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Does Spatial Interaction of Sustainability Matters in the MENA and Sub-Saharan Regions?

Abstract. *This paper examines the spatial dependence of adjusted net savings – a proxy for sustainable development – on renewable energy consumption, non-renewable energy consumption, and gross domestic product across 31 developing countries in the MENA and Sub-Saharan Regions from 2000 to 2021. The study uses a cross-section fixed effect spatial Durbin model to examine the relationship between variables. The empirical results reveal that there is a positive and statistically accepted spatial autocorrelation in adjusted net savings, confirming that sustainability levels in one nation are correlated with those of its neighbours. Besides, while GDP significantly boosts sustainability, both renewable and non-renewable energy consumption exert a negative impact on adjusted net savings. The outcomes show that the spillover effects in short- and long-run for GDP, renewable, and non-renewable energy are insignificant, suggesting that energy policies in this region remain fragmented and lack synergistic cross-border benefits. Therefore, it is challenging for decision-makers to consider economic diversification, sustainability, and the energy transition, especially when it comes to middle-income nations that produce gas and oil.*

Keywords: *sustainable development, adjusted net savings, renewable and non-renewable energy, spatial Durbin model, spillover effects.*

JEL Classification: C33, O44.

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1. Introduction

Sustainable development has garnered immense scholarly attention due to its inherent links with economic growth, energy transition, and climate resilience. The

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World Commission on Environment and Development (1987) defines sustainable development as resource optimisation that satisfies present needs without compromising future generations. Achieving this balance requires innovation, clean production methods, and robust technology policies. In particular, Sustainable Development Goal 7 (SDG-7) promotes universal access to modern, affordable, and reliable energy, emphasising renewable energy technologies as a key component of decarbonisation and long-term sustainability (Islam et al., 2022).

In contrast to previous research that largely relied on GDP as a measure of economic growth or the economic factor of sustainability, as mentioned previously in paper of Sari Hassoun and Ayad (2020), this study employs adjusted net savings as a more holistic indicator of comprehensive economic factor of sustainable development (World Bank, 2021). Pearce and Atkinson (1993) and Hamilton (1994) were the first to introduce the adjusted net savings concept during their work at the World Bank. The adjusted net savings known informally as genuine saving, as a decent index to quantify the sustainable development in nations, based on the concepts of extended national accounts. Accordingly, Islam et al. (2022) found a positive relationship between renewable energy and adjusted net savings, while Güney (2021) showed a positive impact of renewable energy and GDP on adjusted net savings.

On the other hand, while neoclassical growth theories (Solow, 1956; Swan, 1956) predict convergence driven by capital accumulation and technological change, they often overlook the spatial dimension of development. As noted by Chica-Olmo et al. (2020), the geographical proximity and spatial distribution influence the economic behaviour in several regions. The natural resource endowments and economic structures of developing nations from the MENA and Sub-Saharan regions differ significantly, yet they have important spatial correlations (Sari-Hassoun et al., 2025). Consequently, models using conventional econometric methods that disregard spatial dependence may be skewed. In order to close this gap, this paper combines spatial econometric models and exploratory geographical data analysis to examine the relationship between sustainability, energy consumption, and economic growth. In this regard, Radmehr et al. (2021) found that GDP is strongly spatially correlated with renewable energy consumption in 21 EU nations, while Jeetoo (2022) established that renewable energy consumption is positively spatially correlated.

Therefore, by integrating the spatial dimension, this paper provides novel insights into how renewable energy policies in one nation may or may not have a spillover impact on the sustainability of its neighbours. Besides, the purpose of this study is to contribute to the body of literature by offering a novel approach based on spatial clustering and examining the spatial connection of renewable energy consumption, non-renewable energy consumption, and GDP on adjusted net savings in 31 developing countries from the MENA and Sub-Saharan regions during the period of 2000 to 2021. Upon reviewing previous research, we discovered that a number of studies focus on the effects of renewable energy development within regions or on the growth of renewable energy over time, frequently ignoring the

concept of sustainability as well as the spillover effect of renewable energy development in nearby regions.

