ANALYSIS OF ENERGY TRANSITION COSTS IN REGIONS DEPENDENT ON FOSSIL FUELS*

Assessing How the Costs of Energy Transition Affect the Applicability of Policies

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This study addresses the critical question of whether regions heavily dependent on fossil fuels should undergo an energy transition, considering the slow progress and high costs associated with such a transformation. Focusing on China's energy transition amidst its Renewable Energy Law amendments, we examine the economic feasibility of transitioning from traditional to renewable energy sources for both resource-abundant and non-resource-abundant cities. Utilizing a difference-in-difference approach, we analyze data from the National Bureau of Statistics of China, comparing energy consumption costs and pollution abatement expenditures between traditional energy-dependent northeastern districts and diverse south-central districts before and after the 2013 renewable energy policy implementation.Our findings reveal that the transition towards renewable energy significantly affects the Gross Regional Product (GRP) levels differently across regions. In the treatment group, represented by Zhejiang province, the shift towards renewable energy correlates with positive GRP growth, indicating the beneficial impact of renewable energy adoption. Conversely, in the control group, Liaoning province, heavy reliance on coal and traditional energy sources tends to decrease GRP levels, underscoring the challenges posed by dependency on fossil fuels. These results suggest that while environmental protection and renewable energy adoption are critical for sustainable development, the economic implications of such transitions vary significantly across regions, influenced by their energy dependency nature. The study contributes to the understanding of the economic impacts of energy transition policies, highlighting the importance of regional context in assessing the feasibility and effectiveness of such transitions.

*https://github.com/MaEasonH/-ANALYSIS-OF-ENERGY-TRANSITION-COSTS-IN-REGIONS-DEPENDENT-ON-FOSSIL-FUELS.git

Table of contents

1 Introduction

1.1 Context:

Over the last three decades, following the promising ever-developing economic growths globally, there have also been increasingly large demand for energy for human activities. However, it is frequently reported that there are significant climate changes, of which global warming is the most alarming (Qian, 2021). According to data from the United Nations (2011), CO2 emissions of China have already reached the highest in the global rank, surpassing those of the United States (Qian, 2021). Apart from the environmental pollution caused by industrial cities, low efficiency is also one of the reasons that supports the necessity of carrying out these transformations. To be more precise, as suggested by Xiangyan, the issues of over-dependence on resource exploitation and low efficiency are observed in coal-mining cities of China (Qian, 2021). It is found that economies with abundant resources tend to rely too much on the primary product sector for gaining profits, and such sectors often have the characteristics of low human capital requirements, weak innovation, and poor technology spillovers (Qian, 2021). Consequently, this kind of restricted economic growth as a result of over-exploitation of resources directly links the transformation of cities to their contemporary and future economic developments.

By the issuing of Renewable Energy Law of the People's Republic of China in 2005 and its later renewal in 2013, in the context of China's efforts to popularize renewable energy nationwide, whether heavy-industry based regions like northeastern parts of China should still stick to the transformation into environmental cities, while facing challenges of making slow progresses and high costs, is a critical question that deserves more attention. Indeed, the transformation of cities is often a great concern for decision-makers from the perspectives of contemporary and future economic developments of these places. Just like how Bernard examines the transformation of the city Chattanooga from a major industrial city to an environmental-friendly one, although the positive effects that environment brought to economic developments are highlighted, it is undeniable that the time-consuming and costly process is the main challenge that this kind of transformation might face. Therefore, for developing countries like China, whether popularizing environmental-friendly natural resources is economically feasible for both inherently resource-abundant cities and non-resource-abundant cities, is a valuable question to study. However, as suggest by Xiaoyan, China's national strategy, formulated between 1995 to 2009, for changing the mode of economic growths, was hindered by the huge size of China's territory, and more specifically, the enormous discrepancies in industrial structures and technology displays of different regions of China (Qian, 2021). In this way, our project separates cities into different groups to study the effects of the popularization of new energy resources on economic developments.

1.2 Questions and hypothesis:

Upon the importance of figuring out whether a city should go through the transformation as discussed previously, the related studies in this field have contributed to controversial statements. For instance, it has been suggested that the impact of natural resources is meaningful to economic growths only if a certain threshold point of institutional quality has been attained, which indicates that the abundance or lack of institutional quality could be one of the reasons for positive or negative relationships between new energy resources and economic developments (Sarmidi, 2013). What's more, as stated by Smith, there is a positive effect on GDP per capita levels following the exploitation of natural resources that persists in the long term (Smith, 2015). However, in this case, natural resources are not separated into different categories, like the renewable and non-renewable ones. Thus, from this aspect, our study about renewable energies and industrial cities of China could contribute to the existing literature. Additionally, the paper by Sarmidi, as discussed previously, also sheds light on the potential hysteretic nature of policies in terms of its effects on economic developments, which we may further discuss as one of the limitations of our project (Sarmidi, 2013).

Therefore, due to the uncertainties involved with factors like the institutional quality and the hysteretic nature of the policy implementation and unspecified energy types in previous studies, we hypothesize that the transformation into the popularization of renewable energy may have detrimental effects on the economic developments of traditional energy-dependent districts of China. In China, more specifically, traditional energy-dependent districts refer to those regions that rely on traditional energies like coal and nuclear power. According to related statistics in 2014, as illustrated in the map below, it can be found that northern regions like the provinces of Shandong, Inner Mongolia, and Liaoning take up a great proportion of coal and nuclear power plants in China, while for south central regions like the provinces of Guangdong and Zhejiang tend to use renewable and alternative energy sources (EVB) more frequently for power generations (Baker Institute, 2024). Thus, in this paper, each representative region with traditional energy dependence and renewable energy dependence, the provinces of Liaoning and Zhejiang respectively, is selected for our study.

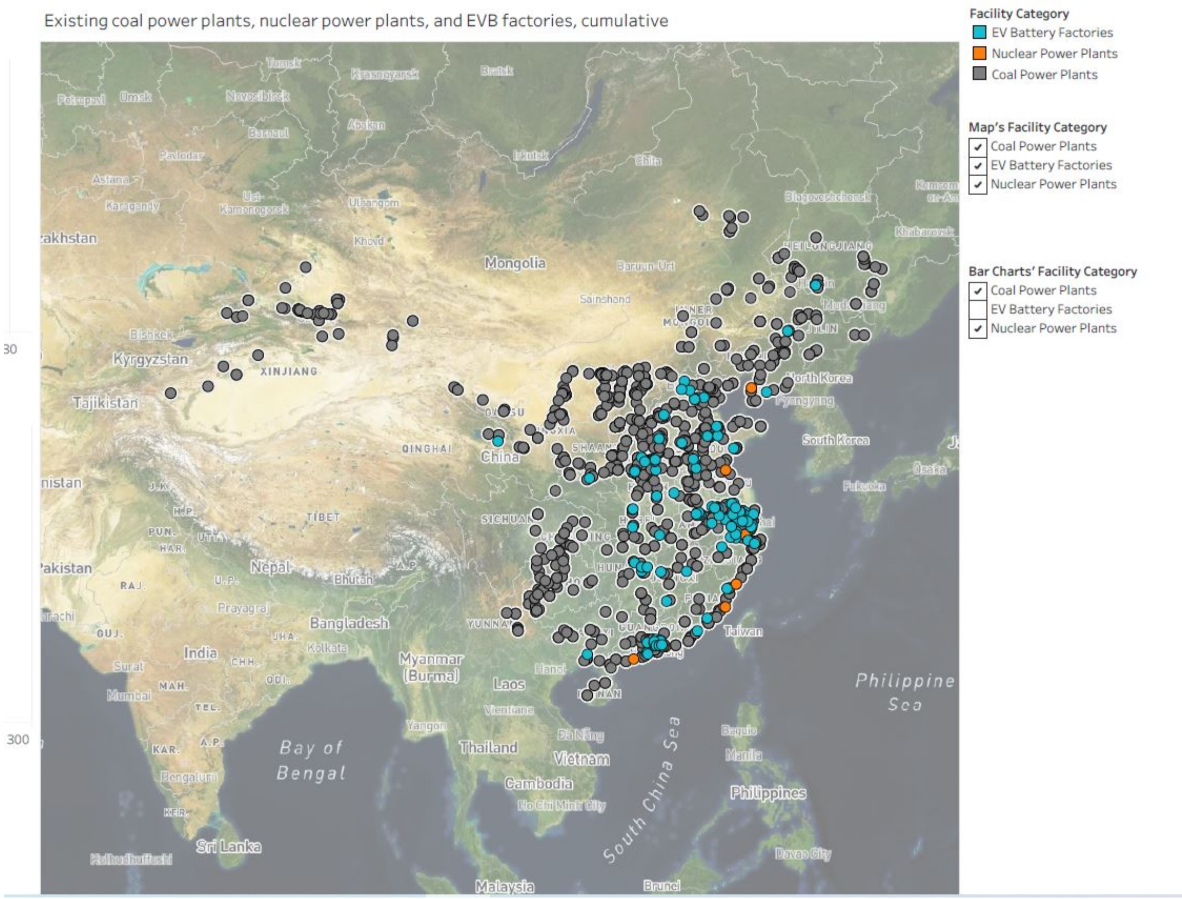

Figure 1: China's Energy Structure in 2014

For our data and empirical strategy, the main data source for our study is the National Bureau of Statistics of China website, which is an urgency under the jurisdiction of the State Council of China that established in 1952, responsible for collecting and publishing statistical data on the country's economy. In our model, we specifically focus on the related statistics on costs of regional energy consumption, expenditures on pollution abatements, and the public's health leve. Then, relevant statistics are selected and organized for our study on the regional energy transformation costs into the popularization of renewable energy, through applying a difference-in-difference model as our empirical strategy to compare energy consumption costs between traditional energy-dependent northeastern districts and multifarious southcentral districts of China during the implementation of the renewable energy policy in 2013. Difference-in-difference approach is applied, since our study tends to explore the casual relationship between the transformation into the popularization of renewable energy in those traditional energy-dependent districts of China and its effects on the gross regional product (GRP), and related data also suggest that the parallel trends assumption is satisfied for selected regions. Moreover, irrelevant data like the data of natural gas were removed from our model, since it remained unaffected by the policy intervention in 2013. And lastly, for the missing data, multiple interpolation method is applied, where averages of data values were used initially but later iterative interpolation was applied for better maintaining the integrity of our data and also reducing discrepancies.

