Article

The Role of Renewable Energy Consumption in Promoting Sustainability and Circular Economy. A Data-Driven Analysis

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Abstract: In this article we investigate the role of "*Renewable Energy Consumption*" in the context of Circular Economy. We use data from the World Bank for 193 countries in the period 2011-2020. We perform several econometric techniques i.e., Panel Data with Fixed Effects, Panel Data with Random Effects, Pooled OLS, WLS. Our results show that "*Renewable Energy Consumption*" is positively associated among others to "*Cooling Degree Days*" and "*Adjusted savings: net forest depletion*" and negatively associated among others to "*GHG net emissions/removals by LUCF*" and "*Mean Drought Index*". Furthermore, we perform a cluster analysis with the application of the k-Means algorithm optimized with the Silhouette Coefficient and we find the presence of two clusters. Finally, we compare eight different machine learning algorithms to predict the value of Renewable Energy Consumption. Our results show that the Polynomial Regression is the best algorithm in the sense of prediction and that on average the renewable energy consumption is expected to growth of 2.61%.

JEL CODE: Q5, Q50, Q51, Q52, Q53.

Keywords: Environmental Economics; General; Valuation of Environmental Effects; Pollution Control Adoption and Costs; Recycling.

1. Introduction-Research Question

In the following article we analyze the role of renewable energy consumption in the context of the circular economy with attention to environmental sustainability. The reasons that prompted us to tackle this analysis consist on the one hand in the empirical evidence of the existence of climate change and on the other hand in the international economic policies that increasingly push states to invest in the green economy. Finally, it is necessary to consider the role of economic science which has always warned about the negative externalities generated in connection with pollution. Certainly, the link between economic growth led by industry and pollution is a historical fact of the capitalist development of all countries. Even in Europe, at the origins of capitalism, pollution destroyed rivers, forests, polluted cities and destroyed entire populations. Awareness about the need to introduce green elements into capitalism is therefore not just a trend of generation Z but rather a real long-term need first of Western civilization and then of global civilization.

Of course, renewable energies have received a lot of funding and subsidies in both developing and industrialized countries. However, there are many doubts about the possibility of relying totally on the energy efficiency of renewables. In fact, many countries that grow a lot in terms of GDP continue to pollute. The use of non-renewable forms of energy and the related CO2 production are inextricably linked to economic growth. It is

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therefore difficult to propose to newly industrialized countries, especially Asian countries, a total transition to renewable energy. In fact, the need to get out of poverty, underdevelopment, ignorance, and hunger could overshadow the environmental and renewables issues in many low-income countries.

Furthermore, it must also be considered that the current state of technological knowledge does not allow for the creation of renewables that can fully replace non-renewable energies. However, it is very probable that in a medium-long term it will be very probable to increase the efficiency and production of renewables. In this regard, it must also be considered that for example the issue of energy storage, currently still unresolved from a technological and economic point of view, could greatly help renewables, which are often subject to seasonality. Furthermore, new discoveries in the physical field could lead to the knowledge of new energies, such as dark energies, connected to dark matter, which could open up absolutely new and unpredictable energy scenarios. It is therefore very probable that investments in green-tech can make renewable energies much more advanced and efficient in the future, creating the conditions for a reduction in the use of non-renewables.

Certainly, in the scientific literature presented in the article, the idea of the existence of the Environmental Kuznets Curve-EKC is often used, which is a type of curve that describes the transition to sustainability because of per capita income. The EKC curve is an inverted U-shaped curve. In the beginning, per capita income and pollution grow together to a maximum. Beyond the maximum point, the further growth of per capita GDP generates a reduction in pollution. This curve is much discussed and much criticized. Certainly at an ideal level it could be understood as a theoretical reference. But it is also true that, many highly developed countries, such as the USA for example, have levels of pollution and CO2 emissions that are still very high despite the growth of the gross domestic product. It is therefore clear that the application of the EKC is not a historical necessity, but rather the consequence of environmental economic policies that are oriented towards investment and the application of new technologies capable of producing renewable energy.

Therefore, even knowing there are many doubts and many economic policy discussions on the application of renewable energies, we nevertheless wanted to address the issue as we believe that renewables will certainly be a very important trend in the future of the development of globalization and international economics.

The article proceeds as follows: the second paragraph contains the strategy of the applied methodology, the third paragraph presents a brief analysis of the literature, the fourth paragraph presents the results of the econometric analysis, the fifth paragraph contains the clustering analysis, the sixth paragraph presents the machine learning algorithms for prediction, seventh paragraph discusses the results, eighth paragraph concludes.

2. Methodological Strategy for the Investigation of the Renewable Energy Consumption

From a methodological point of view, a large set of analytical tools was used for the investigation of the presented dataset. The data used in the analysis refer to the World Bank's ESG database. The database analyzes 193 countries in a period between 2011 and 2020. The following analytical tools were used, namely:

- *Regression with panel data models*: regression models were used to verify the presence of a relationship between the dataset variables. Various panel regression models were used, i.e. panel models with Fixed Effects, panel models with Random Effects, Pooled OLS and WLS. The regression analysis is necessary to identify the relationships between the variables which are also compared with the results of the literature to verify the presence of innovations or possible confirmations of the theoretical results. Obviously, only the variables statistically significant in terms of p-value were considered.

- *Clustering with k-Means algorithm*: then clustering with k-Means algorithm was used. Clustering is required to check for clustering in the data. However, to find the optimal number of k it was necessary to use optimization tools. In particular, the Silhouette coefficient was used. The Silhouette coefficient is a value that varies from -1 to +1 and manifests the ability of an element to stay within a certain cluster. That is, given a certain element of the distribution, the closer the value of the Silhouette coefficient is to 1, the more the attribution of the element to the cluster is correct. Obviously, once the number of k has been set, it is verified that there are no elements close to zero or negative. If all the elements have a positive value in terms of Silhouette coefficient, then it is possible to consider the clustering correct.
- *Prediction with Machine Learning algorithms*: it is used to predict the future trend of renewable energy consumption. Eight different algorithms are compared among which a choice is made based on the maximization of the R-squared and the minimization of the main statistical errors. Prediction offers the possibility of identifying future elements that could anticipate future trends.

The set of methodological elements identified allows to have a complete picture of the development of the consumption of renewable energies, both in the context of the ESG variables of the WB, and in the context of clustering and finally with attention to prediction.

3. Literature Review

A brief analysis of the scientific literature related to renewable energy consumption is presented below. The analysis highlights very contradictory results. In fact, some results highlight the role of renewable energy consumption for the reduction of pollution from CO_2 emissions, others highlight how it is not possible to identify a clear impact of renewable energy in the sense of economic growth. However, it should be noted that the studies presented consider both developing and industrialized countries. Obviously, it is more difficult for developing countries to access renewable energy while remaining on the path of economic growth. In fact, at present it seems that it is not possible for a country to grow without polluting. The use of renewable energies, on the other hand, tends to be an objective of economic policy especially for middle-high income countries for more ethical-moral than economic-financial reasons.

[1] highlight the relationship between the use of non-renewable energy and the growth of carbon dioxide emissions. The authors analyze the case of Pakistan for the period 1970-2022. The results are tested using the Granger Causality tool. [2] analyze the connection between economic complexity, i.e. the knowledge based economic structure of the economy, and the renewable and non-renewable energy consumption. Authors consider 14 European Countries in the period 1990-2017. Results show that economic complexity increase renewable energy consumption and decrease non-renewable energy consumption. [3] show the presence of a positive association between renewable energy consumption and the reduction of CO_2 emission in Pakistan in the period 1975-2016. The authors refuse the hypothesis of the inverted U-shaped Kuznets Environmental Curve-KEC and they find that GDP growth and Foreign Direct Investment-FDI inflows increase the level of pollution at country level. Finally, the article suggests that improving the renewable energy consumption can have better results on reduction of CO_2 emission in respect to regulation and environmental compliance. [4] consider the impact of urbanization on GDP per capita and non-renewable energy consumption in 110 countries for the period 1971-2017. The authors find that non-renewable energy consumption Granger cause urbanization for all levels of real per capita income. [5] find a positive relationship between GDP growth and non-renewable consumption for ten South America Countries in the period 1971-2014. [6] analyzes the relationship among economic growth, renewable energy consumption and CO_2 emissions in Turkey during the period 1974-2014. The authors ap-

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ply several cointegration test. Results are twofold. On one side, the results show that economic growth generates CO2 emissions as a consequence of urbanization and financial development and on the other hand renewable energy consumption has no effect on the reduction of CO2 emissions. The research question recognizes the validity of the Kuznets Environmental Curve-KEC as an assumption. The authors conclude that the Turkish economy has not reached the level of GDP per capital required to reduce the level of CO2 according to KEC. [7] consider the socio-economic determinants that can sustain the improvement in renewable energy consumption for 32 Sub-Saharian Africa in period 1990-2015. Results show that renewable energy consumption is positively associated with advancement in technology, quality of governance, economic progress, biomass consumption, and climatic conditions. However, the authors also find some characteristics that can reduce the renewable energy consumption i.e. urbanization and economic globalization. [8] consider the impact of an environmental tax on the increase of renewable energy consumption. The authors consider various countries along the Belt and Road-B&R in the period 1998-2019. The results shows that the existence of a negative relationship between the environmental tax and the renewable energy consumption in the short-run. In the long-run the increase in 1% in the environmental tax improve the level of renewable energy consumption of 1.2%. The authors apply the Pooled Mean Group Estimator-PMGE. [9] verify the presence of a positive relationship between the consumption of renewable energy, the reduction of CO2 and the increase in GDP per capita in 16 Latin America and Caribbean countries in the period 1990-2015. Results convalidate the existence of an Environmental Kuznets Curve for the observed countries. [10] the renewable energy consumption has a positive relationship with total trade, imports and exports in a set of 35 OECD countries in the period 1999-2018. The results suggest that an increase in the degree of trade openness can promote renewable energy consumption at least in in high-income per capita countries. [11] find the presence of a positive relationship between renewable energy consumption and international trade in the short-term. The authors analyse the case of Tunisia in the period 1980-2011 using ARDL and cointegration test. [12] analyze the economic determinants of the renewable energy consumption in Ghana. The authors find that in the long-run, the level of renewable energy consumption grows with price, income and financial development, while in the short-run, the degree of renewable energy consumption is positively associated to industrialization and financial development. [13] analyses the relationship between economic growth and energy consumption in Algeria in the period 1980-2012. The authors use Autoregressive Distributed Lag-ARDL and find the presence of a positive relationship between economic growth and non-renewable energy consumption while there is no significant effect of renewable energy consumption on economic growth.

