Firstly, this research conducts empirical research based on technologically advanced countries, unlike past studies which relied on the data on small developing regions. Second, we applied a robust empirical methodology by using an alternative of the selected dependent variable and robust tests to investigate the hypotheses proposed in this study. This study fills an evident research gap regarding the role of high-technology exports in environmental sustainability by giving insightful results that past studies have not presented.

The sections of this paper are organized as follows; Section 1 explains the introduction part, and Section 2 describes the literature review and hypotheses. Section 3 discusses the methodology part. Section 4 presents the results and discussion. Section 5 sheds light on the conclusion and future directions of the study.

## 2. Literature review and hypothesis development

In the past, most researchers examined the environment and trade relationship by considering the variables of trade openness (Destek & Sinha, 2020; Murshed & Dao, 2020; Umar et al., 2020; Yang & Umar, 2022), and very few studies investigated the influence of export separately on atmospheric pollution. Considering the importance of this relationship, three theories are generally used to describe the relationship: composition effect, technique effect, and scale effect (Muhammad et al., 2020). The scale effect presents that an increase in trade activities increases economic growth, increasing environmental pollution. Technique effect claims that trade liberalization helps in the processes of environmentally friendly technologies, which helps in improving environmental quality and decreases pollution. As per the composition effect, trade activities negatively affect the environment at the initial level because of the weak regulations related to environmental protection. But at the latter stages, trade activities reduce environmental pollution because of strong environmental regulations.

Mainly, the relationship between exports and carbon emissions has two school of thought. As per the first thought, it is considered that exports increase the trade competition between countries for increasing the efficiency in using limited resources. This enhances the use of green technologies to decrease environmental pollution. Second thought claims that exports lead to a rapid depletion of natural resources and increased CO2 emissions. Further, it is claimed that international trade causes an increase in carbon emissions, particularly in newly industrialized countries (Muhammad et al., 2020). The intelligent and digital economy has recently rapidly grown (Litvinenko, 2020). High technology exports (HTE) have gradually become an important pillar in economic advancement, influencing a country's environmental sustainability in several ways (Mohamed et al., 2022). In addition, the impact of HTE on environmental sustainability can also be affected through various channels (Zaman & Abd-el Moemen, 2017). Therefore, HTE influences carbon intensity levels, as environmental protection is threatened due to the diversified use of different technological methods and systems. Further, HTE may decrease energy consumption if innovative green strategies are used (Aldakhil et al., 2019). It is widely acknowledged that HTE can transform society and the economy from energy consumption to energy-saving systems. Moreover, HTE can also decrease the demand for energy and flourish environmental sustainability by highlighting the uses of online and less energy-consuming channels. HTE can decrease energy consumption by ensuring that energy is used optimally through implementing modern technology systems (Bojnec & Papler, 2011). This way, using HTE is useful in controlling power and environmental sustainability issues. Considering the above analysis, HTE can influence environmental sustainability in various ways.

**H1:** High technology exports are likely to directly influence environmental sustainability.

They are considering the significance of human capital in the high-technology export processes. Improving human capital can help workers learn new methods and explore new techniques, ultimately enhancing the technical knowledge in the export sector and leading to improved HTE (N. Mahmood et al., 2019). As technology plays a crucial role in people's lives, improving technical skills will improve the efficiency of R&D activities, ultimately improving human capital (Chou et al., 2019; Khursheed et al., 2020). Thus, developing HTE can help innovators and learners overcome time and space limitations by boosting production in the high-technology export sector (Shahbaz et al., 2020). Additionally, HC significantly affects environmental sustainability because educated people use less energy-consuming products, and factory workers are more efficient in reducing carbon intensity levels. Therefore, we formulate the second hypothesis. Thus, the following hypothesis is formulated.