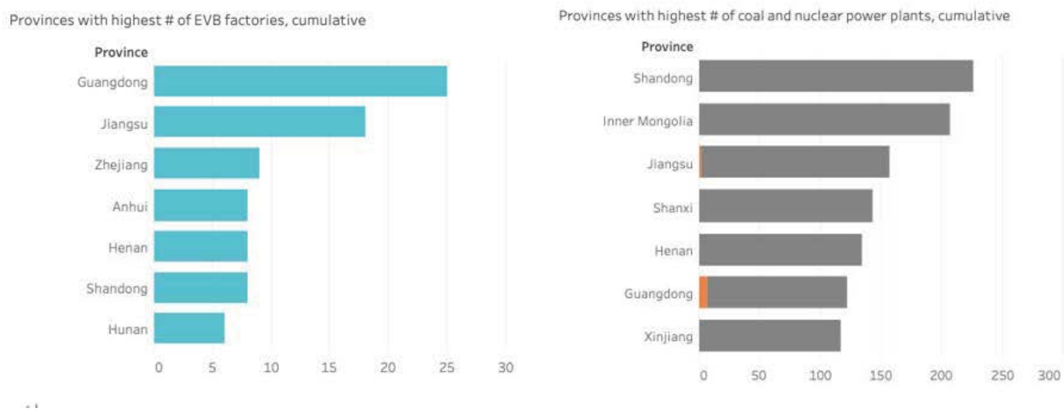

Figure 2: Reginal Energy Structure Graph

For main findings of this paper, firstly, it is suggested that various factors, including the consumption of various fossil energies, electricity consumption, investments in environmental industries, and investments in pollution abatements, all significantly affect the levels of gross regional product (GRP) of any specific regions in China in that contemporary period. More specifically, in the treatment group as the province of Zhejiang, the transition into the popularizations of renewable energy could positively influence the growths of GRP. However, in our control group as the province of Liaoning, the challenges brought by its heavy dependence on coal and other traditional energy, are likely to decrease GRP levels. Despite some of the insignificant direct effects illustrated by our model, as witnessed in the case of Liaoning, environmental protection remains essential for China's goals of sustainable developments.

Therefore, in the rest of the essay, the process of exploring the causal relationship between the renewable energy policy and the gross regional product (GRP) of traditional energy-dependent districts in China, will be illustrated in multiple steps. To be more precise, firstly, in the data section, the reliability of the data source, and the processes of data collection and data organization are described in detail, as well as the potential implications of those operations. Secondly, in the part for the empirical strategy, we begin with illustrating the casual relationship of interest, and then explain our difference-in-difference model by detailed empirical specification of every involved element in our model. Also, we also identify the assumptions and assess the plausibility of them under the context of our study. Thirdly, for the results section, we describe our study results, as the renewable energy could lead to different effects with respect to the fossil-energy dependence of any specific regions. And finally, conclusions section provides a summary of our results, limitations of our study, our contribution to the literature, as well as any potential policy implications.

2 Data

Our data source is mainly from one of the official data websites of China – National Bureau of Statistics of China website. It is an agency under the jurisdiction of the State Council of China. And it was established in the August of 1952, which is responsible for the collection, investigation, research, and publication of statistical data on the country's economy, that is capable of providing reliable information required for macroeconomic managements of the country. More specifically, this data site offers related statistics on costs of energy consumption in terms of different regions of China, like energy consumption, costs for local pollution abatements, population health data, and so forth. Among these multiple different data objects, we have selected those that particularly conforms to the theme of our study. However, also due to the official quality of our chosen data, we found that every given csv file consists of countless concerned and unconcerned statistics. Thus, to make our empirical process more effective, the corresponding collection and organization of data are required.

Based on the subject of our study, the process of our data organization is generally about regional costs for energy transformation and its later use in our difference-in-difference model. To explain, our study specifically focuses on contrasting the differences in the costs for energy consumption between northeastern traditional energy-dependent districts and southcentral districts with multifarious and disordered energy reliance patterns. In this way, relevant data before and after the study period (2013) were selected, also, we extracted only those relevant regional statistics out of the chosen data source. Moreover, in the original data source, the related data for energy consumption basically contain all of the available types of energy resources, but energies like the natural gas are irrelevant to our research. Consequently, as part of our data organization procedure, we particularly compared the statistics of the natural gas before and after the intervened period (which is the renewal of Renewable Energy Law of the People's Republic of China in 2013) through applying the difference-in-difference approach, and the results suggest that this type of energy was unaffected by the intervention, so its related data were removed. Additionally, like the natural gas, although it is widely considered as a fossil fuel, it is actually much cleaner than conventional fossil fuels, and so technically natural gas cannot be categorized as a clean energy source. From this perspective, data about other energy resources that are similar to the natural gas were also removed during our process of data organization.

For missing data in our dataset, corresponding data organization was also carried out, through applying multiple interpolation method. To be more precise, we firstly applied the imputation method. We filled the missing values by using the average values of each selected variable in each year. However, during our analysis of results from the difference-in-difference model, it is found that the standard error of the prediction results tends to be small, in which we considered the filling of missing data by the average values may potentially cover up some significant economic phenomena or trends. So, that's why we turned to the elimination method. Completely deleting those variables with missing values was our first thought. Yet, as one of our most crucial factors, the statistics for GRP (Gross Regional Product) still contain missing values. Therefore, the elimination method is also rejected. Ultimately, we decided to combine the multiple imputation method with a search for missing data. By generating estimates for some of the missing values based on the probability distribution of part of the data, including the Consumption of Coke (10,000 tons) and Sulphur Dioxide Emission in Waste Gas (10,000 tons), due to their similarity, these were not discussed in detail in the text. For more critical data, such as Consumption of Coal (10,000 tons), Gross Regional Product (100 million yuan), and the PM2.5 index, these required special discussion. Therefore, we resorted to searching through other channels, including the World Bank and some provincial documents published in China, to fill in the missing values. After multiple verifications, the data were official and authentic.

3 Empirical strategy

Our study tends to explore the casual relationship between the transformation into the popularization of renewable energy in those traditional energy-dependent districts of China and its effects on the gross regional product (GRP). According to the aforementioned analysis on the existing literature, we postulate that the transformation into the popularization of renewable energy may have detrimental effects on the economic developments of traditional energy-dependent districts of China. Therefore, to estimate the causality, the difference-in-difference methodology is introduced, in which our DiD model could be written as

$$GRP_{it} = \alpha + \beta * Post_t * Treatment_i + \gamma * X_{it} + \delta_t + \lambda_i + \epsilon_{it}$$

3.1 Model set-up

Where GRP_{it} represents the gross regional product (GRP) of the traditional energy-dependent districts of China in the time period t. Correspondingly, GRP_{nt} signifies the gross regional product (GRP) of the non-fossil energy-dependent districts of China in time period t, which is a crucial index on measuring the sizes of the economies and the levels of the developments in any specific areas, and so it is often used to evaluate the impacts of economic policies. Then, $Post_t$ is a dummy variable for time, which indicates whether any particular regions are during the periods before or after our study period (the renewal of the policy in 2013). For instance, if the observed year is after the renewal of the policy for renewable energy, then $Post_t$ will be 1, otherwise, it will be 0. $Treatment_i$ is a dummy variable for the treatment, which denotes whether the policy for popularizing the new energy has been implemented in regions i or t (the province of Liaoning or Zhejiang). Straightforwardly, for the region where the policy for popularizing the new energy has been implemented, this variable will be 1, otherwise, it will be 0.

What's more, X_{it} denotes the aggregate of control variables, which includes other potential factors that may also affect GRP. More precisely, this variable involves factors like regional energy consumption, environmental quality, environmental investment, costs for environmental abatements, and so forth, which are all possibly associated with the changes in GRP levels. Therefore, by controlling these variables, discrepancies brought by omitted variables could be reduced in a great extent, and thus our measure to the effects of renewable energy policy on GRP levels becomes more accurate. In addition, δ_t signifies the fixed effects for time, which is capable of controlling the influences of the time-specific factors relevant to all districts in our dataset on GRP, like the national economic growth rates and annual policy changes. In this way, the possible impacts of time trends on our analysis could be better limited. Then, fixed effects for regions are represented by λ_i . For those region-specific factors that are irrelevant with changes in time periods, like geographical locations, cultures, and infrastructures, this variable is responsible for controlling their effects on GRP. Through applying this factor into our model, the inherent differences between different areas of China could be controlled in a great extent. Moreover, is the classical error term, which captures all the random variations that are unexplained by other parts of our model. More precisely, it includes measuring errors, the potential effects of omitted variables, as well as possible impacts led by other unobservable factors. Consequently, as described above, (according to the interaction terms "$Post_t \times Treatment_i$") our model aims to estimate the causal relationship between the transformation into the popularization of renewable energy in those traditional energy-dependent districts of China and its effects on the gross regional product (GRP), while controlling the effects of other possible factors on GRP.