[14] find a positive relationship between economic growth, CO2 emissions and renewable energy consumption. But while the relationship between economic growth and CO2 emission is bidirectional, the relationship between economic growth and renewable energy consumption is unidirectional. [15] show the presence of a positive relationship between renewable energy consumption and sustainable development in 16 EU countries in the period 1997-2014. [16] consider the presence of a positive relationship between renewable energy consumption and the reduction of CO2 emissions in G-7 countries. The authors verify the presence of the Environmental Kuznets Curve-EKC. The positive relationship between renewable energy consumption and CO2 emissions is mediated by the effect of renewable energy consumption on energy prices. [17] find a positive relationship between board gender diversity and renewable energy consumption in a panel of 11.677 firms operating in USA in the period 2008-2016. The authors also show the positive impact of board gender diversity and renewable energy consumption on firm financial performance. [18] analyze the presence of a negative relationship between renewable energy consumption and economic growth in 15 West African countries in the period 1995-2014. The negative counterfactual relationship is due to the specific typology of renewable energy used i.e. wood biomass. The authors conclude that others renewable energy such as

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solar, wind and geothermal energy, could be more efficient in promoting either environmental sustainability either economic growth. [19] show the of two relevant effects in a global panel of 192 countries. On one side there is a negative relationship between renewable energy consumption and carbon emission, and on the other side there is positive impact of renewable energy consumption on financial development. [20] find the absence of a Granger causality between renewable energy consumption and economic growth.

Synthesis of the Literature Review

Article	Main Findings	Country	Period	Tools and Methodological Issues
Zhang, B., Wang, B., & Wang, Z. (2017). Role of renewable energy and non-renewable energy consumption on EKC: evidence from Pakistan. Journal of Cleaner Production, 156, 855-864. ISO 690	A positive relationship between the consumption of non-renewable energy and the increase of CO2 emissions.	Pakistan	1970-2022	Granger Causality
Can, M., & Ahmed, Z. (2022). Towards sustainable development in the European Union countries: Does economic complexity affect renewable and non-renewable energy consumption?. Sustainable Development.	A positive relationship between economic complexity and the increase in renewable energy consumption.	14 European countries	1990-2017	Granger Causality
Naz, S., Sultan, R., Zaman, K., Aldakhil, A. M., Nassani, A. A., & Abro, M. M. Q. (2019). Moderating and mediating role of renewable energy consumption, FDI inflows, and economic growth on carbon dioxide emissions: evidence from robust least square estimator. Environmental Science and Pollution Research, 26(3), 2806-2819.	A positive relationship between renewable energy consumption and the reduction of CO2 emissions.	Pakistan	1975-2016	Confutation of Kuznets Environmental Curve-KEC
Alvarado, R., Ortiz, C., Bravo, D., & Chamba, J. (2020). Urban concentration, non-renewable energy consumption, and output: do levels of economic development matter?. Environmental Science and Pollution Research, 27(3), 2760-2772.	A positive relationship between non-renewable energy consumption and real income per capita in the context of accelerated urbanization.	110 countries	1971-2017	Cointegration and Granger Causality
Deng, Q., Alvarado, R., Toledo, E., & Caraguay, L. (2020). Greenhouse gas emissions, non-renewable energy consumption, and output in South America: the role of the productive structure. Environmental Science and Pollution Research, 27(13), 14477-14491.	A positive relationship between GDP growth and non-renewable energy consumption.	10 American Latina countries	1971-2014	Cointegration and causality technique.
Pata, U. K. (2018). Renewable energy consumption, urbanization, financial development, income and CO2 emissions in Turkey: testing EKC hypothesis with structural breaks. Journal of cleaner production, 187, 770-779.	Economic growth generates pollution. The renewable energy consumption does not reduce the level of CO2 emissions.	Turkey	1974-2014	Cointegration tests and causality techniques.
Baye, R. S., Olper, A., Ahenkan, A., Musah-Surugu, I. J., Anuga, S. W., & Darkwah, S. (2021). Renewable energy consumption in Africa: Evidence from a bias corrected dynamic panel. Science of the Total Environment, 766, 142583.	Renewable energy consumption is positively associated with advancement in technology, quality of governance, economic progress, biomass consumption, and climatic conditions.	32 Sub-Saharan Countries	1990-2015	Least Squares Dummy Variable Corrected
Bangake, C., & Eggoh, J. C. (2012). Pooled Mean Group estimation on international capital mobility in African countries. Research in Economics, 66(1), 7-17.	The environmental tax has a marginal positive effect on renewable energy consumption in the long-run and a negative one in the short-run.	15 countries of the Belt and Road-B&R	1998-2019	Pooled Mean Group Estimator-PMGE
Anser, M. K., Hanif, I., Alharthi, M., & Chaudhry, I. S. (2020). Impact of fossil fuels, renewable energy consumption and industrial growth on carbon emissions in Latin American and Caribbean economies. Atmósfera, 33(3), 201-213.	Renewable Energy Consumption is positively associated to CO2 emissions and GDP growth.	16 Latin America and Caribbean countries	1990-2015	Environmental Kuznets Curve-EKC
Zhang, M., Zhang, S., Lee, C. C., & Zhou, D. (2021). Effects of trade openness on renewable energy consumption in OECD countries: New insights from panel smooth transition regression modelling. Energy Economics, 104, 105649.	Find a positive relationship between the consumption of renewable energy and the degree of openness to international trade.	35 OECD countries	1999-2018	Panel Data Regression Models
Brini, R., Amara, M., & Jemmali, H. (2017). Renewable energy consumption, International trade, oil price and economic growth inter-linkages: The case of Tunisia. Renewable and Sustainable Energy Reviews, 76, 620-627.	There is a positive relationship between renewable energy consumption and international trade.	Tunisia	1980-2011	Autoregressive Distributed Lag-ARDL and cointegration test
Kwakwa, P. A. (2020). What determines renewable energy consumption? Startling evidence from Ghana. International Journal of Energy Sector Management.	In the long-run, the level of renewable energy consumption grows with price, income and financial development, while in the short-run, the degree of renewable energy consumption is positively associated to industrialization and financial development.	Ghana		
Amri, F. (2017). The relationship amongst energy consumption (renewable and non-renewable), and GDP in Algeria. Renewable and Sustainable Energy Reviews, 76, 62-71.	There is of a positive relationship between economic growth and non-renewable energy consumption while there is no significant effect of	Algeria	1980-2012	Autoregressive Distributed Lag-ARDL

	renewable energy consumption on economic growth.			
Radmehr, R., Henneberry, S. R., & Shayanmehr, S. (2021). Renewable energy consumption, CO2 emissions, and economic growth nexus: a simultaneity spatial modeling analysis of EU countries. Structural Change and Economic Dynamics, 57, 13-27.	A positive unidirectional relationship between economic growth and renewable energy consumption.	European Union Countries	1995-2014	Panel GMM and panel GS2SLS.
Alola, A. A., Bekun, F. V., & Sarkodie, S. A. (2019). Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Science of the Total Environment, 685, 702-709.	A positive relationship between renewable energy consumption and sustainable development	16 European Countries	1997-2014	PMG-ARDL
Ike, G. N., Usman, O., Alola, A. A., & Sarkodie, S. A. (2020). Environmental quality effects of income, energy prices and trade: the role of renewable energy consumption in G-7 countries. Science of The Total Environment, 721, 137813.	A positive indirect relationship between renewable energy consumption and CO2 emissions mediated through the impact on energy prices.	G-7 countries	United Kingdom (1970-2014), Germany (1970-2014). For the other five G7 countries 1960-2014.	Panel Data, Granger Causality, EKC.
Atif, M., Hossain, M., Alam, M. S., & Goergen, M. (2021). Does board gender diversity affect renewable energy consumption? Journal of Corporate Finance, 66, 101665.	A positive relationship between board gender diversity and renewable energy consumption.	USA	2008-2016	OLS, Lagged OLS.
Maji, I. K., Sulaiman, C., & Abdul-Rahim, A. S. (2019). Renewable energy consumption and economic growth nexus: A fresh evidence from West Africa. Energy Reports, 5, 384-392.	A negative relationship between wood biomass and economic growth.	15 West African countries.	1995-2014	Dynamic Ordinary Least Squares.
Khan, H., Khan, I., & Binh, T. T. (2020). The heterogeneity of renewable energy consumption, carbon emission and financial development in the globe: a panel quantile regression approach. Energy Reports, 6, 859-867.	A negative relationship between renewable energy consumption and CO2 emissions. A positive relationship between renewable energy consumption and financial development.	192 countries	1980-2018	Panel quantile regressions
Li, R., & Leung, G. C. (2021). The relationship between energy prices, economic growth and renewable energy consumption: Evidence from Europe. Energy Reports, 7, 1712-1719.	Find the absence of a Granger causality between renewable energy consumption and economic growth.	European Countries	1985–2018	Granger Causality

4. The Econometric Model for the Estimation of the Renewable Energy Consumption

We have used Panel Data with Random Effects, Panel Data with Fixed Effects, WLS, and Pooled OLS to estimate the value of renewable energy consumption in 193 countries for the period 2011 and 2020. We have estimated the following equation:

$$\begin{aligned}\boldsymbol{RenewableEnergyConsumption_{it}} &= \boldsymbol{a_1 + b_1(CoolingDegreeDays)_{it}}\\ &+ \boldsymbol{b_2(AdjustedSavingsNetForestDepletion)_{it}}\\ &+ \boldsymbol{b_3(AgricultureForestryAndFishing)_{it} + b_4(AgriculturalLand)_{it}}\\ &+ \boldsymbol{b_5(PM2.5AirPollution)_{it} + b_6(RenewableElectricityOutput)_{it}}\\ &+ \boldsymbol{b_7(ForestArea\ )_{it} + b_8(EnergyUse)_{it} + b_9(EnergyImports)_{it}}\\ &+ \boldsymbol{b_{10}(AccessToElectricity)_{it} + b_{11}(FossilFuelEnergyConsumption)_{it}}\\ &+ \boldsymbol{b_{12}(AdjustedSavingsNaturalResourcesDepletion)_{it}}\\ &+ \boldsymbol{b_{13}(CO2Emissions)_{it}}\\ &+ \boldsymbol{b_{14}(Maximum5day\ Rainfall25yearReturnLevel)_{it}}\\ &+ \boldsymbol{b_{15}(GHGnetEmissions/RemovalsbyLUCF)_{it}}\\ &+ \boldsymbol{b_{16}(MeanDroughtIndex\ )_{it}}\end{aligned}$$

$$\boldsymbol{Where\ i = 139\ and\ t = [2011; 2020]}$$

The value of Renewable Energy Consumption is positively associated to:

- *Cooling Degree Days:* it is a measurement designed to quantify the energy demand needed to cool buildings. It is the number of degrees that the average temperature of a day is above 18°C. There is a positive relationship between renewable energy consumption and the increase in days that have an average temperature above 18 degrees. This relationship can be better understood considering that the countries that have the greatest consumption of renewable energy are African or South Asian countries which therefore necessarily have a number of days with a high temperature above 18 degrees. Furthermore, the fact that the temperature is above 18 degrees leads to an increase in the use of air conditioning systems and therefore to an increase in the consumption of renewable energy. Obviously, the impact of climate change can also be identified in this dynamic of the growth in the number of degrees above 18 degrees. In fact, the adverse effects of global change could generate a further growth in the consumption of renewable energy due precisely to the need to cool buildings.