**H2**: Human capital is a crucial channel that influences the link between HTE and environmental sustainability.

## 3. Methodology and data

### 3.1. Methodology

For establishing a suitable model to identify the influence of high-technology exports on environmental sustainability, it is important to understand the factors affecting it. It is widely acknowledged that high-technology exports significantly depend on environmental sustainability (Aldakhil et al., 2019). Therefore, HTE is selected as the core independent variable in this study. Further, considering the significance of ICT and exports in the past literature (Waheed et al., 2021), we have taken ICT goods exports (HTE1) and commercial service exports (HTE2) as alternative variables of the main independent variable HTE.

$$ENVS_{it} = \beta_0 + \beta_1 HTE_{it} + \beta_2 Control_{it} + \mu_t + \mu_i + \varepsilon_{it} \quad (1)$$

In this equation, the country is represented as i, which is (1, …., 25), time is represented by 't' (t = 1, 2, …, T), and $ENVS_{it}$ refers to the country's high technology exports level in selected time (t). $HTE_{it}$ presents the main independent variable used to access HTE level $Control_{it}$ presents the three variables that may influence high technology exports: Urbanization (URB), GDP per capita (GDP), and Industry (IND). $\mu_i$ and $\mu_t$ present the fixed effects of country and year. $\varepsilon_{it}$ presents the error term.

#### 3.1.1. Moderation

Based on our theoretical scrutiny, it is found that human capital is a significant moderating variable that can influence the relationship between HTE and environmental sustainability. The model is presented as follows:

$$ENVS_{it} = \gamma_0 + \gamma_1 HTE_{it} + \gamma_2 Control_{it} + \gamma_3 HC_{it} + \mu_i + \mu_t + \upsilon_{it} \quad (2)$$

$$HC_{it} = £_0 + \alpha_1 HTE_{it} + \alpha_2 Control_{it} + \mu_i + \mu_t + \upsilon_{it} \quad (3)$$

In these equations, $HC_{it}$ presents the moderating variable, human capital (HC).

### 3.2. Data description

This study examines the relationship between HTE and environmental sustainability for the period from 2009 to 2018 for 25 technologically advanced countries. The reason for selecting this particular time period is the data availability, and the selection of these countries is their recent novel contributions to technology and innovation. All variables analyzed in this research are important environmental sustainability factors. The dependent variables, including carbon intensity level, are measured as CO2 emissions (kt), and PM 2.5 intensity level is measured in the PM 2.5 air pollution level to which the population is exposed (1% of total).

Among independent variables, the (HTE1) is the percentage of manufactured exports, and the information and communication technology goods exports (HTE2) is the percentage of total goods exported. The control variables, including industry (IND), are measured as value addition in the industry (% in GDP), GDP is measured as real GDP per constant, urbanization (URB) is measured as urban population divided by the total number of population. The moderator is the human capital, which is measured as the HC is the percentage of literacy rate of people aged between 15-24; all data is extracted from World Bank. The descriptive statistics of selected variables used in this research are presented in the Appendix. As per the results, the mean CI is 6.22. In the case of HTE1, the maximum value is around 7.31 while the mean is around 5.86; this shows little difference regarding HTE formation among the selected countries.

Before starting the main analysis, we initially conducted preliminary observations. Then correlation matrix is developed, as shown in Table 1, showing the high correlation between the selected variables. Then we performed the variance inflation factor test in Table 2, which revealed no multicollinearity issue between the selected

**Table 1.** Correlation matrix.

| | HTE1 | HTE2 | URB | GDP | IND | HC |
|---|---|---|---|---|---|---|
| HTE1 | 1 | | | | | |
| HTE2 | 0.7946 | 1 | | | | |
| URB | −0.0201 | −0.0608 | 1 | | | |
| GDP | 0.2314 | 0.2562 | −0.7527 | 1 | | |
| IND | 0.4981 | 0.5634 | 0.221 | −0.2827 | 1 | |
| HC | 0.1571 | −0.0858 | −0.3688 | 0.4108 | −0.3463 | 1 |

Notes: The correlation between the variables is presented in this table. The main independent variables are HTE1 and HTE2. HTE2 is the alternative variable of HTE; Control variables are IND, GDP, and URB; Moderating variable is HC.
Source: Author's Calculations.

**Table 2.** Variance inflation factor results.

| Variable | VIF |
|---|---|
| HTE1 | 3.577865 |
| HTE2 | 3.792123 |
| HC | 1.637543 |
| URB | 2.640186 |
| GDP | 3.526846 |
| IND | 2.367966 |

Notes: The VIF result is presented in this table. Carbon Intensity (CI) is the dependent variable; the Core independent variable is HTE1; the alternative variable is HTE2 of HTE; Control variables are URB, IND, and GDP; Moderating variable is human capital.
Source: Author's Calculations.