3.2 Model Justification

We expect that for the treatment group, being in non-fossil energy-dependent areas, there will be a positive correlation between the time variable $Post_t$ and GRP, due to the favorable conditions for transitioning away from fossil fuels. Similarly, the treatment group variable $Treatment_i$ is expected to have a positive relationship with GRP, as these areas have better conditions for transformation. Within the aggregate of control variables X_{it}, because of the independence from coal, coal consumption is expected to have a negative correlation with GRP. In contrast, electricity consumption, as a primary factor of production, is anticipated to have a positive relationship with GRP. Furthermore, the environmental investment factor, after treatment, is better adapted to the policy and is expected to have a positive correlation with GRP.Conversely, the control group is expected to have relationships opposite to those of the treatment group.

3.3 Identifying Assumptions

The assumption of parallel trends: we hypothesized that both control and treatment groups have similar increasing trends on the levels of gross regional product (GRP) before the implementation of the new energy policy. This means that both control and treatment groups will still have consistent growth patterns if the policy was not put into effect.

The assumption of no intervention spillover effects: we assumed that the impacts of the new energy policy is solely limited to those districts where the policy is implemented, and there is no indirect effects on the regions where the policy is not carried out.

We consider that dealing with endogeneity issues and determining control variables are crucial procedures for identifying the reliability of assumptions relevant to our approach. Then we still assume that endogeneity issues are generally derived from omitted variables. For instance, factors, like regional technological levels and fiscal situations of local governments, may simultaneously affect the implementation and acceptability of the renewable energy policy and regional economic developments. Therefore, to make sure that we have accurately incorporated potential control variables in the greatest extent and thus ensuring the reliability of identifying assumptions of our model, certain relevant literatures are referred. More specifically, governmental fiscal expenditures and air quality index are chosen as our control variables. To explain, governmental fiscal expenditure is defined as the total annual fiscal expenditure solely on environmental protection by governments at all levels in the provinces of Liaoning and Zhejiang, including but not limited to public services, social insurances, economic constructions and other aspects. And the air quality index is defined as the major indicator for measuring the air quality by the contents of PM2.5 in the air, which could effectively reflect the degree of air pollution in provinces of Liaoning and Zhejiang respectively. All of the data associated with these control variables are collected from the official data website of the National Bureau of Statistics of China, which ensures the accuracy and standardization of the data. These variables were selected because government spending, especially in infrastructure, energy projects, and research and development, can significantly affect regional economic growth and development. For instance, in the case study of Indonesia by Aisyah, fiscal policy, acting as a stabilizing instrument, continues to stimulate the growth of national income of Indonesia when other developed countries were experiencing negative economic growths in the contemporary periods (Aisyah, 2024). And more specifically, the regional internal effects of government expenditure, investment, and education variables on regional economic growth in Indonesia are suggested to be positive and significant (Anwar, 2020). In this way, government spending is highly likely to directly or indirectly promote the development and application of new energy technologies, with an impact on regional GRP. What's more, in the case of air quality index, as illustrated by the case study of Chinese cities, air pollution (i.e. haze pollution) indeed has a significantly negative impact on economic developments by increasing costs on air pollution regulations (Hao, 2018). And also, it is obvious that the issuing of the renewable energy policy by Chinese government is directly related to worsening air quality in that contemporary period. Therefore, government spending and air quality index are selected as the control variables of our model.

Based on these analysis, we updated our model:

$$GRP_{it} = \alpha + \beta * Post_t * Treatment_i + \gamma_1 * X_1 it + \gamma_2 * X_2 it + \gamma_3 * X_3 it + \delta_t + \lambda_i + \epsilon_{it}$$

Where variables $X_2 it$,it and $X_3 it$,it indicate the newly added control variables as governmental fiscal expenditure and air quality index respectively. And the coefficients represent the magnitudes of the effects of each control variable on the dependent variable (GRP).

Before substituting these above variables into our model, correlation checks are performed, as well as variance inflation factor (VIF) is calculated for evaluating the severity of collinearity. It is found that although there is some degree of correlation between these control variables and the main explanatory variables, they are not highly correlated and so there is no issues associated with multicollinearity. What's more, to further ensure the reliability of our results, sensitivity analysis is also performed on the data, aiming to observe whether the coefficients and significance of the main explanatory variables change significantly when adding or excluding some control variables one by one in our model.

4 Results

4.1 Comprehensive DiD analysis (incorporating the impact of all variables on GRP): Treatment group: Zhejiang.

First of all, in our model, the treatment group is the province of Zhejiang of China, which has no dependence on traditional energy, and so the renewable energy policy was well received and carried out in this area. On the other hand, the control group is the province of Liaoning, which is a conventionally industrial city that relies heavily on the fossil energy and behaved poorly on the acceptance of this new policy while facing difficulties in the transformation of its traditional energy structure.

Then, in our comprehensive analysis on the difference-in-difference model, which is the analysis of the effects on gross regional product (GRP) when all variables are substituted into the model:

$$GRP_{it} = \alpha + \beta * Post_t * Treatment_i + \gamma_1 * X_1 it + \gamma_2 * X_2 it + \gamma_3 * X_3 it + \delta_t + \lambda_i + \epsilon_{it}$$

Table 1

Comprehensive Analysis for Zhejiang

GRP and Environmental Factors				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−1,966,874.3119	911,561.7919	−2.1577	[1] 0.0563	(Intercept)
8,033.2713	2,216.2240	3.6248	[1] 0.0047	treatment
2,404.0154	1,121.4256	2.1437	[1] 0.0577	post_treatment
−1.2833	0.6105	−2.1019	[1] 0.0619	\`Consumption of Coal(10000 tons)\`
−1.7300	1.4668	−1.1795	0.2655	\`Consumption of Coke(10000 tons)\`
13.3562	1.6759	7.9693	[1] 0.0000	\`Consumption of Electricity(100 million kwh)\`
1.6807	1.7656	0.9519	0.3636	\`Investment in Energy Industry(100 million yuan)\`
−0.0033	0.0022	−1.4862	0.1681	\`Investment Completed in the Treatment of Industrial Pollution(10000 yuan)\`
−0.0017	0.0042	−0.4061	0.6932	\`Investment Completed in the Treatment of Waste Gas(10000 yuan)\`
24.7352	15.9043	1.5553	0.1509	\`Sulphur Dioxide Emission in Waste Gas(10000 tons)\`
100.4660	62.9460	1.5961	0.1416	\`PM2.5 index\`
−1.5889	6.4488	−0.2464	0.8104	\`Local Governments Expenditure Environmental Protection(100 million yuan)\`
980.0006	456.7643	2.1455	[1] 0.0575	Year
−4,283.8091	1,808.2763	−2.3690	[1] 0.0393	treatment:post_treatment

[1] Note: *** p < 0.01, ** p < 0.05, * p < 0.1, it shows the Comprehensive DiD analysis comparing all factors and GRP for treatment grout Zhejiang

Figure 3: Comprehensive Analysis For ZheJiang

A few of the key results could be illustrated under this model. Firstly, for “treatment”, the estimated value for the treatment is 8.033e+03, and the standard error is 2.216e+03, t value is 3.625, p value is 0.00465, which means that the treatment is significant and has a positive influence on GRP ($p < 0.01$). Then, for “post_treatment”, the estimated value is 2.404e+03, the standard error is 1.121e+03, t value is 2.144, p value is 0.05767, so it could significantly positively affect GRP levels ($p < 0.1$). For “Consumption of Electricity”, the electricity consumption has a positive impact on GRP, with the coefficient 1.336e+0.1, and this imapct is strongly significant (p<0.001). Moreover, the coefficient for the variable “Year” is 9.8003+02, which indicates that the GRP levels will increase approximately by 98 billion RMB every year, and with statistical significance. Consequently, from the results discussed above, with the positive and significant estimates for both the treatment and post treatment, we can then conclude that this policy of popularizing the renewable energy could indeed effectively boost the gross regional product in areas that are not dependent on fossil energy in China. For example, in the case of coal consumption, the impact of it on GRP is negative and close to significant, which means larger coal consumption is likely to reduce GRP, in which we speculate that it is due to the high cost and low efficiency of coal power generation (Qian, 2021). However, it is the transformation into the use of renewable energy prevents the overdependence on coal and other fossil energy, which could be beneficial for the long-term developments of these regions (Smith, 2015; Qian, 2021). Also, by the significantly positive estimate for electricity consumption, it is suggested that GRP levels will increase significantly by increasing electricity consumption. In this sense, the popularization of more efficient power generation, like renewable energies, could stimulate the local economic growths in a significant way. Additionally, while the effect of government expenditure on environmental protection is not considered significant, it can still imply the correlation between environmental factors and energy consumption patterns in some extent. Therefore, the application of renewable energy has become an important way that could reduce the costs on power generation and thus improve the efficiency of it, which again emphasizes the positive role that this energy transformation could play in non-traditional-energy-dependent districts of China.