- *Adjusted savings: net forest depletion:* is calculated as the product of unit resource rents and the excess log harvest over natural growth. There is a positive relationship between the growth of renewable energy consumption and the net depletion of forests. This relationship can be better understood considering that the growth in the consumption of renewable energy may be due to the possibility of creating new plants for the production of renewable energy such as for example solar or wind energy. These systems can be located precisely in correspondence with wooded areas or forests. The result is a zero-sum game between the production of renewable energy necessary to support the consumption of renewable energy and the presence of wooded or forested areas. It should also be considered that the reduction of forest and wooded areas has an adverse impact on the reduction of the global temperature increase leading to an increase in energy consumption in general, including renewable energy.
- *Agriculture, forestry, and fishing, value added* considers the value of the gross domestic product deriving from agriculture, forestry and fishing as a percentage of GDP. There is a positive relationship between the value of renewable energy consumption and the development of gross national product from agriculture, forestry and fisheries. This positive relationship can be understood considering that the consumption of renewable energy can also be a tool for strengthening the economy of the primary sector. In fact, one of the characteristics of renewable energy consumption is that it is decentralized, that it grows mainly in rural and countryside areas and can therefore be highly compatible with the development of farms, which also operate in forestry and fishing. In fact, by reducing the costs of traditional energy, the consumption of renewable energy can allow a low-cost supply for agricultural businesses, also supporting them in the transformation processes.
- *Agricultural Land:* considers the value of agricultural land with respect to the share of arable land, with permanent crops and permanent pastures. Arable land includes land defined by the FAO as land under temporary crops, temporary grassland for mowing or grazing, market land or market gardens, and land temporarily fallow. Land abandoned due to cultivation shifts is excluded. Land under permanent crops is land planted with crops that use the land for long periods and do not need to be replanted after each harvest, such as cocoa, coffee, and rubber. Permanent pasture is land used for five or more years for forage, including natural and cultivated crops. There is a positive relationship between the value of land cultivated for agricultural purposes and the value of renewable energy consumption. This report indicates that the development of renewable energy makes it possible to reduce the prices of energy supply for agricultural enterprises by improving their production capacity and causing the expansion of agricultural enterprises.
- *PM2.5 air pollution, mean annual exposure:* considers the population's weighted exposure to environmental pollution from PM2.5. Such exposure is defined as the average level of exposure of a nation's population to concentrations of airborne particles measuring less than 2.5 microns in aerodynamic diameter, which are capable of penetrating deeply into the respiratory tract and causing serious damage to health. Exposure is calculated by weighting the average annual concentrations of PM2.5 by population in urban and rural areas. There is a positive relationship between the

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value of renewable energy consumption and the value of exposure to environmental pollution from PM2.5. This relationship indicates that the fact that countries consume more renewable energy does not necessarily free them from the need to also consume more polluting forms of energy. In fact, in order to consider the energy balance at the country level as a whole in terms of sustainability, it is necessary to consider the mix of energy sources and evaluate their impact in terms of negative externalities.

- *Renewable electricity output:* calculates the share of electricity generated by renewable energy plants in the total electricity generated by all types of plants. There is a positive relationship between the value of renewable energy production and the value of renewable energy consumption. This relationship may appear tautological in nature. Obviously, the possibility for companies and organizations to consume renewable energy also depends on the production capacity installed at the country level. Obviously, developing countries tend to be more oriented towards renewable energy both from the point of view of production and from the point of view of consumption, also because this type of energy is more convenient from an economic point of view than using traditional coal, gas or oil fired energy systems. From this derives the possibility of creating a green turnaround at the global level which is precisely induced by reasons of economic convenience and not only by ideological reasons regarding the climatic effects of the western-style capitalist industrial system.
- *Forest area:* describes land under natural woodland or planted trees of at least 5 meters in situ, whether productive or not, and excludes woodland in agricultural production systems and trees in urban parks and gardens. There is a positive relationship between the value of renewable energy consumption and the value of forest area. This relationship can be understood considering that the forest area understood in this variable does not take into consideration the land endowment that can be exploited for economic reasons through forestry or timber harvesting. There is therefore a positive relationship between the value of renewable energy consumption and the value of forest areas that cannot be exploited economically.
- *Energy Use:* refers to the consumption of primary energy before transformation into other end-use fuels, equal to domestic production plus imports and changes in stocks, minus exports and fuels supplied to ships and aircraft engaged in international transport. There is a positive relationship between the value of energy consumption and the value of energy use. The growth in energy use is particularly relevant especially for developing countries. In fact, one of the reasons that explain the gap between high-income countries and low per capita income countries is due to the growth in energy consumption. In this sense, it must be considered that obviously the growth of the consumption of renewable energy increases the consumption of energy at a quantitative level. However, the growth in the consumption of renewable energy also affects the improvement of the energy mix at the country level, creating the conditions for greater sustainability of the newly industrialized economic systems.

Econometric Estimation to Evaluate the Value of Renewable Energy Consumption										
		Pooled OLS		**Fixed Effects**		**Random Effects**		**WLS**		**Average**
		Coefficient	**p-Value**	**Coefficient**	**p-Value**	**Coefficient**	**p-Value**	**Coefficient**	**p-Value**	
	Constant	0,134603		0,864397		0,782813		-0,927839		0,2134935
A2	*Access to electricity (% of population)*	-0,0835935	***	-0,0801385	***	-0,0805122	***	-0,0642803	***	-0,077131125
A3	*Adjusted savings: natural resources depletion (% of GNI)*	-0,202787	***	-0,186089	***	-0,188005	***	-0,285265	***	-0,2155365
A4	*Adjusted savings: net forest depletion (% of GNI)*	2,50274	***	2,43591	***	2,44311	***	2,98075	***	2,5906275
A5	*Agricultural land (% of land area)*	0,399825	***	0,407253	***	0,406575	***	0,379098	***	0,39818775
A6	*Agriculture, forestry, and fishing, value added (% of GDP)*	0,499634	***	0,483336	***	0,485011	***	0,52613	***	0,49852775

A11	*CO2 emissions (metric tons per capita)*	-0,987779	***	-0,894552	***	-0,905014	***	-0,897511	***	-0,921214
A13	*Cooling Degree Days (projected change in number of degree Celsius)*	7,95296	**	6,36222	*	6,55062	**	13,1092	***	8,49375
A17	*Energy imports, net (% of energy use)*	-0,0135271	**	-0,0140287	**	-0,0139805	**	-0,0155368	***	-0,014268275
A19	*Energy use (kg of oil equivalent per capita)*	0,00229778	***	0,00215669	***	0,00217334	***	0,0018323	***	0,002115028
A22	*Forest area (% of land area)*	0,251868	***	0,22458	***	0,227616	***	0,243401	***	0,23686625
A23	*Fossil fuel energy consumption (% of total)*	-0,194452	***	-0,191801	***	-0,192157	***	-0,166195	***	-0,18615125
A25	*GHG net emissions/removals by LUCF (Mt of CO2 equivalent)*	-7,17613	***	-6,88342	***	-6,91556	***	-6,46297	***	-6,85952
A37	*Maximum 5-day Rainfall, 25-year Return Level (projected change in mm)*	-2,95262	**	-2,79825	**	-2,81559	**	-2,72424	***	-2,822675
A38	*Mean Drought Index (projected change, unitless)*	-98,0934	***	-93,4056	***	-93,9537	***	-110,218	***	-98,917675
A46	*PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)*	0,297817	***	0,278347	***	0,280443	***	0,264457	***	0,280266
A56	*Renewable electricity output (% of total electricity output)*	0,279309	***	0,276429	***	0,276683	***	0,271142	***	0,27589075

The value of Renewable Energy Consumption is negatively associated to:

- *Net Energy Imports:* considers net energy imports are estimated as energy consumption minus production, both measured in oil equivalents. A negative value indicates that the country is a net exporter. Energy consumption refers to the use of primary energy before transformation into other end-use fuels, equal to domestic production plus imports and inventory changes, minus exports and fuels supplied to ships and aircraft engaged in international shipping. There is a negative relationship between the value of net energy imports and the value of renewable energy consumption. As a result, the growth in the value of renewable energy consumption improves energy autonomy and independence at the country level. It therefore follows that the growth in the consumption of renewable energy has a positive impact in reducing imports, above all of oil, making countries less sensitive to exogenous oil shocks.
- *Access to electricity:* is the percentage of the population that has access to electricity. Electrification data is collected from industry, national surveys and international sources. Access to electricity is particularly crucial for human development as electricity is, in practice, indispensable for some basic activities, such as lighting, refrigeration and the operation of household appliances, and cannot be easily replaced by others forms of energy. Individuals' access to electricity is one of the clearest and most unbiased indicators of a country's state of energy poverty. There is a negative relationship between the value of access to electricity and the value of renewable energy consumption. This relationship can be explained by considering that the countries in which the consumption of renewable energy is more widespread are generally countries with a low-medium per capita income which therefore tend to have problems in accessing electricity. Moreover, the growth in the consumption of renewable energy is also motivated by the population's poor access to electricity.
- *Fossil fuel energy consumption:* includes coal, oil, and natural gas-based products. Fossil fuels are non-renewable resources because they take millions of years to form and reserves are depleted much faster than new ones are created. There is a negative re-

lationship between the value of renewable energy consumption and the value of fossil fuel energy consumption. This negative relationship shows the presence of a substitution effect between the value of renewable energy consumption and the value of fossil fuel energy consumption. In this sense, a zero-sum game condition is determined between the two sources of energy consumption. The fact that there is a growth in the consumption of renewable energy structurally improves the quality of the composition of the energy mix basket, creating the conditions for a more sustainable economy that is more oriented to the circular economy.