**Table 3.** Results of unit root analysis.

| Method | Statistic | Prob.** |
|---|---|---|
| Null: Unit root (assumes common unit root process) | | |
| Levin, Lin & Chu t* | −93.5842 | 0.0000 |
| Null: Unit root (assumes individual unit root process) | | |
| Im, Pesaran and Shin W-stat | −18.6761 | 0.0000 |
| ADF – Fisher Chi-square | 165.680 | 0.0000 |
| PP – Fisher Chi-square | 223.206 | 0.0000 |

Note: The dependent variable is CI; the Core independent variable is HTE1; the Control variables are URB, IND, and GDP. The significance level is taken at 5%.
Source: Author's Calculations.

**Table 4.** OLS results.

| Variable | Coefficient | Std. Error | P-value |
|---|---|---|---|
| HTE1 | 5.8201 | 2.4601 | 0.0190 |
| IND | −0.0969 | 0.0549 | 0.0792 |
| URB | 0.3553 | 0.3269 | 0.2783 |
| GDP | 6.4300 | 1.1200 | 0.0000 |
| C | 6.8236 | 1.3958 | 0.0000 |

Notes: OLS test results are shown in this table. The dependent variable is CI; the Core independent variable is HTE1; the Control variables are URB, IND, and GDP. The significance level is taken at 5%.
Source: Author's Calculations.

variables. In the last, we applied panel unit root tests to check the stationary in data. Table 3 reveals that each of the selected variables is stationary.

## 4. Empirical analysis

After ensuring data stationarity, we tested the impact of HTE on carbon intensity along with the traditional linear regression models. This research uses ordinary least squares (OLS) regression to estimate equation one. The estimation results are presented in Table 4, which reveals that HTE shares a positive relationship with CI level, consistent with H1. Furthermore, to this, HTE also has a positive impact on carbon intensity levels even when we included control variables. Thus, it is evident from the results that conducting more high-technology exports will directly affect carbon intensity levels, ultimately affecting environmental sustainability.

Concerning the results of control variables, the results also reveal that most of the variables presented a statistically significant result when country and year were fixed. The outcome depicts urbanization (URB) positively impacting carbon intensity. This result suggests that by increasing urbanization, there will be more carbon dioxide emissions, which will negatively affect environmental sustainability. Concerning industrialization, the results reveal a positive relationship again with the carbon intensity level. While in the case of GDP, the result reveals that GDP shares a negative relationship with carbon intensity level, which indicates that the higher the economic development level (GDP), the lower the carbon intensity levels will be.

In this research, we have also applied additional tests to ensure the empirical results' reliability and credibility. Initially, the study performs an alternative test by using ICT goods exports as a replacement for high technology exports. Table 5 presents results that provide evidence of the inhibitory impact of HTE, thus supporting our outcomes. Additionally, we replicated all estimated values by considering PM 2.5 emissions as a

**Table 5.** Robust test with CI.

| Variable | Coefficient | Std. error | P-value |
|---|---|---|---|
| HTE1 | −3.4701 | 1.7601 | 0.0502 |
| HTE2 | 0.2359 | 0.0450 | 0.0000 |
| GDP | 7.0400 | 1.65E − 05 | 0.0000 |
| URB | 0.5422 | 0.304669 | 0.0765 |
| IND | −0.1259 | 0.034892 | 0.0004 |
| C | 6.3199 | 0.902436 | 0.0000 |

Notes: Results of the robust test shows in this table. CI is the dependent variables; the core independent variable is HTE1; the alternative variable is HTE2; the Control variables are URB, IND, and GDP. The significance level is taken at 5% (Table 6).
Source: Author's Calculations.

**Table 6.** Robust test with PM2.5.

| Variable | Coefficient | Std. error | P-value |
|---|---|---|---|
| HTE1 | −5.0901 | 2.6301 | 0.0544 |
| HTE2 | 2.0095 | 0.5094 | 0.0001 |
| URB | −9.2134 | 2.5074 | 0.0003 |
| GDP | 0.0003 | 8.4105 | 0.0000 |
| IND | 0.5502 | 0.4060 | 0.1768 |
| C | 57.7379 | 10.4432 | 0.0000 |

Notes: Results of the robust test shows in this table. PM2.5 is the dependent variables; the core independent variable is HTE1; the alternative variable is HTE2; the Control variables are URB, IND, and GDP. The significance level is taken at 5%.
Source: Author's Calculations.

carbon intensity alternative variable to check that varying CI levels give consistent outcomes in Table 6. The results presented a strong link between the main independent variable HTE and carbon intensity, which also aligns with the previous results. Therefore, HTE has a significant relationship with carbon intensity, supporting our research objective. In this way, there is sufficient evidence that the obtained empirical findings are novel and reliable from a new perspective.