4.1.1 For the control group: The province of Liaoning:

Table 2

Comprehensive DiD analysis for Liaoning

GRP and Environmental Factors				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−1,966,874.3119	911,561.7919	−2.1577	[1] 0.0563	(Intercept)
8,033.2713	2,216.2240	3.6248	[1] 0.0047	treatment
2,404.0154	1,121.4256	2.1437	[1] 0.0577	post_treatment
−1.2833	0.6105	−2.1019	[1] 0.0619	\`Consumption of Coal(10000 tons)\`
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[1] Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$,it shows the Comprehensive DiD analysis comparing all factors and GRP for control group grout Liaoning

Figure 4: Comprehensive Analysis for Liaoning

As illustrated in Table 1, the estimated value for the consumption of coal is -1.283e, with p value of 0.06188, which means that increases in the consumption of coal is likely to lead to decreases in GRP growths of any specific regions in our model, since our p value is very close to significance. This relationship could be explained by the low efficiency of the fossil energy, as well as its connection to the environmental quality (Fan, 2022). Although, as suggested by our findings, the environmental protection does not have a direct and significant impact on GRP levels considering the insignificant results associated with the variable about investments in environmental abatement, governmental spending on protecting the environment is still required to promote China's contemporary goal of sustainable developments, which then explains the reductions in GRP (Qian, 2021). While if taking into account the well-developed heavy industry and the overdependence on the energy supply by coal of the province of Liaoning, caused by its issues left over by the regional history, as well as the significantly positive relationship between the electricity consumption and GRP (as the estimated value is 1.336e+01, p value is 1.22e-05), then the power generation by electricity is illustrated to be very effective for improvements in GRP. Thus, considering all factors mentioned above, the conflict of the dependence on fossil energy for power generation and accompanying detrimental effects on the environment and then high costs on the corresponding environmental abatement is what the province of Liaoning had to face, which suggests that this energy transformation is not beneficial for GRP growths in Liaoning, that may turn into a long-term issue for the local governments.

4.1.2 Weird stuffs: Large Intercept Term

In our analysis of results, it is shown that the estimate for the intercept term is negatively large, which is something that we did not expect. Because this means that GRP might be a large negative number when effects from any other variables are not involved, which does not make sense in our real lives. Thus, we first suspect that multicollinearity issues may exist among certain variables. To solve this problem, correlation checks could be performed on any two groups of variables, and the observed results of correlation coefficients could help us to find out those variables that have multicollinearity problems. So, through the correlation checks, it is found that there is a strong correlation between the regional government expenditures on environmental protection and GRP, with the coefficient being 0.7869542. Then, through the analysis of the difference-in-difference model, it can be stated that although regional government expenditures on environmental protection could signify the government control on environmental pollution, and we could thus infer whether the transformation is necessary based on either low of high cost of energy transformation or other related factors, this variable is not statistically significant under this condition. Consequently, we considered whether we need to remove this variable for decreasing the magnitude of the intercept term.

4.1.3 The Assumption of Parallel Trends

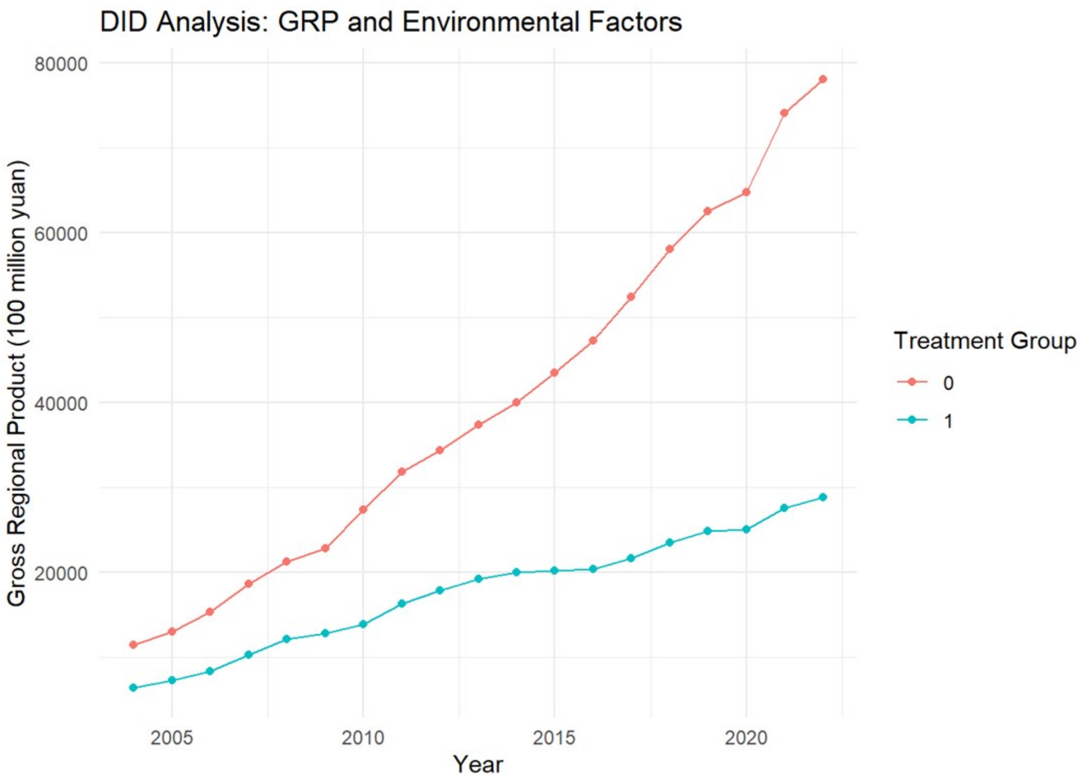


Figure 5: Assumption of Parallel Trends

The assumption of parallel trends in comprehensive analysis of difference-in-difference model:From the above graph, it is illustrated that the treatment group (signified as 1) and control group (signified as 0) follow a parallel trend before the treatment in the year of 2013. This indicates that the patterns of gross regional product in both groups were similar before the intervention, which is a critical prerequisite for DID analysis. After the implementation of renewable energy policy in China in 2013, it can be seen that the growth in GRP levels of the treatment group is accelerated, while that of the control group does not show a remarkable change or increases in a relatively slow pace. So, this indicates that the intervention has positive effects on the treatment group.

4.2 Correlation Checks:

4.2.1 PM2.5 index and Gross Regional Product

We firstly perform correlation checks on included control variables, of which the correlation coefficients between PM2.5 (fine particulate matter) level and gross regional product (GRP) is -0.7120874. This means that there is a moderate negative relationship between them, which suggests that GRP tends to decrease by the increase in PM2.5 level. Corresponding to results of the previous studies, it is found that the reduction of GRP levels, as the result of excessive pollution emissions and corresponding pollution controls in the process of trying to shift their economic structures from the traditional heavy industry to the high-tech industry, is considered as one of the main challenges of the energy transition of regions that heavily rely on the fossil energy in China (Zhou, 2013).

4.2.2 Government Expenditures on Environmental Protection and Gross Regional Product

Secondly, the correlation coefficient between the regional government expenditures on environmental protection and GRP is 0.7869542, which shows a moderate degree of correlation. This demonsrates that the regional government expenditures on environmental protection of a specific region is likely to increase when the size of economy (i.e. GRP) of that region improves, and vice versa. The expansion of the size of economy generally means that the government has more resources on supporting various public services and reaching policy goals, including environmental protection. So, this implicitly proves that, for those districts that depend heavily on fossil energy, government expenditure on environmental protection is also one of the challenges in the energy transition process.

4.2.3 Government Expenditures on Environmental Protection and PM2.5 index

And finally, through correlation checks, it is found that the regional government expenditures on environmental protection and PM2.5 level are moderately correlated, with the correlation coefficient of -0.4998035. This denotes that the PM2.5 level of a specific region tends to reduce when the regional government expenditures on environmental protection of this region increases, and vice versa. This correlation is likely to reflect the positive effect of increasing government spending on environmental protection to cutting down the air pollution (especially PM2.5 pollution. In the case of environmental regulation in China, the government expenditure is likely to be used for things like emission reduction measures, environmental remediation projects, and the renewal of pollution monitoring and control technologies, which all contribute to drive the PM2.5 level down (Imran, 2022; Xin, 2022).

4.3 Sensitivity Analysis:

when not substituting control variables of PM2.5 and the regional government expenditures on environmental protection into the model, then we get:

$$GRP_{it} = \alpha + \beta * Post_t * Treatment_i + \gamma * X_{it} + \delta_t + \lambda_i + \epsilon_{it}$$

For our assumption to be more reliable, considering and assuming the endogeneity may arise from omitted variables, we then select relevant control variables. For variables of PM2.5 index and the regional government expenditures on environmental protection, sensitivity analysis is performed through adding and removing comparison results, which could refine discrepancies related to the endogeneity that are possible derived from missing variables.