- *Adjusted savings: natural resources depletion:* considers the depletion of natural resources as the sum of the net depletion of forests, energy depletion and mineral depletion. Net forest depletion is the unit resource rent multiplied by the excess harvest of timber in excess of natural growth. Energy depletion is the ratio between the value of the stock of energy resources and the remaining life of the reserve, limited to 25 years. It covers coal, crude oil and natural gas. Mineral depletion is the ratio of the value of the mineral resource stock to the remaining life of the reserve, limited to 25 years. Covers tin, gold, lead, zinc, iron, copper, nickel, silver, bauxite and phosphate. There is a negative relationship between the value of natural resource depletion and the value of renewable energy consumption. This report highlights the fact that the growth of renewable energy consumption helps the country in completing the transition to a green energy system and reduces dependence on traditional energy sources. The consumption of renewable energy therefore also improves the possibility of preserving natural resources at the country level.
- *CO2 emissions:* are those deriving from the combustion of fossils and the production of cement. They include carbon dioxide produced during the burning of solid, liquid and gaseous fuels and gas flaring. There is a negative relationship between the value of carbon dioxide emissions and the value of renewable energy consumption. This relationship turns out to be because the consumption of renewable energies makes it possible to significantly reduce carbon dioxide emissions, creating the conditions for an improvement in the environmental condition. Economic policies aimed at the production of green energy are a necessary complement to environmental economic policies. It is therefore possible to improve the condition of the environment through the implementation of energy economic policies capable of reducing carbon dioxide emissions.
- *Maximum 5-day Rainfall, 25-year Return Level:* A 25-year yield level of 5-day cumulative precipitation is the maximum amount of precipitation over a 5-day period that can be expected once in an average 25-year period. Infrequent precipitation events are often referred to as events of some return level. It is possible for two or more events of that magnitude to occur in much shorter intervals. However, such events would only occur once every 25 years in the long run. The maximum precipitation accumulated over a 5-day period represents a proxy for medium-severity floods induced by prolonged and heavy rainfall, relevant for infrastructure, agricultural productivity and disaster risk management. There is a negative relationship between the value of renewable energy consumption and the aggressiveness of rainfall. This relationship may be because the growth in the consumption of renewable energy can improve the overall climatic condition at a country level by reducing the aggressiveness of meteorological phenomena, which can destroy or even damage crops and create hydrogeological instability.
- *GHG net emissions/removals by LUCF:* considers changes in atmospheric levels of all greenhouse gases attributable to forestry and land use change activities. There is a negative relationship between the value of the variation of the change in atmospheric levels of greenhouse gases and the value of the consumption of renewable energy. The consumption of renewable energy, also through its production, reduces the use of land aimed at emitting gas. The result is therefore an overall improvement in the

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environmental and climatic condition at country level with the possibility of structurally reducing pollution deriving from emissions. Furthermore, it is also necessary to consider the cultural change that the consumption of renewable energy generates in the population and in the industrial system. In fact, the awareness of the possibility of producing and consuming clean and low-pollution energy allows you to make strategic choices oriented towards sustainability and closer to the circular economy.

- *Mean Drought Index:* is an average drought index, calculated for a 12-month period, found to be closely related to the impacts of drought on ecosystems, crops and water resources. The indicator is designed to account for both rainfall and potential evapotranspiration in determining drought. There is a negative relationship between the value of the average drought index and the value of the consumption of renewable energy. This relationship can be better understood considering that the value of precipitation is generally positively associated with an improvement in climatic conditions, a reduction in the increase in temperature, a green economic policy orientation, or rather with that set of effects and economic policies that make it possible to avoid extreme weather phenomena such as drought or excessive rainfall. It follows that the consumption of renewable energy has the possibility of operating as a real economic policy capable of producing systemic effects and causing macroeconomic changes in the sense of environmental sustainability.

Average Value of Regressions for the Estimation of Renewable Energy Consumption		
Variable	**Average**	**Relation**
Cooling Degree Days (projected change in number of degree Celsius)	8,4938	Positive
Adjusted savings: net forest depletion (% of GNI)	2,5906	
Agriculture, forestry, and fishing, value added (% of GDP)	0,4985	
Agricultural land (% of land area)	0,3982	
PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)	0,2803	
Renewable electricity output (% of total electricity output)	0,2759	
Forest area (% of land area)	0,2369	
Energy use (kg of oil equivalent per capita)	0,0021	
Energy imports, net (% of energy use)	-0,0143	Negative
Access to electricity (% of population)	-0,0771	
Fossil fuel energy consumption (% of total)	-0,1862	
Adjusted savings: natural resources depletion (% of GNI)	-0,2155	
CO2 emissions (metric tons per capita)	-0,9212	
Maximum 5-day Rainfall, 25-year Return Level (projected change in mm)	-2,8227	
GHG net emissions/removals by LUCF (Mt of CO2 equivalent)	-6,8595	
Mean Drought Index (projected change, unitless)	-98,9177	

5. Clusterization with k-Means Algorithm Optimized with the Silhouette Coefficient

Below is a clustering with k-Means algorithm maximized with the Silhouette coefficient. For the clusterization, we have used the interval period 2010-2021 for the same 193 countries of the econometric model. The analysis shows the presence of two clusters as indicated below, namely:

- *Cluster 1:* Afghanistan, Albania, Algeria, Andorra, Antigua and Barbuda, Argentina, Armenia, Australia, Austria, Azerbaijan, The Bahamas Bahrain, Bangladesh, Barbados, Belarus, Belgium, Belize, Bolivia, Bosnia and Herzegovina, Botswana, Brunei Darussalam, Bulgaria, Cabo Verde, Canada, Chile, China, Colombia, Croatia, Cuba, Cyprus, Czechia, Denmark, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, Arab Rep., El Salvador, Equatorial Guinea, Estonia, Fiji, Finland, France, Georgia, Germany, Greece, Grenada, Guyana, Hungary, India, Indonesia, Iran, Islamic Rep., Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Korea, Dem. People's Rep., Korea, Rep., Kuwait, Kyrgyz Republic, Latvia, Lebanon, Lesotho, Libya, Lithuania, Luxembourg, Malaysia, Maldives, Malta, Marshall Islands, Mauritania, Mauritius, Mexico, Micronesia, Fed. Sts., Moldova, Monaco, Mongolia, Morocco, Namibia, Nauru, Netherlands, New Zealand, North Macedonia, Oman, Palau, Panama, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russian Federation, Samoa, San Marino, Sao Tome and Principe, Saudi Arabia, Senegal, Serbia, Seychelles, Singapore,

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Slovak Republic, Slovenia, South Africa, South Sudan, Spain, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Suriname, Switzerland, Syrian Arab Republic, Thailand, Timor-Leste, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Tuvalu, Ukraine, United Arab Emirates, United Kingdom, United States, Uzbekistan, Vanuatu, Venezuela RB, Vietnam, Yemen, Rep.

- *Cluster 2:* Angola, Benin, Bhutan, Brazil, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, Comoros, Congo Dem. Rep., Congo Rep., Cote d'Ivoire, Eritrea, Eswatini, Ethiopia, Gabon, The Gambia, Ghana, Guatemala, Guinea, Guinea-Bissau, Haiti, Honduras, Iceland, Kenya, Kiribati, Lao PDR, Liberia, Liechtenstein, Madagascar, Malawi, Mali, Montenegro, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Norway, Pakistan, Papua New Guinea, Paraguay, Rwanda, Sierra Leone, Solomon Islands, Somalia, Sri Lanka, Sudan, Sweden, Tajikistan, Tanzania, Togo, Uganda, Uruguay, Zambia, Zimbabwe.

From the point of view of the median, it is clear that the median value of Cluster 2-C2 is higher than the median value of Cluster 1-C1. In fact C2=73.61>C1=12.14. As is evident, the median value of cluster 2 is about 6 times higher than the median value of cluster 1. This means that in the countries of Cluster 2 almost all of the energy, about ¾ of the total consumption, is made through renewable energy. Obviously, as can be seen, the countries in cluster 2 are almost all developing countries or countries with low per capita income. However, there are exceptions: Iceland, Liechtenstein, Norway, Sweden. Such exceptions can especially be understood considering that such countries have the possibility of using hydroelectric, wind or geothermal energy. Furthermore, these countries are not too large and not too populous and therefore do not express a particularly articulated demand for energy. It follows therefore that these countries, despite being evolved from an industrial point of view and having a very high per capita income, are able to consume large quantities of renewable energy. Specifically, the country that consumes the most renewable electricity among those with high-middle income is Iceland with a value equal to 78.69%, followed by Norway with a value equal to 58.97%, Liechtenstein with an amount of 55.43% and from Sweden with a value of 49.85%. Particular attention should be paid to Norway, which, despite being a country that has significant quantities of oil, continues to consume renewable energy. Norway exports oil in significant quantities. In 2021, oil exports accounted for about 60% of total exports to Norway [21]. It follows that the choice to create a consumption model based on renewable energy in Norway is not due to a lack of other energy sources but, on the contrary, it is precisely a green choice oriented towards the circular economy. As regards the other countries that are part of Cluster 2-C2, it is necessary to consider that these are African or Asian countries that consume renewable energy also because they are in the geographical conditions of being able to use above all solar and wind energy. The fact that African countries consume very large quantities of renewable energy can help the same countries to develop a green approach to industrial economic policies avoiding the mistakes of the Western world. In fact, the custom with renewable energy could help African countries to have sustainable industrial systems and to plan a new phase of green development by also innovating traditional economic policies.