The contribution is to provide a fresh perspective on the corpus of adjusted net savings-related literature. In addition to conducting a spatial analysis on adjusted net savings, renewable energy, non-renewable energy, and GDP. It is important to consider the spatial dimension as well as the spatial effects between nearby locations and the spillover effect among these 31 selected developing countries.

2. Literature review

According to the World Commission on Environment and Development (1987), the adjusted net savings stands for intergenerational equity, which denotes the resources quantity available to meet the needs of future generations. Natural resources rise in proportion to the assistance that modern society wants to meet its ambitious growth targets. Natural resources will continue to be depleted and rendered unusable for upcoming generations as long as they are used to generate carbon emissions. To put it succinctly, the adjusted net savings calculation is perfect for the sustainable development definition. A measure of an economy's sustainability based on the ideas of extended national accounts or genuine saving informally. The World Bank has demonstrated the significance of the adjusted net savings by pointing out that it was created expressly to serve as a trustworthy proxy for sustainable development in order to evaluate the economic, social, and environmental development aspects of the nation (Van and Manuel, 2008). Therefore, it is evident that ANS is a trustworthy proxy for measuring SD given its benefits and significance.

Relatively few empirical studies examine the effects of renewable energy and GDP on adjusted net savings, especially when employing a spatial model, and most replace sustainable development with economic growth. For instance, Islam et al. (2022) use fully modified ordinary least squares (FMOLS), dynamic ordinary least squares (DOLS), and canonical cointegration regression (CCR) to investigate the influence of renewable energy on adjusted net savings in Association of Southeast Asian Nations countries during the period of 1980-2018. They established that renewable energy positively influences the adjusted net savings. In the same stream, Wei and Huang (2022) find that renewable energy has a positive contribution to the level of adjusted net savings in ten Asian economies. Noor et al. (2023) employ ARDL and establish that renewable energy has a positive effect on adjusted net savings in five South Asian nations during the period of 1995-2019. In developing and developed countries, Güney (2019) establish that renewable energy positively and significantly influences the adjusted net savings for the period of 1990 to 2014. In the Organisation for Economic Co-operation and Development nations, Güney (2021) find that renewable energy and GDP have a positive and significant contribution to the level of adjusted net savings for the period of 1990 to 2015. Ahmad et al. (2023) use method of moments quantile regression (MMQR) and find that switching to renewable energy has a positive influence on adjusted net savings

in 21 emerging nations for the period of 1990 to 2020. Sari-Hassoun and Kahwi (2024) establish with FMOLS, DOLS, and CCR that renewable energy consumption impact positively and significantly the adjusted net savings in five North African countries. Dradra et al. (2024) establish with the quantile regression that there is a positive relationship between renewable energy consumption and adjusted net savings in 24 members of the Organisation for Economic Cooperation and Development. They show that the mature green technology sectors propel domestic value creation. On the other hand, developing countries frequently depend on imported renewable technologies, which result in a large initial capital expenditure (high CAPEX) that temporarily reduces the "savings" component of adjusted net savings. Sari-Hassoun et al. (2025) employ the dynamic cross-section fixed effect Spatial Durbin Model (SDM-FE) with dlag (3) and find that GDP and renewable energy consumption positively and significantly influence the adjusted net savings in 37 selected European nations for the period of 2000 to 2021. However, the spillover results show that renewable energy consumption and GDP negatively and significantly impact the adjusted net savings. However, Sari Hassoun and Ayad (2020) find that there is a negative relationship between renewable energy and adjusted net savings in 17 the Organisation for Economic Co-operation and Development nations for the period of 1990 to 2017. In 23 Sub-Saharan African countries, Zhu et al. (2024) reveal with MMQR that GDP and renewable energy influence negatively the adjusted net savings during the period of 2000 to 2022.