Table 3

Sensitivity analysis

GRP and Environmental Factors				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−1,617,508.2867	678,913.6235	−2.3825	[1] 0.0299	(Intercept)
5,264.3136	1,060.5624	4.9637	[1] 0.0001	treatment
2,572.7207	645.1719	3.9877	[1] 0.0011	post_treatment
−1.2236	0.2493	−4.9077	[1] 0.0002	`Consumption of Coal(10000 tons)`
−0.2568	1.0376	−0.2475	0.8077	`Consumption of Coke(10000 tons)`
13.9071	1.4312	9.7169	[1] 0.0000	`Consumption of Electricity(100 million kwh)`
−0.1338	1.2410	−0.1078	0.9155	`Investment in Energy Industry(100 million yuan)`
−0.0022	0.0019	−1.1767	0.2565	`Investment Completed in the Treatment of Industrial Pollution(10000 yuan)`
0.0002	0.0034	0.0618	0.9515	`Investment Completed in the Treatment of Waste Gas(10000 yuan)`
34.9512	12.9954	2.6895	[1] 0.0161	`Sulphur Dioxide Emission in Waste Gas(10000 tons)`
806.7028	339.4257	2.3767	[1] 0.0303	Year
−4,057.2373	1,169.0696	−3.4705	[1] 0.0032	treatment:post_treatment

[1] Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, it shows the Sensitivity Analysis not include all control variable PM2.5 index and regional government expenditures on environmental protection

Figure 6: Sensitivity Analysis for PM2.5 and Government Expenditures on Pollution

Then, as our result, the estimated value of multiple R-squared demonstrates that the model could still explain almost all of the variations (approximately 99.8%) in the data, even if these two variables are removed from the model. This means that our model is capable of capturing the variations in the dependent variable (GRP) without these two variables. Also, when variables of PM2.5 and the regional government expenditures on environmental protection are removed, results of some variables like the consumption of coal, consumption of electricity, and the treatment (including "treatment", "post_treatment", and their interaction term) are still significant, which implies that the relationship between these variables and GRP are more direct than we imagined. Moreover, the results for Sulphur Dioxide Emission in Waste Gas becomes significant, when removing variables of PM2.5 index and the regional government expenditures on environmental protection. Then this means that the emission of other environmental pollutants has a more direct impact on GRP, while the costs of regulating or the cause of PM2.5 is not as important as other factors in this case. What's more, the result for the intercept term becomes smaller in magnitude and more significant, which illustrates that these two control variables also account for one of the reasons leading to multicollinearity. With removing variables of PM2.5 index and the regional government expenditures on environmental protection, other variables in the model become relatively more significant, which suggests that energy consumption and governing measures are still core factors with respect to GRP, comparing with the less proportion of environmental protection expenditure on regulating PM2.5.

4.3.1 Weird stuffs:

The assumption of parallel trends in sensitivity analysis is similar to the previous comprehensive analysis:

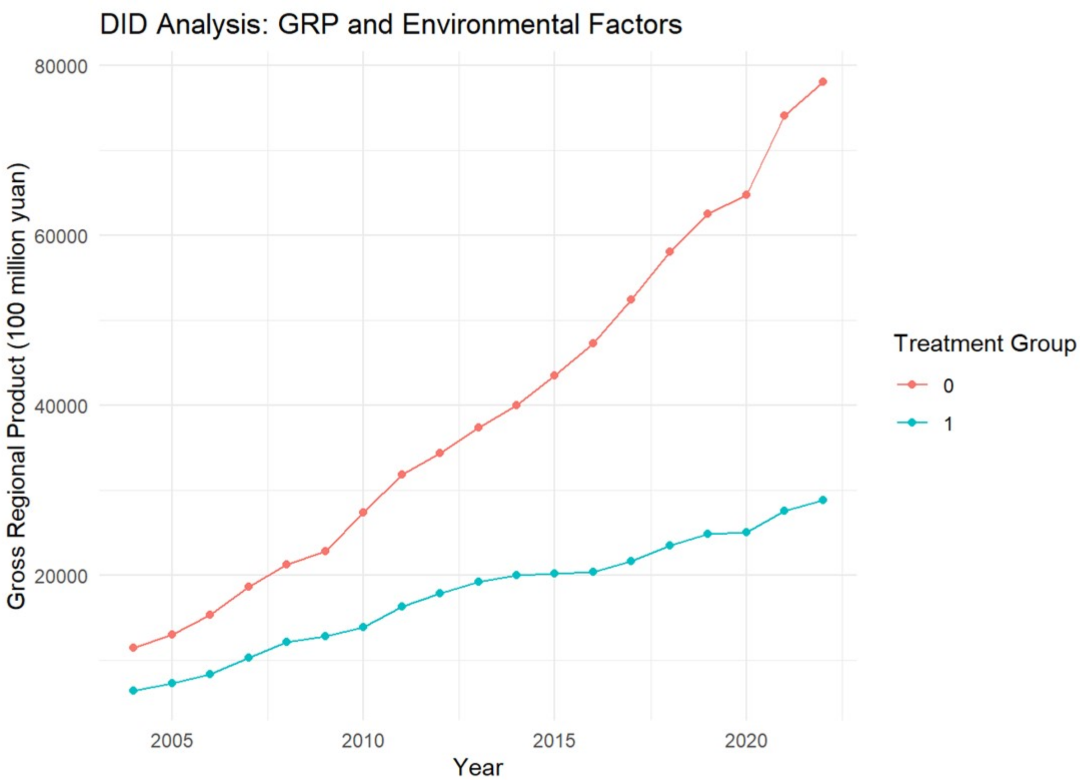


Figure 7: Sensitivity Analysis Parallel Trends

From the graph, it is illustrated that the parellel trends in this sensivity analysis are the same as that in the previous comprehensive analysis. It demonstrates that, for the non-fossil-energy-dependent region Zhejiang before and after the renewable energy policy was implemented (2013), GRP patterns before the intervention did not change due to the addition or deletion of variables about PM2.5 index and the regional government expenditure on environmental protection in the model. Thus, according with findings of the previous literature, these two variables might not be considered as leading factors in affecting economic growths, while witnessing their indirect and inconsistent relationships with economic developments (Xin, 2022; Fan, 2022). This might be because, in the case of Zhejiang that does not rely on fossil energy, the proportion of government expenditure on the environmental regulation spent on Zhejiang is not large with respect to the total expenditure, and PM2.5 as a kind of particulate matter in the air, cannot fully stand for the pollution caused by the dependence on heavy industry and fossil energy. In this way, the removal of these variables did not cause variations in GRP trends. Therefore, to deal with this issue and the previously stated intercept term issue (which suggests that these variables are the primary causes for the multicollinearity problem), we decided to directly remove variables of PM2.5 index and the regional government expenditure on environmental protection from our model.

4.4 Separate Analysis (on each variable in our model):

4.4.1 Investment in Industrial Pollution

For studying the individual effects of specific policies or interventions on the local economic developments, as well as quantifying the effects of each individual policy in a more accurate and detailed way, we conducted DID analysis on GRP for each variable separately, in which we can also visually witness the changes in economic impacts led by each variable both before and after the treatment of the renewable energy policy.

Firstly, for the variable of “Investment Completed in the Treatment of Industrial Pollution”, the result changed from insignifiance to significance after the treatment:

$$GRP_{it} = \alpha + \beta * Post_t * Treatment_i + \gamma_1 * X_1 it + \delta_t + \lambda_i + \epsilon_{it}$$

Table 4

Separate Analysis

GRP and Investment Completed in the Treatment of Industrial Pollution				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−4,937,323.2154	452,038.4250	−10.9224	[1] 0.0000	(Intercept)
−11,742.1916	1,673.0383	−7.0185	[1] 0.0000	treatment
11,967.6543	2,860.0780	4.1844	[1] 0.0002	post_treatment
−0.0019	0.0048	−0.3984	0.6930	`Investment Completed in the Treatment of Industrial Pollution(10000 yuan)`
2,470.2350	225.0306	10.9773	[1] 0.0000	Year
−24,832.8247	2,870.0402	−8.6524	[1] 0.0000	treatmentpost_treatment

[1] Note: *** p < 0.01, ** p < 0.05, * p < 0.1, it shows the Separate DID Analysis only comparing variable GRP and Investment Completed in the Treatment of Industrial Pollution

Figure 8: Separate Analysis for GRP and Investment of Industrial Pollution

Where $\gamma_1 * X_1 it$,it solely represents the investment in industrial pollution abatement. Before the treatment, the estimated value is -1.898e-03, which suggests that the investment in industrial pollution abatement does not show significant effects on the dependent variable in our model. Through related literature, it is suggested that although the investment in industrial pollution abatement plays a positive role in improving economic developments, it cannot directly reflect on either economic growths or reduction (Imran, 2022). Instead, it is more reflected in other aspects like how higher investment in pollution abatement could possibly improve the environmental quality and health conditions of the public, and thus indirectly improve economic growths (Imran, 2022). Thus, the result is not significant. However, after the treatment, the estimated value is -2.483e+04, which means that there is a relatively large negative effect of the treatment on the control group. As a result of the implementation of the renewable energy policy, the energy sector is more mature, and companies that invest in pollution treatment are able to improve their operational efficiency and reduce long-term operating costs (Qian, 2021). For example, reducing energy consumption by improving energy efficiency, or by recycling and utilizing waste resources, can reduce raw material costs and thus directly improve economic development (Qian, 2021). Since the meaning of this variable is very close to that of the variables about the investment in energy industry and the investment completed in the treatment of waste gas, it can be seen that the degrees of their significance stay consistent in the periods before and after the treatment.