In Cluster 1-C1, there are the upper middle-income countries and the countries of Latin America together with the major Asian countries. These countries consume very little renewable energy. The minimum value of renewable energy consumption in the countries of Cluster 1 is equal to zero. However, there are several countries that have a renewable energy consumption measured in 2021 between 0 and 1, namely: Bahrain with 0%, Oman with 0%, San Marino 0%, Brunei Darussalam with 0.01%, Kuwait with 0.01, Saudi Arabia with 0.01, Qatar 0.06%, Turkmenistan with 0.06%, Palau with 0.08%, Algeria with 0.13%, United Arab Emirates with 0.21%, Nauru with 0.26, Trinidad and Tobago with 0.4%, Singapore with 0.63%, Iraq with 0.91% and Iran with 0.96% . Among these countries, it is necessary to consider that there are many of the major oil producing countries in the world such as Saudi Arabia, Algeria, Iraq, Iran and Qatar. However, among

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the countries that have a value of renewable energy consumption between 0 and 1, there is also Singapore which is a country with a high per capita income. The presence of Singapore among the countries that consume less than 1% of their energy needs from renewable energy is a fact that is very difficult to justify. Indeed Singapore is in fact part of world global governance and tends to reflect the cultural, scientific and political innovations produced in the Western world. The fact that Singapore consumes less than 1% of its energy needs from renewable energy is certainly the result of a political choice that views the circular economy and environmental sustainability with suspicion. Furthermore, Cluster 1 comprehends almost all Western countries that have low levels of consumption deriving from renewable energies. Lesotho is the country in Cluster 1 that has the largest consumption of renewable energy with an amount of about 42.06%. However, it is possible to verify that many Latin American countries, which are part of Cluster 1, have a much higher value of renewable energy consumption than the countries of North America and the vast majority of European countries. There is therefore a sort of inverse relationship between the growth of per capita income and the value of the consumption of renewable energy. Even if the cases of Sweden and Norway demonstrate the opposite, it appears that the consumption of renewable energy tends to decrease with the increase in per capita income and with the endowment of oil as a natural resource at the country level.

6. Machine Learning and Predictions

Below is a machine learning analysis for predicting the future value of renewable energy consumption. Specifically, eight different machine learning algorithms were compared in terms of performance. The predictive performance of the algorithms was evaluated on the basis of the following elements, namely the R-squared and the following statistical errors, namely:

$$R^2 = 1 - \frac{SumSquaredRegression}{TotalSumOfSquares} = 1 - \frac{\sum(y_i - \widehat{y_i})^2}{\sum(y_i - \bar{y}_i)(y_i - \bar{y}_i)}$$

$$MAE = \frac{\sum_{i=1}^{n}|y_i - x_i|}{n} = \frac{\sum_{i=1}^{n}|e_i|}{n}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)(Y_i - \hat{Y}_i)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\hat{y}_i - y_i)(\hat{y}_i - y_i)}$$

For each of the indicators identified, a ranking was created and a ranking was assigned to the algorithms. The rankings are then added up. It follows that the algorithm that has a lower overall score has the highest ranking value in the four rankings analysed. Obviously, in the attribution of the ranking, the value of the R-squared is maximized and the value of the statistical errors analyzed is minimized. The machine learning algorithms were trained with 80% of the data and the prediction was made with the remaining 20% of the data.

In base all'analisi sono stati ottenuti i seguenti risultati ovvero:

- Polynomial Regression con un valore del payoff pari a 7;
- Gradient Boosted Trees con un valore del payoff pari a 9;
- Simple Regression Tree con un valore del payoff pari a 11;
- Linear Regression con un valore del payoff pari a 18;

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- Tree Ensemble Regression e Random Forest Regression con un valore del payoff pari a 19;
- PNN-Probabilistic Neural Network con un valore del payoff pari a 25;
- ANN-Artificial Neural Network con un valore del payoff pari a 29.

Predictions with the Best Predictor Algorithm i.e. Polynomial Regression											
Rank	Country	2019	Prediction	Abs Var	% Var	Rank	Country	2019	Prediction	Abs Var	% Var
1	*Barbados*	4,31	5,65	1,34	31,00	21	*Kiribati*	41,03	40,88	-0,15	-0,37
2	*Bhutan*	82,27	82,13	-0,14	-0,17	22	*Korea, Dem. People's Rep.*	11,31	14,97	3,66	32,40
3	*Cabo Verde*	22,19	23,49	1,30	5,87	23	*Liberia*	87,24	86,74	-0,50	-0,58
4	*Central African Republic*	91,26	90,44	-0,82	-0,90	24	*Maldives*	1,11	1,36	0,25	22,37
5	*Comoros*	53,43	54,92	1,49	2,80	25	*Marshall Islands*	11,7	11,67	-0,03	-0,25
6	*Congo, Dem. Rep.*	96,24	96,85	0,61	0,63	26	*Mongolia*	3,32	3,59	0,27	8,01
7	*Congo, Rep.*	68,67	69,12	0,45	0,66	27	*Myanmar*	57,85	58,36	0,51	0,89
8	*Croatia*	31,6	33,39	1,79	5,66	28	*Niger*	80,83	81,66	0,83	1,02
9	*Denmark*	37,52	35,77	-1,75	-4,68	29	*North Macedonia*	16,32	22,43	6,11	37,45
10	*Dominican Republic*	13,98	15,39	1,41	10,07	30	*Panama*	18,91	24,81	5,90	31,21
11	*Estonia*	31,29	29,60	-1,69	-5,41	31	*Philippines*	26,73	27,18	0,45	1,69
12	*France*	15,53	15,36	-0,17	-1,09	32	*Poland*	12,18	11,60	-0,58	-4,75
13	*Ghana*	41,8	40,16	-1,64	-3,93	33	*Portugal*	28,19	27,18	-1,01	-3,59
14	*Guyana*	11,35	16,98	5,63	49,62	34	*Qatar*	0,04	0,24	0,20	492,14
15	*Honduras*	45,96	49,92	3,96	8,62	35	*Serbia*	21,53	21,05	-0,48	-2,22
16	*India*	32,93	32,68	-0,25	-0,76	36	*Solomon Islands*	48,39	49,73	1,34	2,76
17	*Ireland*	12,34	11,27	-1,07	-8,67	37	*South Africa*	10,5	10,34	-0,16	-1,49
18	*Italy*	17,27	17,33	0,06	0,34	38	*Suriname*	14,4	16,87	2,47	17,14
19	*Jamaica*	9,09	9,09	0,00	-0,04	39	*Tuvalu*	8,2	8,97	0,77	9,43
20	*Kenya*	68,08	71,31	3,23	4,75						

It follows that therefore using the best predictor algorithm Polynomial Regression it is possible to make the following predictions, namely:

- Barbados with a variation from an amount of 4.31 up to a value of 6.56 or a variation equal to 1.34 units equal to a value of 31.00%;
- Bhutan with a variation from an amount of 82.27 up to a value of 82.13 units or a variation equal to -0.14 units equal to an amount of -0.17%;
- Cape Verde with a variation from an amount of 22.19 up to a value of 23.19 or a variation equal to 1.30 units equivalent to a value of 5.87%;
- Central African Republic with a variation from an amount of 91.26 up to a value of 90.44 or a variation equal to a value of -0.82 units equal to a value of -0.90%;
- Comoros with a variation from an amount of 53.43 up to a value of 54.92 or a variation equal to an amount of 1.49 units equal to a value of 2.80%;
- Congo Dem. Rep. with a variation from an amount of 96.24 up to a value of 96.85 units or equal to a value of 0.61 units equal to a value of 0.63%;
- Congo Rep. With an increasing variation from an amount of 68.67 units up to a value of 69.12 units or equal to a value of 0.45 units equal to a value of 0.66%;
- Croatia with a variation from an amount of 31.6 units up to a value of 33.39 units or equal to a value of 0.45 units equal to an amount of 0.66%;
- Denmark with a variation from an amount of 37.52 up to a value of 35.77 units or equal to a value of -1.75 units equal to a value of -4.68%;

Statistical Results of the Machine Learning Algorithms				
Algorithms	**R^2**	**Mean absolute error**	**Mean squared error**	**Root mean squared error**
ANN	0,981838	0,025922	0,001680	0,040993
PNN	0,984111	0,024687	0,001470	0,038343
Simple Regression Tree	0,995165	0,014137	0,000000	0,021151
Gradient Boosted Trees	0,996037	0,013366	0,000000	0,019148
Random Forest Regression	0,994291	0,016532	0,001000	0,022983
Tree Ensemble Regression	0,994347	0,016555	0,001000	0,022870
Linear Regression	0,997569	0,911196	1,796870	1,340474
Polynomial Regression	0,997568	0,010409	0,000000	0,015000

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- Dominican Republic with a change from an amount of 13.98 units up to a value of 15.39 units or a change equal to an amount of 1.41 units equal to a value of 10.07%;
- Estonia with a diminutive variation from an amount of 31.29 units up to a value of 29.60 units or equal to a value of -1.69 units equal to a value of -5.41%;
- France with a variation from an amount of 15.53 units up to a value of 15.36 units or equal to a variation of -0.17 units equal to a value of -1.09%;
- Ghana with a diminutive variation from an amount of 41.8 units up to a value of 40.16 units or a variation equal to an amount of -1.64 units equal to -3.93%;
- Guyana with an increasing variation from an amount of 11.35 units up to a value of 16.98 units or a variation equal to 5.63 units equivalent to 49.62%;
- Honduras with a variation from an amount of 45.96 up to a value of 49.92 units or equal to an amount of 3.96 units equal to a value of 8.62%;
- India with a variation from an amount of 32.93 units up to a value of 32.68 units or equal to a variation equal to an amount of -0.25 units equal to an amount of -0.76%;
- Ireland with a variation from an amount of 12.34 units up to a value of 11.27 units or equal to a value of -1.07 units equal to an amount of -8.67%;
- Italy with an increasing variation from 17.27 up to a value of 17.33 or equal to a variation of 0.06 units equal to an amount of 0.34 units;
- Jamaica with zero variation and a constant predicted absolute value at an amount of 9.09;
- Kenya with an increasing variation from an amount of 68.08 units up to a value of 71.31 units or equal to a value of 3.23 units equal to an amount of 4.75%;
- Kiribati with a variation from an amount of 41.03 units up to a value of 40.88 units or equal to -0.15 units equal to -0.37%;
- North Korea with an increasing variation from an amount of 11.31 units up to a value of 14.97 or equal to a value of 3.66 units equal to an amount of 32.40%;
- Liberia with a diminutive variation from an amount of 87.24 units up to a value of 86.74 units or equal to a value of -0.50 units equal to a value of -0.58%;
- Maldives with a variation from an amount of 1.11 units up to a value of 1.36 units or equal to a value of 0.25 units equal to a value of 22.37%;
- Marshall Island with a variation from an amount of 11.7 up to a value of 11.67 units equal to a value of -0.03 units equal to a value of -0.25%;