Previous research showed that a number of analyses about renewable energy, non-renewable energy, GDP, and adjusted net savings variables were performed on either individual or panel data. First of all, the spatial panel analysis is the main topic of this paper, since it does not only represent a substantial contribution, but a new research gap as well. Then, the study is the first to employ the adjusted net savings in a spatial econometric context, because it accounts for the costs of pollution and environmental degradation, the depletion of natural resources, investments in the development of human capital, and the depreciation of produced capital. Therefore, it is a significant improvement over GDP as a metric. Moreover, the study measures the cross-border effects of both direct (within a nation) and indirect (spillover to neighbours) effects. Furthermore, the model identifies and measures the degree of spatial interdependence across countries, in addition to modelling how renewable energy policies in one country affect sustainability outcomes in other countries. Finally, this spatial approach provides crucial insights for the creation of coordinated regional policies by recognising that environmental and economic systems are not limited by national boundaries.

3. Data and methodology

3.1 Data

We use 31 developing countries from The MENA and Sub-Saharan regions during the period of 2000-2021. The countries are Algeria, Angola, Benin, Botswana, Burundi, Cameroon, Republic of the Congo, Democratic Republic of the

Congo, Egypt, Eswatini (eSwatini), Gambia (The Gambia), Ghana, Guinea, Guinea-Bissau, Jordan, Kenya, Kuwait, Libya, Mali, Morocco, Namibia, Niger, Nigeria, Oman, Saudi Arabia, Senegal, Sierra Leone, South Africa, Tanzania, Togo, and Tunisia.

The World Bank defines the following variables. The first is adjusted net savings including particulate emission damage and serves as both the study's endogenous variable and an indicator of sustainability. This variable is the total of net national savings and educational costs, less particulates from CO2 emissions, net depletion of energy, minerals, and forests. It is calculated using percentage of GNI, while a high level of adjusted net savings means that there is a high level of sustainability and vice versa. However, it is tough to estimate accurately and does not consider all aspect of sustainability, for instance biodiversity loss and social factors. The first exogenous variable is renewable energy consumption, which is expressed as a percentage of total energy consumption, and includes solar, wind, hydropower, geothermal, solid biomass, liquid biomass, biogas, and municipal and industrial waste. The second exogenous variable is non-renewable energy consumption, which is expressed as a % of total energy consumption and it includes coal, oil, petroleum, and natural gas products. The third exogenous variable is gross domestic product or globally recognised as “GDP”, which are expressed as a % annually at market prices using constant local currency. The aggregates are expressed in US dollars and are based on constant prices from 2015. GDP is the sum of the gross value added by all producers who are residents of the country, plus any product taxes, and minus any subsidies that are not factored into the product value. It is computed without accounting for the depletion and degradation of natural resources or the depreciation of artificial assets.

All variables are explained in Table 1:

Table 1. Variable and source of data

Variables	Symbol / measure	Unit	Data source
<i>Dependent variable</i>			
Adjusted net savings, including particulate emission damage	ANS	(% of GNI)	WB
<i>Independent variable</i>			
Renewable energy consumption (REC)	REC	% of total final EC	WB
Non-renewable energy consumption (NREC)	NREC	% of total final EC	WB
Gross Domestic Product (GDP)	GDP	GDP growth (annual %)	WB

Source: Authors' processing.

The model will be expressed as follows:

$$ANS_{it} = \beta_0 + \beta_1(REC_{it}) + \beta_2(NREC_{it}) + \beta_3(GDP_{it}) + \varepsilon_{it} \quad (1)$$

i and t indicate the country “i” in time “t”, while β are the parameters of the model and the error term of the estimation is “ ε ”. The model is particularly

concerned with examining the influence of energy, and economic aspect on the sustainability factor.

This study examines the economic, environmental, and energy contexts within the framework of "Ecological Economics," or more accurately, "Biophysical Economics." This subfield of economics examines how energy and natural resources function in economic systems by combining the study of physics, ecology, and economics. The economy theory in this context focuses on the relationship between energy, GDP, and sustainability as well as the long-term viability of economic systems given the limitations of limited natural resources and environmental capacity (**Georgescu-Roegen, 1971**). We chose renewable energy consumption and non-renewable energy consumption as exogenous variables because, in the production function of **Solow's (1956)** and **Swan's (1956)** neoclassical growth theory, they represent the energy and technology factor, whereas GDP represents the formation and accumulation of capital. In addition, the choice of such variables is based on a previous econometric model and literature review. Since the time period is short, it is best to apply it to four or five variables in order to obtain objective results.