4.4.2 Consumption of Electricity

Then, for the variable of "Consumption of Electricity", the result shifts from being positively significant to being negatively significant after the treatment:

$$GRP_{it} = \alpha + \beta * Post_t * Treatment_i + \gamma_1 * X_1 it + \delta_t + \lambda_i + \epsilon_{it}$$

Table 5

Separate Analysis

GRP and Consumption of Electricity				
Estimate	Std. Error	t value	Pr(>|t|)	Term
330,793.7652	304,830.6071	1.0852	0.2860	(Intercept)
3,379.7611	925.0154	3.6537	[1] 0.0009	treatment
5,165.6942	872.6084	5.9198	[1] 0.0000	post_treatment
15.2589	0.8011	19.0474	[1] 0.0000	`Consumption of Electricity(100 million kwh)`
−171.6533	152.6548	−1.1245	0.2692	Year
−3,965.1492	1,297.5293	−3.0559	[1] 0.0045	treatmentpost_treatment

[1] Note: *** p < 0.01, ** p < 0.05, * p < 0.1, it shows the Separate DID Analysis only comparing variable GRP and Consumption of Electricity

Figure 9: Separate Analysis for GRP and Consumption of Electricity

Where $\gamma_1 * X_1 it$,it represents only the electricity consmption, and its estimtaed value if 15.26, with the p vlaue far below 0.01, which shows a highly significant positive effect. As suggested by Zhang, electricity provides the sustainable power for economic and social development, and the increase of electricity consumption has further promoted the progress of the industrial economy of China, which could surely raise GRP levels (Zhang, 2017). And in that contemporary period, electricity mainly relied on fossil energy as the dominant energy form, like coal and natural gas, which are generally low-cost energy sources that could support a mushrooming in economic expansion (Zhang, 2017). Therefore, before the treatment of the renewable energy policy, the consumption of electricity is positively related to economic developments, while reflecting a growth pattern based on traditional energy sources.

While after the treatment, the estimated value is -3.965e+03, with the p value of 0.004501, which is an exceedingly significant negative effect. It has been studied that the environmental-friendly policy, like the implementation of renewable energy policy in China in 2013, could effectively reduce the electricity consumption by improving the situation of how these resource-rich regions are generally prone to resources curses through the crowing-out effect of human capital, technological innovation, and manufacturing (Qian, 2021). This means that now the same or even less amount of electricity is consumed for higher economic outputs, which exactly accords with our finding of the negative relationship between the consumption of electricity and GRP growths. While at the beginning of the transformation, popularizing the applications of renewable energy increases electricity costs, based on the fact that turning the resource curse into resource blessing requires time and costs that are way higher than what it took when we relied heavily on traditional energy for periods (Qian, 2021). Such high costs may have suppressed the growths of some power-intensive industries, making increases in electricity consumption no longer directly linked to economic expansion.

4.4.3 GRP Itself Without Adding Independent Variables:

$$GRP_{it} = \alpha + \beta * Post_t * Treatment_i + \delta_t + \lambda_i + \epsilon_{it}$$

Table 6

Separate DID

GRP without other variable				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−4,930,593.9200	445,927.3731	−11.0569	[1] 0.0000	(Intercept)
−11,715.0673	1,650.2060	−7.0992	[1] 0.0000	treatment
11,749.8600	2,771.3206	4.2398	[1] 0.0002	post_treatment
2,466.6319	221.9641	11.1128	[1] 0.0000	Year
−24,328.8702	2,543.1382	−9.5665	[1] 0.0000	treatmentpost_treatment

[1] Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, it shows the Separate DID Analysis only comparing GRP with no other chosen variable

Figure 10: Separate Analysis for GRP Without Other Factors

The estimated value for "post_treatment" is -24,329, with the p value below 2.2e-16. This means that after the intervention, comparing the treatment group with the control group before the intervention, the GRP levels decrease by approximately 24,329 million RMB, which is a very remarkable change. This result indicates that the policy intervention may take time to come into play, that is, in the short term, the implementation of this new policy may involve the direct costs of the transition from traditional energy sources to clean energy, such as the construction of new energy infrastructure, the renovation or elimination of old facilities, and the development and application of new technologies. Just like what is suggested by previous studies, the issuing of a certain policy might have a hysteretic nature in terms of its effects in economic developments (Qian, 2021). So, these transition costs could possibly lead to slower GRP growths in the short term, as reflected in the negative values of intercept terms both before and after the treatment. But in the long term, this transition into the applications of renewable energy is essential for achieving the sustainable developments, reducing environmental pollution, and coping with climate changes. And after dealing with the hysteretic nature of the policy, as the technology for renewable energy becomes more mature and less costly, as well as how the implementation of this policy raises the awareness of people on environmental protection, the economic patterns in the province of Zhejiang and other regions of China are expected to become greener, more efficient, and more sustainable finally, just like how Qian illustrates the process of resource curses turning into resource blessings in the contemporary period of China (Qian, 2021).

4.5 The Limitations of Results:

There are not enough variables included in this model, in which only some specific economic factors, such as electricity consumption and investments in industrial pollution abatement, are involved. This could ignore other potential factors in affecting the gross regional product (GRP) of certain regions of China, such as the population and technology, which could lead to omitted variable bias. For instance, assuming that in the periods before and after the policy intervention, technological progress is one of the key factors driving local economic growths, which enables the same amount of inputs (e.g., labor, capital, energy, etc.) to produce higher economic output. While the electricity consumption is often closely related to technological progress, and the application of new technologies often requires larger electricity consumption, especially in the cases of information technology and automated production, which can also assist these areas in carrying out energy transformation (Zhang, 2017). Thus, if our model does not include the variable of technological progress, then there will be an overestimation of the effects of electricity consumption on GRP growths and thus incorrect estimations on the costs of regional transformation, since the increase in electricity consumption cannot be directly reflected in the improvements of the application of new technologies.

5 Conclusion

5.1 Summary of results:

This paper serves as a comprehensive overview and exploration of the relationship between the implementation of the renewable energy policy and regional economic developments, in the context of China's transformation in 2013. According to our results, the consumption of various fossil energies, electricity consumption, investments in environmental industries, and investments in pollution abatement, all have a significant impact on the gross regional product (GRP). Moreover, with respect to the differences in fossil-energy-dependence in treatment and control groups, these impacts are relatively different. More precisely, for the province of Zhejiang being the treatment group in our model, it is found that the transformation into the applications of renewable energy could effectively improve the GRP growths. Given the high significance of the correlation found between the energy consumption and GRP levels, it can be stated that every increase in power production efficiency will be directly converted into an increase in the gross regional product (GRP). And as for negative correlation between the fossil energy consumption index and GRP, it also implicitly shows that a particular region does not rely on fossil energy, and instead, tends to get rid of the use of fossil energy, which corresponds with the positively significant effect of pollution regulation and investments in the treatment of industrial pollution on GRP levels, making the energy transformation of this specific region perform a strong positive impact on the GRP. On the other hand, for the province of Liaoning being the control group in our model, given the negative and nearly significant estimate fir the coal consumption in our model, it is illustrated that increases in the consumption of coal is likely to lead to decreases in GRP growths of any specific regions in our model, which could be explained by the low efficiency of the fossil energy, as well as its connection to the environmental quality (Fan, 2022). Although, as suggested by our findings, the environmental protection does not have a direct and significant impact on GRP levels considering the insignificant results associated with the variable about investments in environmental abatement, governmental spending on protecting the environment is still required to promote China's contemporary goal of sustainable developments, which then explains the reductions in GRP (Qian, 2021). While if taking into account the well-developed heavy industry and the overdependence on the energy supply by coal of the province of Liaoning, caused by its issues left over by the regional history, as well as the significantly positive relationship between the electricity consumption and GRP (as the estimated value is 1.336e+01, p value is 1.22e-05), then the power generation by electricity is illustrated to be very effective for improvements in GRP. Thus, considering all factors mentioned above, the conflict of the dependence on fossil energy for power generation and accompanying detrimental effects on the environment and then high costs on the corresponding environmental abatement is what the province of Liaoning had to face, which suggests that this energy transformation is not beneficial for GRP growths in Liaoning, that may turn into a long-term issue for the local governments.

5.2 Main contributions of the results to the literature:

Firstly, different from most of the previous literature, two specific regions of China are studied in this paper, with the provinces of Zhejiang and Liaoning being the treatment group and control group respectively. This degree of precision outperforms other articles about China's energy transformation in the contemporary periods, like how Qian's paper only discusses the reactions of coal-mining cities of China to the renewable energy policy, as well as how Smith suggests the positive effects of exploitation of natural resources on GDP per capita without look specifically into the renewable energies (Qian, 2021; Smith, 2015). More specifically, as the regional differences in terms of the effects of energy policy are revealed through our model, the powerful role that historical legacies could play in affecting the energy structures and future economic developments of any specific regions in a developing economy is witnessed. In this way, this paper also contributes significantly to the previous literature, by including the consideration of the effects of historical periods, rather than solely focusing on that contemporary period of China's energy transformation like most articles did.

5.3 Limitations of the study:

Firstly, with respect to our data, a number of data are missing, since the data comes from China' s official website – National Bureau of Statistics of China website, in which their datasets are not updated frequently enough for us to find appropriate statistics that correspond with certain time periods in our study. So, when organizing our data in the later stages, our data were extracted from several different data websites for corresponding years, which could possibly result in deviations from obtained values to actual values, due to the differences in the initial data statistics and sources, and thus lead to some discrepancies in our model.

What's more, since our study mainly sheds light on the impacts of the policy intervention on economic developments in the short term in the case of China, the long-term effects of the policy intervention have not been fully explored and discussed. It is commonly known that whether the energy transformation or policy effectiveness requires long-term processes for its economic, social and environmental impacts to fully emerge. This is also why we witnessed a series of negative effects of the energy transformation on both the treatment and control groups in the short term, like increased costs in many energy-related industries, rising unemployment rates, environmental degradation, and so forth. However, in the long run, the implementation of renewable energy policy could significantly reduce greenhouse gas emissions and improve the environmental quality, with gradually replacing traditional industries with emerging industries, and finally stimulating economic developments. Unfortunately, these factors are not summarized by the model, so that we are unable to explain these changes.