Ranking of Algorithms in Terms of Predictive Performance

Rank	Algorithms	R^2	Mean absolute error	Mean squared error	Root mean squared error	Sum
1	*Polynomial Regression*	2	1	3	1	7
2	*Gradient Boosted Trees*	3	2	2	2	9
3	*Simple Regression Tree*	4	3	1	3	11
4	*Linear Regression*	1	1	8	8	18
5	*Tree Ensemble Regression*	5	5	5	4	19
5	*Random Forest Regression*	6	4	4	5	19
6	*PNN*	7	6	6	6	25
7	*ANN*	8	7	7	7	29

- Mongolia with a variation from an amount of 3.32 units up to a value of 3.59 units or equal to a value of 0.27 units equal to a value of 8.01%;
- Myanmar with a variation from an amount of 57.85 units up to a value of 58.36 units or a variation equal to an amount of 0.51 units equal to a value of 0.89%;
- Niger with a variation from an amount of 80.83 units up to a value of 81.66 units or equal to a variation of 0.83 units equal to a value of 1.02%;
- North Macedonia with a variation from an amount of 16.32 units up to a value of 22.43 units or equal to a variation of 6.11 units equal to a value of 37.45%;
- Panama with a variation from an amount of 18.91 units up to a value of 24.81 units or a variation equal to a value of 5.90 units equal to a value of 31.21%;

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- Philippines with a variation from an amount of 26.73 units up to a value of 27.18 units or equal to a variation of 0.45 units equal to 1.69%;
- Poland with a variation from an amount of 12.18 units up to a value of 11.60 units or a variation equal to -0.58 units equal to a value of -4.75%;
- Portugal with a variation from an amount of 28.19 units up to a value of 27.18 units or equal to a variation of -1.01 units equal to a value of -3.59%;
- Qatar with an increasing variation from an amount of 0.04 units up to a value of 0.24 units or equal to a value of 0.20 units equal to +492.14%;
- Serbia with a variation from an amount of 21.53 units up to a value of 21.05 units or a variation equal to -0.48 units equal to a value of -2.22%;
- Solomon Islands with a variation from an amount of 48.39 up to a value of 49.73 or equal to a variation of 1.34 units equal to a value of 2.76%;
- South Africa with a variation from an amount of 10.5 units up to a value of 10.34 units or equal to a value of -0.16 units equal to a value of -1.49%;
- Suriname with a variation from an amount of 14.4 units up to a value of 16.87 units or equal to a value of 2.47 units equal to an amount of 17.14%;
- Tuvalu with a variation from an amount of 8.2 units up to a value of 8.97 units or equal to a variation of 0.77 units equal to 9.43%.

Overall, considering the average values, it appears that the value of renewable energy consumption is expected to grow from a value of 32.99 up to a value of 33.85 or a variation equal to an amount of 0.86 units equal to a value of 2.61%.

7. Limitations, Implications and Further Research

The analysis highlights the ambiguous effect of the use of renewable energies especially in the context of economic growth. On the one hand, at the level of international economic policy, the states have moved towards a greener and more sustainable orientation, on the other hand, it is not clear what kind of advantages this choice could have in terms of economic growth for middle-low income countries . Indeed, it is very probable that the environmental issue will end up increasing social inequalities between the North and the South of the world.

Also very relevant is the issue of new technologies and scientific research on renewable energies. In fact, it is very probable that in the future there will be new, more efficient technologies both for the production, storage and distribution of renewable energy. In this sense, even further innovations and discoveries in physics could still expand the range of renewable energies available.

However, one of the most relevant limitations of the considered analysis is the impossibility of distinguishing between the various types of renewable energy. In fact, not all renewable energies have the same degree of energy efficiency. For example, biomass energy that is used in West African regions exhibits a reduced level of efficiency compared to hydroelectric energy produced in Norway or Austria. It would therefore be necessary to further expand the analysis and consider the composition of the renewable energy portfolio.

Furthermore, the analyzed dataset takes into consideration 193 countries with a very high degree of heterogeneity. It would probably be the case, within future research, to identify macro-classes that are defined both for geographical reasons and for per capita income and for the value of the implementation of renewable energy.

The policy implications are clear. In fact, it is necessary not only to increase renewable energies but also to improve scientific research capable of discovering new technologies and new sources of renewable energies. However, if the transition to renewable energy for developing countries were to lead to a reduction in the rate of GDP growth, it would also be necessary to intervene with compensatory economic policies to reduce inequality between countries. In fact, the GDP of countries currently with medium-high per capita

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income was also produced thanks to pollution. And most likely many low-income countries will not be able to grow in a context of international regulation excessively oriented towards the reduction of CO_2. Thus, there is the risk of creating a new form of deprivation in terms of equality of opportunity, i.e. green poverty, i.e. the type of poverty produced by compliance with international treaties which weighs on the economic growth of countries with low per capita incomes.

In future research, especially in the field of economic policies and institutional design, it will therefore be very necessary to identify paths that allow the use of renewables, economic growth, and the reduction of inequalities to be held together in a single context aimed at fighting climate change.

8. Conclusions

In summary, it must be considered that the use of renewables on a global level is necessary to combat climate change, for environmental sustainability and to implement the circular economy. However, at present, consistently with what is stated in the scientific literature cited, it is not possible to have a clear idea of the unique effects of the use of renewable energies both for economic growth and in the sense of reducing CO_2 emissions. In fact, not all the studies reported agree that the transition to the consumption of renewable energies can generate economic growth and greater environmental sustainability. From this point of view, it is certainly necessary to consider that the countries that use the most renewable energy are precisely the countries with low per capita incomes, with some rare exceptions such as in the case of Norway and Austria. This condition is positive as it helps to spread a culture of renewables in African and low-income countries that can also be compatible with the circular economy and environmental sustainability. However, it is important to ensure that low-income countries also have effective access to economic growth and therefore develop technologies capable of making renewable energy necessary to support the industrial system. In the future, the role of renewable energies will certainly increase. However, there are still some doubts as to whether renewables energies can support generalized economic growth or are instead a tool to create a gap between high-growth countries using non-renewables energies and low-growth countries using renewables energies.

Data Availability Statement. The data presented in this study are available on request from the corresponding author.

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Declaration of Competing Interest. The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication.

Software. The authors have used the following software: Gretl for the econometric models, Orange for clusterization and network analysis, and KNIME for machine learning and predictions. They are all free version without licenses.

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Appendix

Modello 8: Pooled OLS, usando 1930 osservazioni
Incluse 10 unità cross section
Lunghezza serie storiche = 193
Variabile dipendente: A57

	Coefficiente	*Errore Std.*	*rapporto t*	*p-value*	
const	0,134603	1,37220	0,09809	0,9219	
A2	−0,0835935	0,0141915	−5,890	<0,0001	***
A3	−0,202787	0,0678935	−2,987	0,0029	***
A4	2,50274	0,268638	9,316	<0,0001	***
A5	0,399825	0,0198298	20,16	<0,0001	***
A6	0,499634	0,0474380	10,53	<0,0001	***
A11	−0,987779	0,125541	−7,868	<0,0001	***
A13	7,95296	3,24500	2,451	0,0143	**
A17	−0,0135271	0,00574592	−2,354	0,0187	**
A19	0,00229778	0,000298758	7,691	<0,0001	***
A22	0,251868	0,0183378	13,73	<0,0001	***
A23	−0,194452	0,0159211	−12,21	<0,0001	***
A25	−7,17613	1,79146	−4,006	<0,0001	***
A37	−2,95262	1,15577	−2,555	0,0107	**
A38	−98,0934	11,6636	−8,410	<0,0001	***
A46	0,297817	0,0248207	12,00	<0,0001	***
A56	0,279309	0,0160899	17,36	<0,0001	***

Media var. dipendente	25,20836	SQM var. dipendente	28,60802
Somma quadr. residui	605525,8	E.S. della regressione	17,79135
R-quadro	0,616448	R-quadro corretto	0,613240
F(16, 1913)	192,1615	P-value(F)	0,000000
Log-verosimiglianza	−8285,928	Criterio di Akaike	16605,86
Criterio di Schwarz	16700,47	Hannan-Quinn	16640,66
rho	0,656599	Durbin-Watson	0,676307