### *4.1. Transmission channels of HTE on carbon intensity*

To further examine the ways through which HTE influences carbon intensity level, the influence of human capital (HC) is incorporated in the proposed model in equations 2 and 3. The corresponding result after the addition of human capital as moderating variable is depicted in Table 7. Our findings still support by depicting a significant impact of HTE on carbon intensity which provides evidence for the claimed research question. This indicates that with an increase in the level of human capital, the carbon intensity level also increases. Hence, the results recommend that enhancement in human capital which includes training and practical learning, indirectly enhances the income level, which increases the usage of energy-consuming systems leading to an increase in the carbon intensity level. Undoubtedly, HTE is the driving factor behind economic productivity and growth (Jahanger et al., 2022).

## 5. Results discussion

The results reveal that HTE shares a positive relationship with CI level, consistent with H1. This result aligns with (Su et al., 2021; Wang et al., 2021). While it is in contrast to (Aldakhil et al., 2019). In this way, our results provide deeper insights

**Table 7.** Linear Regression Results (Moderation Model).

| Variable | Coefficient | Std. error | P-value |
|---|---|---|---|
| HC | −1.5301 | 8.2701 | 0.0691 |
| HTE1 | 1.4701 | 8.4601 | 0.0876 |
| HTE2 | 0.4570 | 0.1128 | 0.0001 |
| GDP | 6.9705 | 3.1700 | 0.0317 |
| URB | 0.3284 | 0.5553 | 0.5563 |
| IND | −0.3925 | 0.0703 | 0.0000 |
| C | 11.5098 | 3.0121 | 0.0003 |

Notes: Results of linear regression (mediating effect) are shown in this table. CI is the dependent variable; the Core independent variable is HTE1; Control variables are Urbanization, Industry, and GDP; Moderating variable is human capital (HC). The significance level is taken at 10%.
Source: Author's Calculations.

into the role of HTE in understanding the carbon intensity levels and highlight and strengthen their positive relationship. Past studies have reported a significant relationship between CO2 emissions and high-technology exports. Such as (Can et al., 2020) examined the influence of exports on CO2 emissions from 1971–2014 in 84 countries. They found a significant and positive effect of exports on CO2 emissions. Similarly, exports leading to the development of new products lead to an increase in industrial processes, enhancing energy consumption and leading to environmental degradation (Liu et al., 2019). Hence, with an increase in high technology exports (HTE), an increase in energy consumption and CO2 emissions are expected. In light of the literature mentioned above, this study aims to examine the impact of high technology exports (HTE) on carbon intensity levels in 25 countries.

Even at the international level, several researchers are trying to investigate the impact of high-technology exports on environmental degradation to design appropriate policies regarding climate change. However, the role of PM2.5 intensity level concerning environmental sustainability has not been examined in detail (S. Wang et al., 2020; Zaman & Abd-el Moemen, 2017). Further, past empirical studies have reported mixed findings (Sinha & Akoorie, 2010; Waheed et al., 2020). Such as a study reported that exports cause a decrease in CO2 emissions (Muhammad et al., 2020). At the same time, (Cheng et al., 2019) reported a positive relationship between exports and air pollution with an inverted U-shaped impact. Moreover, (F. Wang et al., 2017) confirmed that interregional trade is a significant indicator in understanding emissions and environmental degradation. Therefore, it is crucial to investigate the impact of HTE on carbon intensity and PM2.5 intensity levels to understand the impact of exports on environmental sustainability.