5.4 Policy Implications:

Our study, through distinguishing between fossil-energy-dependent regions and non-dependent regions of China, has deeply involved into the discussions of the specific impacts of renewable energy policy in different districts, which also reveals the regional differences in terms of the effects of the energy policy. By exploring the issues associated with regional historical legacies, as well as their impacts on the emerging economies at different levels, it can be inferred that blindly applying the systems and policies of developed economies is not feasible for the developing economies. Like in the case of China, we must put ourselves into that position and customize specific policies that are exclusive to a certain developing economy through involving the regional historical analysis. Just like how the treatment group (the province of Zhejiang) could better adapt to the energy transformation comparing with the control group (the province of Liaoning), in terms of the dependence on fossil energy, so that this policy could be implemented smoothly and effectively in that area. But for the control group (the province of Liaoning), facing the huge transformation costs due to historical issues, energy transformation should then be considered as a long-term strategic goal development, as it is not suitable for a short-term radical transformation.

6 References

Aisyah, S., Suarmanayasa, I. N., Efendi, E., Widiastuti, B. R., & Harsono, I. (2024). The impact of fiscal policy on economic growth: A case study of indonesia. Management Studies and Entrepreneurship Journal (MSEJ). https://yrpipku.com/journal/index.php/msej/article/view/4619
Dwi Taruko Putri & Azwardi Azwardi & Taufiq Marwa & Sri Andaiyani. (2018). Does government spending drive regional economic growth?. International Journal of Economics and

Financial Issues. https://ideas.repec.org/a/eco/journ1/2018-05-33.html Anwar, A., Sriyana, J., & Shidiqie, J. (2020). The impact of government spending spillovers on regional economic growth. Montenegrin Journal of Economics, 16(2), 59–76. https://doi.org/10.14254/1800-5845/2020.16-2.5 Hao, Y., Peng, H., Temulun, T., Liu, L.-Q., Mao, J., Lu, Z.-N., & Chen, H. (2018). How harmful is air pollution to economic development? new evidence from PM2.5 concentrations of Chinese cities. Journal of Cleaner Production, 172, 743–757. https://doi.org/10.1016/j.jclepro.2017.10.195 Qian, X., Wang, D., Wang, J., & Chen, S. (2021). Resource curse, environmental regulation and transformation of coal-mining cities in China. Resources Policy, 74, 101447. https://doi.org/10.1016/j.resourpol.2019.101447 Zhang, C., Zhou, K., Yang, S., & Shao, Z. (2017). On electricity consumption and economic growth in China (Vol. 76, pp. 353–368). essay. Imran, M., Hayat, N., Saeed, M. A., Sattar, A., & Wahab, S. (2022). Spatial Green Growth in China: Exploring the Positive Role of Investment in the Treatment of Industrial Pollution. https://doi.org/10.21203/rs.3.rs-1796293/v1 Xin, D., & Xin, L. (2022). The impact of economic policy uncertainty on PM2.5 pollution—evidence from 25 countries. Environmental Science and Pollution Research, 29(25), 38126–38142. https://doi.org/10.1007/s11356-022-18599-z Fan, W., Yan, L., Chen, B., Ding, W., & Wang, P. (2022). Environmental governance effects of local environmental protection expenditure in China. Resources Policy, 77, 102760. https://doi.org/10.1016/j.resourpol.2022.102760 Zhou, X., Zhang, J., & Li, J. (2013). Industrial Structural Transformation and carbon dioxide emissions in China. Energy Policy, 57, 43–51. https://doi.org/10.1016/j.enpol.2012.07.017 Smith, B. (2015). The resource curse exorcised: Evidence from a panel of countries. Journal of Development Economics, 116, 57–73. https://doi.org/10.1016/j.jdeveco.2015.04.001 Sarmidi, T., Hook Law, S., & Jafari, Y. (2013). Resource curse: New evidence on the role of Institutions. International Economic Journal, 28(1), 191–206. https://doi.org/10.1080/10168737.2013.787110 China Coal Nuclear EV Map. Baker Institute. (2024). https://www.bakerinstitute.org/china-coal-nuclear-ev-map

7 Table and Graph

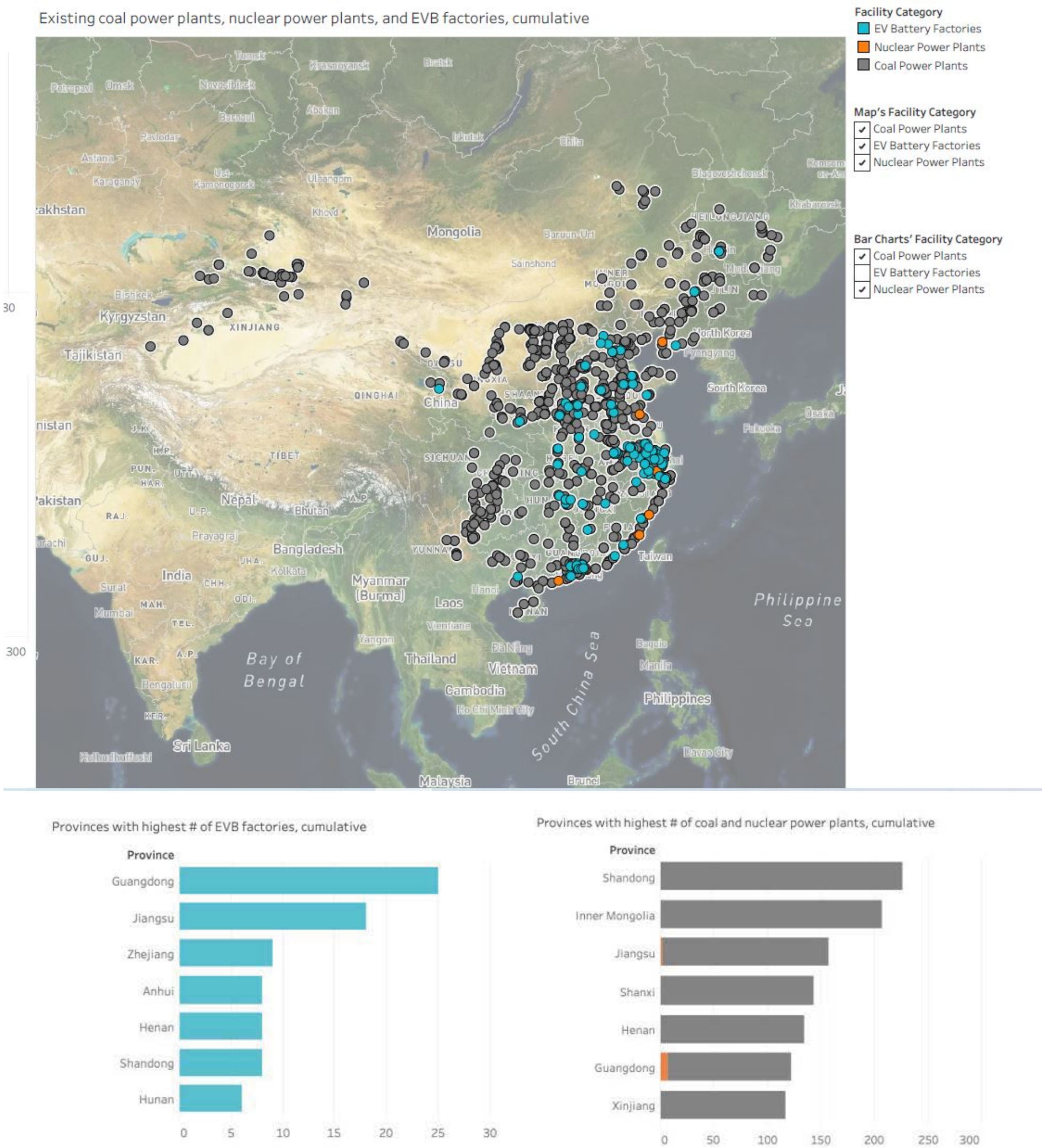


Table 1

Comprehensive Analysis for Zhejiang

GRP and Environmental Factors				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−1,966,874.3119	911,561.7919	−2.1577	[1] 0.0563	(Intercept)
8,033.2713	2,216.2240	3.6248	[1] 0.0047	treatment
2,404.0154	1,121.4256	2.1437	[1] 0.0577	post_treatment
−1.2833	0.6105	−2.1019	[1] 0.0619	\`Consumption of Coal(10000 tons)\`
−1.7300	1.4668	−1.1795	0.2655	\`Consumption of Coke(10000 tons)\`
13.3562	1.6759	7.9693	[1] 0.0000	\`Consumption of Electricity(100 million kwh)\`
1.6807	1.7656	0.9519	0.3636	\`Investment in Energy Industry(100 million yuan)\`
−0.0033	0.0022	−1.4862	0.1681	\`Investment Completed in the Treatment of Industrial Pollution(10000 yuan)\`
−0.0017	0.0042	−0.4061	0.6932	\`Investment Completed in the Treatment of Waste Gas(10000 yuan)\`
24.7352	15.9043	1.5553	0.1509	\`Sulphur Dioxide Emission in Waste Gas(10000 tons)\`
100.4660	62.9460	1.5961	0.1416	\`PM2.5 index\`
−1.5889	6.4488	−0.2464	0.8104	\`Local Governments Expenditure Environmental Protection(100 million yuan)\`
980.0006	456.7643	2.1455	[1] 0.0575	Year
−4,283.8091	1,808.2763	−2.3690	[1] 0.0393	treatment:post_treatment