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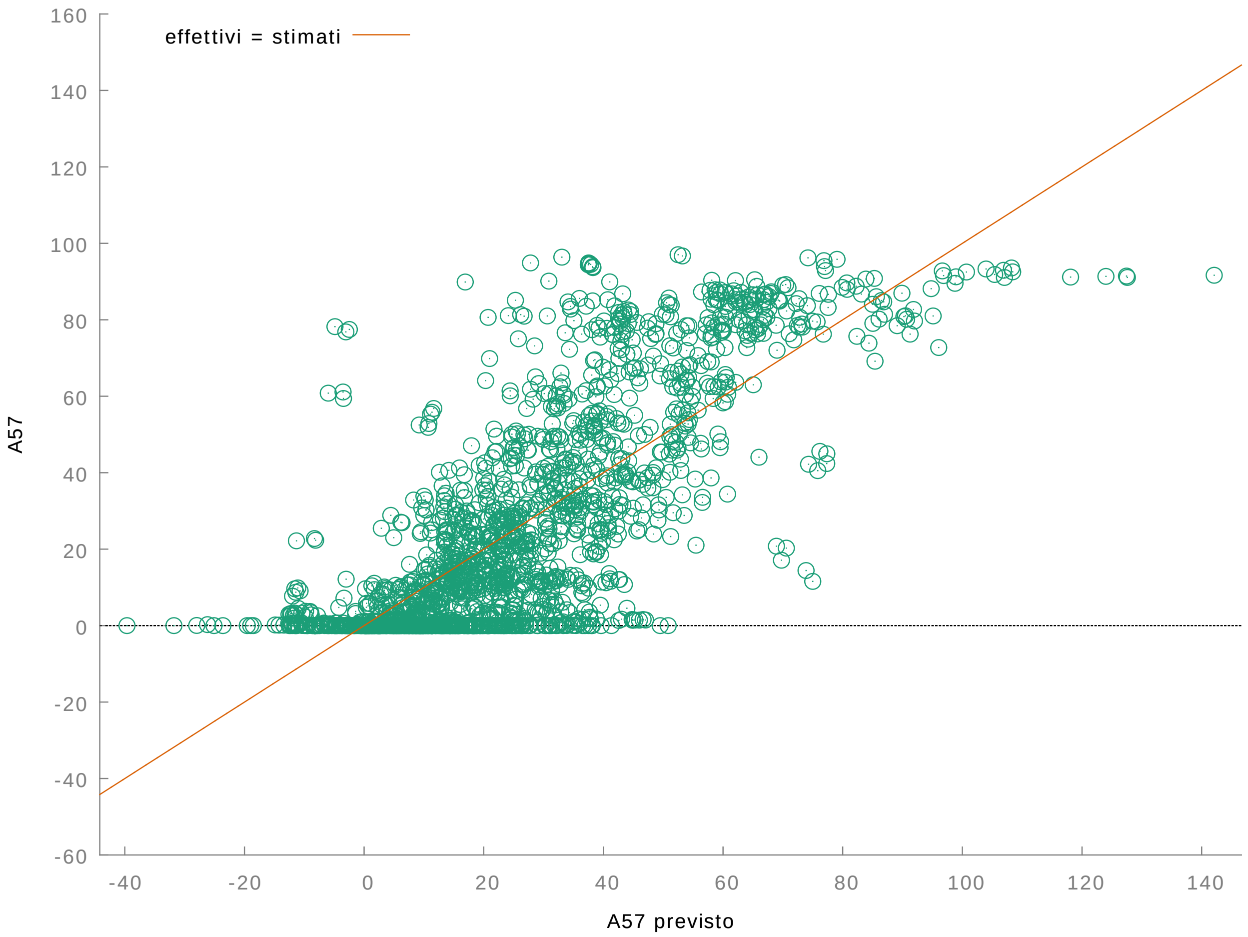

Modello 9: Effetti fissi, usando 1930 osservazioni
Incluse 10 unità cross section
Lunghezza serie storiche = 193
Variabile dipendente: A57

	Coefficiente	*Errore Std.*	*rapporto t*	*p-value*	
const	0,864397	1,35886	0,6361	0,5248	
A2	−0,0801385	0,0140151	−5,718	<0,0001	***
A3	−0,186089	0,0673337	−2,764	0,0058	***
A4	2,43591	0,266578	9,138	<0,0001	***
A5	0,407253	0,0199206	20,44	<0,0001	***
A6	0,483336	0,0478521	10,10	<0,0001	***
A11	−0,894552	0,125860	−7,108	<0,0001	***
A13	6,36222	3,26827	1,947	0,0517	*
A17	−0,0140287	0,00568047	−2,470	0,0136	**
A19	0,00215669	0,000297993	7,237	<0,0001	***
A22	0,224580	0,0186874	12,02	<0,0001	***
A23	−0,191801	0,0157942	−12,14	<0,0001	***
A25	−6,88342	1,76735	−3,895	0,0001	***
A37	−2,79825	1,13710	−2,461	0,0139	**
A38	−93,4056	11,6782	−7,998	<0,0001	***

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A46	0,278347	0,0246981	11,27	<0,0001	***
A56	0,276429	0,0159301	17,35	<0,0001	***

Media var. dipendente	25,20836	SQM var. dipendente	28,60802
Somma quadr. residui	582654,2	E.S. della regressione	17,49331
R-quadro LSDV	0,630935	R-quadro intra-gruppi	0,603026
LSDV F(25, 1904)	130,1993	P-value(F)	0,000000
Log-verosimiglianza	−8248,773	Criterio di Akaike	16549,55
Criterio di Schwarz	16694,24	Hannan-Quinn	16602,77
rho	0,653633	Durbin-Watson	0,682240

Test congiunto sui regressori -
Statistica test: F(16, 1904) = 180,768
con p-value = P(F(16, 1904) > 180,768) = 0

Test per la differenza delle intercette di gruppo -
Ipotesi nulla: i gruppi hanno un'intercetta comune
Statistica test: F(9, 1904) = 8,30444
con p-value = P(F(9, 1904) > 8,30444) = 3,20275e-012

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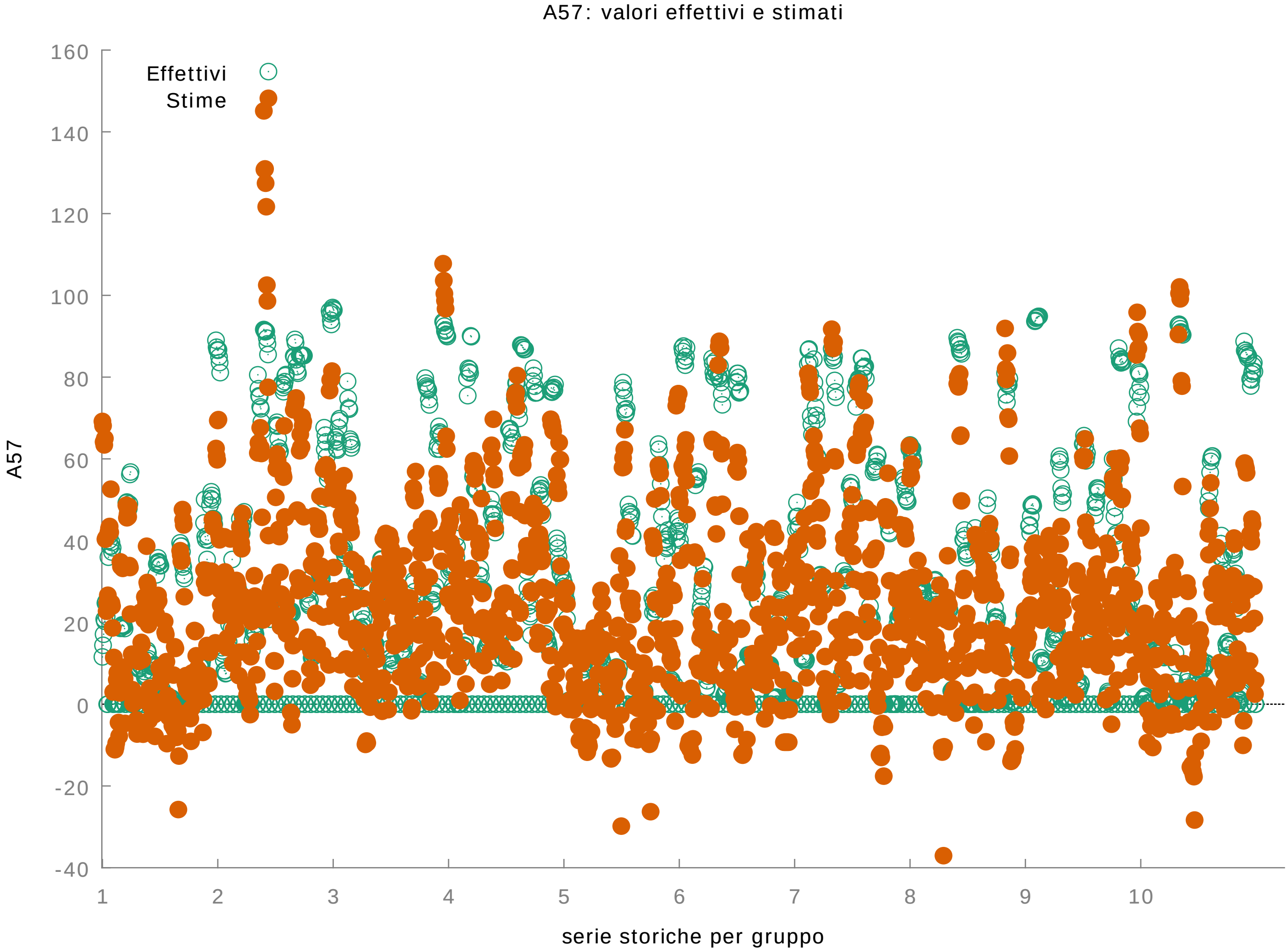

Modello 10: Effetti casuali (GLS), usando 1930 osservazioni
Con trasformazione di Nerlove
Incluse 10 unità cross section
Lunghezza serie storiche = 193
Variabile dipendente: A57

	Coefficiente	*Errore Std.*	*z*	*p-value*	
const	0,782813	1,81462	0,4314	0,6662	
A2	−0,0805122	0,0140048	−5,749	<0,0001	***
A3	−0,188005	0,0672547	−2,795	0,0052	***
A4	2,44311	0,266256	9,176	<0,0001	***
A5	0,406575	0,0198701	20,46	<0,0001	***
A6	0,485011	0,0477135	10,17	<0,0001	***
A11	−0,905014	0,125563	−7,208	<0,0001	***
A13	6,55062	3,25907	2,010	0,0444	**
A17	−0,0139805	0,00567569	−2,463	0,0138	**
A19	0,00217334	0,000297445	7,307	<0,0001	***
A22	0,227616	0,0186102	12,23	<0,0001	***

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A23	−0,192157	0,0157745	−12,18	<0,0001	***
A25	−6,91556	1,76624	−3,915	<0,0001	***
A37	−2,81559	1,13671	−2,477	0,0133	**
A38	−93,9537	11,6524	−8,063	<0,0001	***
A46	0,280443	0,0246607	11,37	<0,0001	***
A56	0,276683	0,0159143	17,39	<0,0001	***

Media var. dipendente	25,20836	SQM var. dipendente	28,60802
Somma quadr. residui	607106,0	E.S. della regressione	17,80989
Log-verosimiglianza	−8288,443	Criterio di Akaike	16610,89
Criterio di Schwarz	16705,50	Hannan-Quinn	16645,69
rho	0,653633	Durbin-Watson	0,682240