It is also found that among the control variables, urbanization (URB) positively impacting carbon intensity. This result suggests that by increasing urbanization, there will be more carbon dioxide emissions, which will negatively affect environmental sustainability. This result is also supported by past studies (Abbasi et al., 2021; Bekhet & Othman, 2017). Further, regarding industrialization, the results reveal a positive relationship again with the carbon intensity level as well, and the result depicts that carbon emissions increase in line with an increase with industrialization (H. Mahmood et al., 2020). Hence, this study highlights the significance of green investment and sustainability, which is important to achieve sustainable development goals (SDGs). Past studies also support the result (Kwakwa, 2022; Xu & Lin, 2015).

Further, the result reveals that GDP shares a negative relationship with carbon intensity level, which indicates that the higher the economic development level (GDP), the lower the carbon intensity levels will be. Thus, validating the past findings (Shoaib et al., 2020; Zi et al., 2016). While this finding is in contrast to a finding of (Mohsin et al., 2022) in which a positive relationship is found. The difference in our results is subjected to a different selection of geographical locations.

## 6. Conclusion and Policy implications

In this research, we have analyzed the data collected from 25 technologically advanced countries from 2009 to 2018 to investigate the impact of HTE on environmental sustainability. In this study, we have also examined the moderating impact of human capital on this relationship. Therefore, this study highlights the importance of considering the significant role of high-technology exports in understanding the environmental sustainability.

We also found that human capital promoted by HTE can increase the carbon intensity level, ultimately strengthening the impact of HTE on carbon intensity levels. The results presented that HTE shares a positive and significant relationship with carbon intensity levels. This research also gives new directions to future researchers, as researchers can use other variables as dependent constructs and apply the model to different regions of the world using different threshold variables. Further, future studies may use mixed-method research to provide a qualitative perspective along with quantitative results. Future studies can use a combination of different control variables and core independent variables to analyze the relationship between environmental sustainability and high-technology exports.

### *6.1. Limitations*

This study also has some limitations as it only included the key variables, high technology exports, carbon intensity, and human capital. Thus, there is an avenue for further examination with other variables, including energy conservation and effectiveness. Moreover, we have examined only 25 countries, therefore, research on other countries can provide deeper insights. Lastly, we have used only the secondary data, therefore, a future study may conduct a mixed method research for enlightening the academicians from a new perspective.

### *6.2. Policy recommendations*

Our results also give practical implications to researchers and academicians. This study will also help policymakers formulate practical policies for establishing a green economy by focusing on high-technology exports and their relation with carbon emissions. Firstly, given the positive impact of HTE on environmental sustainability, a country should focus on economic risks whenever it is going to design policies for the export sector. Countries with low or higher economic risks are confined to formulating high-technology export development guidelines and designing appropriate policies so that HTE may not negatively affect environmental sustainability.

Moreover, the countries should also focus on the importance of human capital, as this factor confirms the positive impact of HTE on CO2 emissions. Therefore, a country should promote human capital with green sustainable strategies for achieving environmental sustainability. Similarly, countries should focus on improving technological innovation processes in the export sector, which is also very significant in increasing the technical knowledge of workers leading to achieving environmental sustainability.

## Disclosure statement

No potential conflict of interest was reported by the author.

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# Appendix

**Table A1.** Descriptive statistics.

| | CI | PM2.5 | HTE1 | HTE2 | HC | GDP | IND | URB |
|---|---|---|---|---|---|---|---|---|
| Mean | 6.22 | 71.38 | 5.86 | 5.40 | 88.41 | 22456.89 | 25.87 | 1.35 |
| Median | 4.92 | 86.21 | 1.80 | 3.11 | 94.30 | 12474.79 | 25.88 | 1.27 |
| Maximum | 17.43 | 100.00 | 7.31 | 29.12 | 99.17 | 56762.73 | 46.49 | 3.25 |
| Minimum | 1.28 | 0.25 | 4.34 | 0.05 | 56.08 | 1101.96 | 18.04 | −0.07 |
| Std.Dev. | 4.04 | 33.98 | 1.09 | 6.51 | 13.40 | 18.07 | 5.44 | 0.83 |

**Table A2.** Countries' list of 25 countries.

| Argentina | Colombia | India | Morocco | Switzerland |
|---|---|---|---|---|
| Australia | Finland | Ireland | Norway | Belgium |
| Austria | France | Italy | Poland | Turkey |
| Canada | Denmark | Japan | Spain | Hungary |
| China | Greece | Mexico | Sweden | United States |