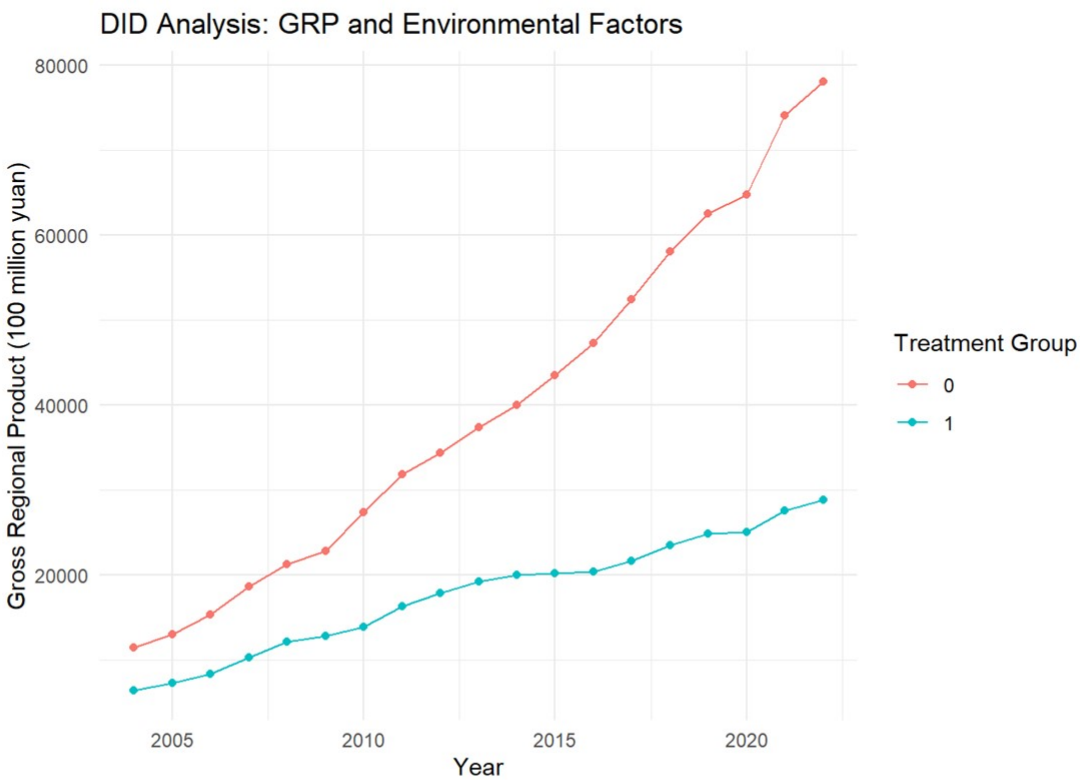
[1] Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, it shows the Comprehensive DiD analysis comparing all factors and GRP for treatment grout Zhejiang

Table 2

Comprehensive DiD analysis for Liaoning

GRP and Environmental Factors				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−1,966,874.3119	911,561.7919	−2.1577	[1] 0.0563	(Intercept)
8,033.2713	2,216.2240	3.6248	[1] 0.0047	treatment
2,404.0154	1,121.4256	2.1437	[1] 0.0577	post_treatment
−1.2833	0.6105	−2.1019	[1] 0.0619	`Consumption of Coal(10000 tons)`
−1.7300	1.4668	−1.1795	0.2655	`Consumption of Coke(10000 tons)`
13.3562	1.6759	7.9693	[1] 0.0000	`Consumption of Electricity(100 million kwh)`
1.6807	1.7656	0.9519	0.3636	`Investment in Energy Industry(100 million yuan)`
−0.0033	0.0022	−1.4862	0.1681	`Investment Completed in the Treatment of Industrial Pollution(10000 yuan)`
−0.0017	0.0042	−0.4061	0.6932	`Investment Completed in the Treatment of Waste Gas(10000 yuan)`
24.7352	15.9043	1.5553	0.1509	`Sulphur Dioxide Emission in Waste Gas(10000 tons)`
100.4660	62.9460	1.5961	0.1416	`PM2.5 index`
−1.5889	6.4488	−0.2464	0.8104	`Local Governments Expenditure Environmental Protection(100 million yuan)`
980.0006	456.7643	2.1455	[1] 0.0575	Year
−4,283.8091	1,808.2763	−2.3690	[1] 0.0393	treatment:post_treatment

[1] Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$,it shows the Comprehensive DiD analysis comparing all factors and GRP for control group grout Liaoning


DID Analysis: GRP and Environmental Factors
Gross Regional Product (100 million yuan)
80000
60000
40000
20000
2005
2010
2015
2020
Year
Treatment Group
0
1

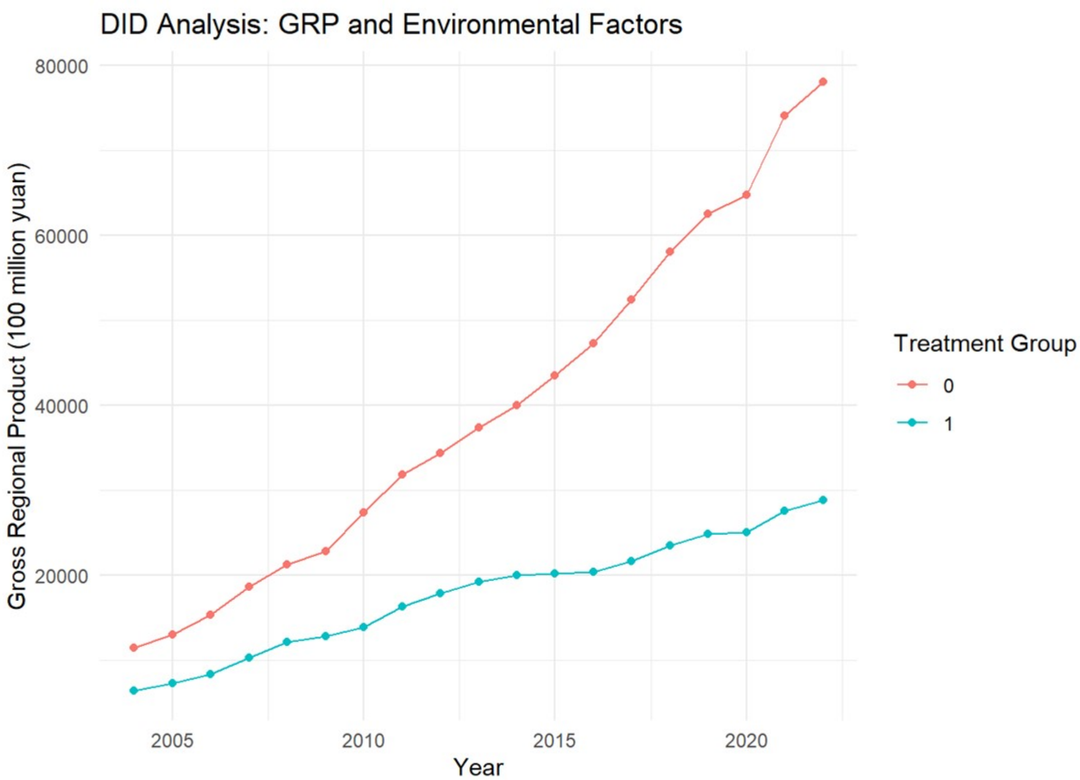


Table 4

Separate Analysis

GRP and Investment Completed in the Treatment of Industrial Pollution				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−4,937,323.2154	452,038.4250	−10.9224	[1] 0.0000	(Intercept)
−11,742.1916	1,673.0383	−7.0185	[1] 0.0000	treatment
11,967.6543	2,860.0780	4.1844	[1] 0.0002	post_treatment
−0.0019	0.0048	−0.3984	0.6930	`Investment Completed in the Treatment of Industrial Pollution(10000 yuan)`
2,470.2350	225.0306	10.9773	[1] 0.0000	Year
−24,832.8247	2,870.0402	−8.6524	[1] 0.0000	treatment:post_treatment

[1] Note: *** p < 0.01, ** p < 0.05, * p < 0.1, it shows the Separate DID Analysis only comparing variable GRP and Investment Completed in the Treatment of Industrial Pollution

Table 5

Separate Analysis

GRP and Consumption of Electricity				
Estimate	Std. Error	t value	Pr(>|t|)	Term
330,793.7652	304,830.6071	1.0852	0.2860	(Intercept)
3,379.7611	925.0154	3.6537	[1] 0.0009	treatment
5,165.6942	872.6084	5.9198	[1] 0.0000	post_treatment
15.2589	0.8011	19.0474	[1] 0.0000	`Consumption of Electricity(100 million kwh)`
−171.6533	152.6548	−1.1245	0.2692	Year
−3,965.1492	1,297.5293	−3.0559	[1] 0.0045	treatmentpost_treatment

[1] Note: *** p < 0.01, ** p < 0.05, * p < 0.1, it shows the Separate DID Analysis only comparing variable GRP and Consumption of Electricity

Table 6

Separate DID

GRP without other variable				
Estimate	Std. Error	t value	Pr(>|t|)	Term
−4,930,593.9200	445,927.3731	−11.0569	[1] 0.0000	(Intercept)
−11,715.0673	1,650.2060	−7.0992	[1] 0.0000	treatment
11,749.8600	2,771.3206	4.2398	[1] 0.0002	post_treatment
2,466.6319	221.9641	11.1128	[1] 0.0000	Year
−24,328.8702	2,543.1382	−9.5665	[1] 0.0000	treatmentpost_treatment

[1] Note: *** p < 0.01, ** p < 0.05, * p < 0.1, it shows the Separate DID Analysis only comparing GRP with no other chosen variable