Varianza 'between' = 14,3145

Varianza 'within' = 301,893

Theta usato per la trasformazione = 0,686136

Test congiunto sui regressori -

Statistica test asintotica: Chi-quadro(16) = 2921,71

con p-value = 0

Test Breusch-Pagan -

Ipotesi nulla: varianza dell'errore specifico all'unità = 0

Statistica test asintotica: Chi-quadro(1) = 164,688

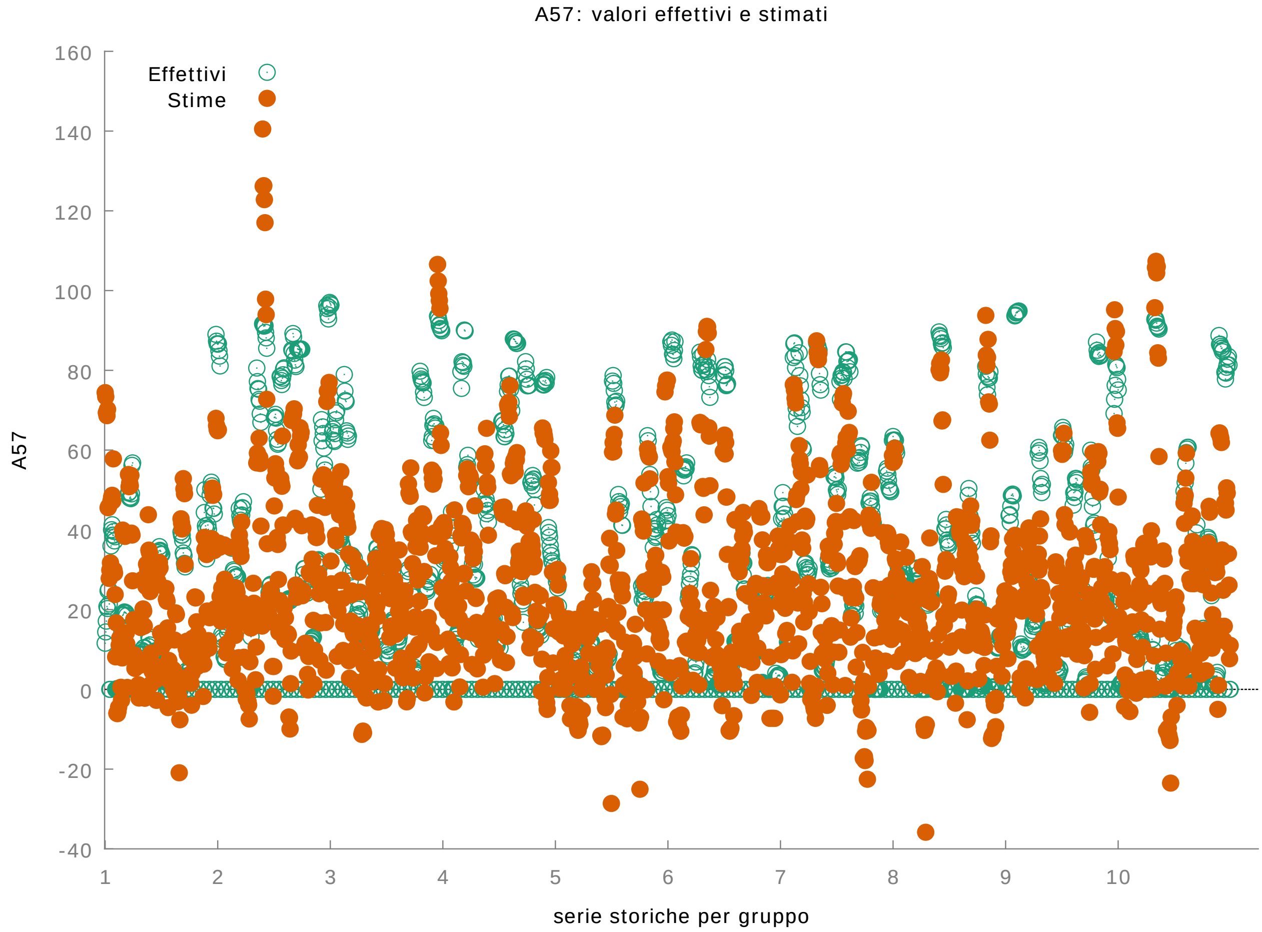
con p-value = 1,07012e-037

Test di Hausman -

Ipotesi nulla: le stime GLS sono consistenti

Statistica test asintotica: Chi-quadro(9) = 8,04222

con p-value = 0,529897



Modello 11: WLS, usando 1930 osservazioni
Incluse 10 unità cross section
Variabile dipendente: A57
Pesi basati sulle varianze degli errori per unità

	Coefficiente	*Errore Std.*	*rapporto t*	*p-value*	
const	−0,927839	1,29497	−0,7165	0,4738	
A2	−0,0642803	0,0134662	−4,773	<0,0001	***
A3	−0,285265	0,0623768	−4,573	<0,0001	***
A4	2,98075	0,276264	10,79	<0,0001	***
A5	0,379098	0,0188805	20,08	<0,0001	***
A6	0,526130	0,0445787	11,80	<0,0001	***
A11	−0,897511	0,113269	−7,924	<0,0001	***
A13	13,1092	3,33999	3,925	<0,0001	***
A17	−0,0155368	0,00543308	−2,860	0,0043	***
A19	0,00183230	0,000290954	6,298	<0,0001	***
A22	0,243401	0,0173652	14,02	<0,0001	***
A23	−0,166195	0,0149289	−11,13	<0,0001	***
A25	−6,46297	1,60427	−4,029	<0,0001	***
A37	−2,72424	0,888258	−3,067	0,0022	***
A38	−110,218	10,4079	−10,59	<0,0001	***

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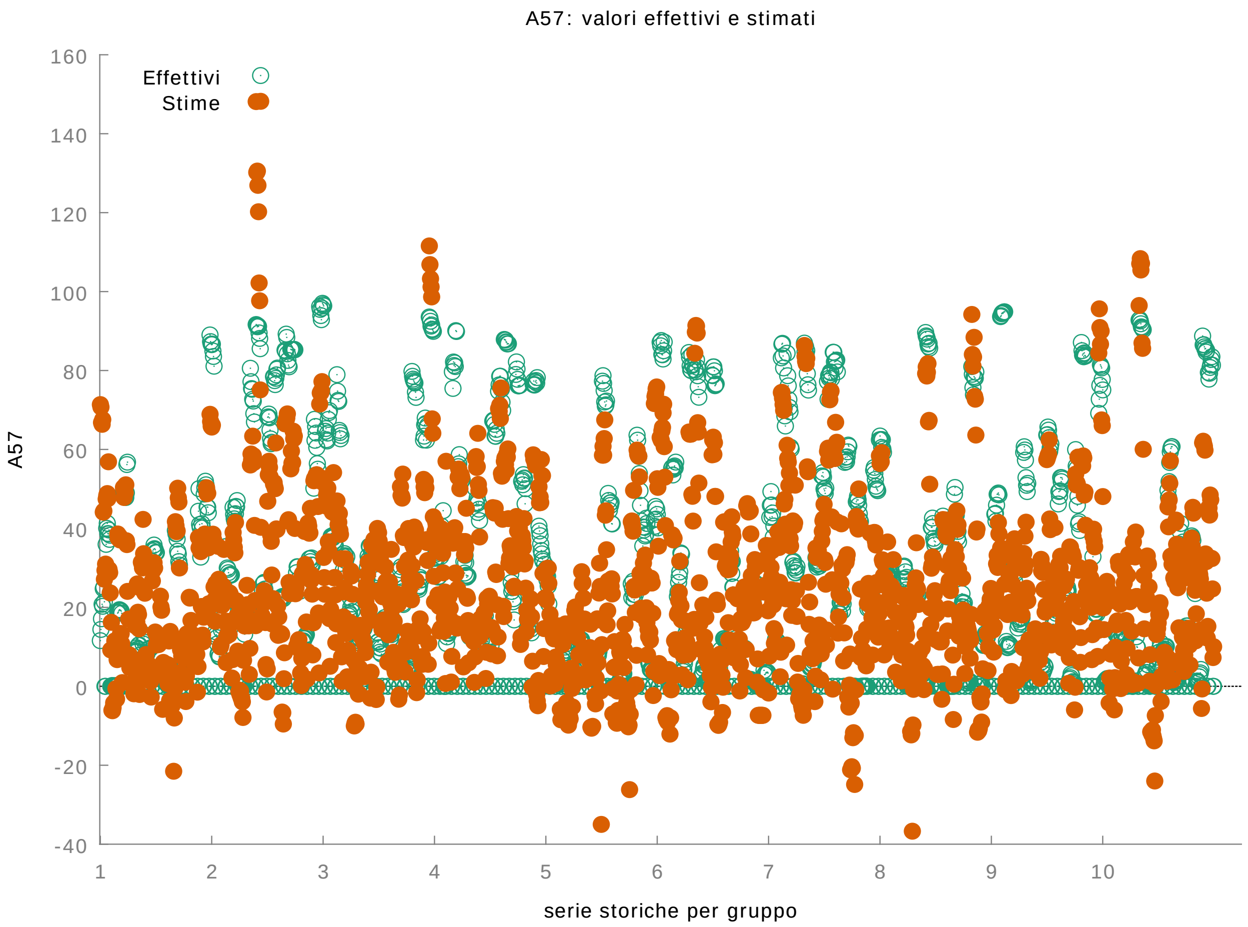
A46	0,264457	0,0234257	11,29	<0,0001	***
A56	0,271142	0,0152100	17,83	<0,0001	***

Statistiche basate sui dati ponderati:

Somma quadr. residui	1916,059	E.S. della regressione	1,000799
R-quadro	0,633709	R-quadro corretto	0,630646
F(16, 1913)	206,8519	P-value(F)	0,000000
Log-verosimiglianza	−2731,555	Criterio di Akaike	5497,111
Criterio di Schwarz	5591,721	Hannan-Quinn	5531,912

Statistiche basate sui dati originali:

Media var. dipendente	25,20836	SQM var. dipendente	28,60802
Somma quadr. residui	609605,8	E.S. della regressione	17,85119



Predictions