3.2 Methodology

Luc Anselin is widely regarded as one of the foundational pioneers of spatial econometrics, particularly for his role in systematising and popularising the field within economics and social sciences. He shows that trade, technology transfer, and the adoption of common policies all contribute to the existence of spatial autocorrelation among nations (Anselin, 1988). The spatial correlation analysis quantifies the extent of spatial agglomeration. According to Tobler's First Law (Tobler, 1970), when geographic data is considered, there will be a spatial spillover effect and model disturbances will show spatial autocorrelation. Consequently, if this hypothesis is rejected, the OLS estimation will not be effective (Anselin, 1988). Tobler states that "everything is related to everything else, but near things are more related than distant things". We can say that there is a positive spatial autocorrelation (clustered) when objects with similar values are closer to each other, and a negative spatial autocorrelation (dispersed) when objects with dissimilar values are closer to each other. However, there is no spatial autocorrelation when a variable is not correlated with other variables or with itself across space. Therefore, to measure the spatial dependence and spatial autocorrelation, Anselin (1995) employ the index of Moran's I.

We only consider local Moran's I in this paper since it can quantify the variation in spatial association between nations.

$$\text{Local Moran's } I = \frac{n(X_i - \bar{X})}{\sum_j (X_j - \bar{X})^2} \sum_j W_{ij}(X_j - \bar{X})$$

Where X_i and X_j are defined as the value of variables of country i and j , \bar{X} is the average value of X , W_{ij} represents the spatial weight matrix, n is the total number

with spatially autocorrelated errors model (SAC) or (SARAR) proposed by Kelejian and Prucha (2010).

SAR:

$$y_{it} = \rho W y_{it} + i_N \alpha_{it} + X_{it} \beta + \varepsilon_{it} \tag{2}$$

SEM:

$$y_{it} = i_N \alpha_{it} + X_{it} \beta + u_{it} \tag{3}$$

$$u_{it} = \lambda W u_{it} + \varepsilon_{it} \tag{4}$$

SAC:

$$y_{it} = \rho W y_{it} + i_N \alpha_{it} + X_{it} \beta + u_{it} \tag{5}$$

$$u_{it} = \lambda W u_{it} + \varepsilon_{it} \tag{6}$$

SDM:

$$y_{it} = \rho W y_{it} + i_N \alpha_{it} + X_{it} \beta + W X_{it} \gamma + \varepsilon_{it} \tag{7}$$

ρ represents the parameter of the spatial autoregressive, which denotes the presence of spatial spillover effect. $W y_{it} = WANS$, it denotes the spatial lagged of adjusted net savings in our model. λ specifies the spatial autoregressive error parameter. $W u_{it}$ symbolises the spatial lagged errors. $W X_{it}$ is spatial lagged independent variables matrix. However, coefficients from SAR and SEM estimation do not represent marginal effects (LeSage and Pace, 2009). Therefore, we will focus on the spatial Durbin model, which Elhorst (2014) displays it as following:

$$y_t = (1 - \rho W)^{-1} (X \beta + W X \gamma) + M \tag{8}$$

Where the intercept and error term are represented by M

At the end, we shall estimate a dynamic cross-section fixed effect spatial Durbin model with dlag SDM-FE, which is a new method that examine the relationship between adjusted net savings, renewable energy consumption, non-renewable energy consumption, and GDP. Thus, the partial derivatives matrix of the predicted values of ANS_t with respect to the k_{th} explanatory variable in unit 1 ... N at time t is:

$$\begin{bmatrix} \frac{\partial E(ANS_t)}{\partial X_{1k}} & \dots & \frac{\partial E(ANS_t)}{\partial X_{Nk}} \\ \vdots & \ddots & \vdots \\ \frac{\partial E(ANS_{tN})}{\partial X_{1k}} & \dots & \frac{\partial E(ANS_{tN})}{\partial X_{Nk}} \end{bmatrix} = \begin{bmatrix} \frac{\partial E(ANS_{t1})}{\partial X_{1k}} & \dots & \frac{\partial E(ANS_{t1})}{\partial X_{Nk}} \\ \vdots & \ddots & \vdots \\ \frac{\partial E(ANS_{tN})}{\partial X_{1k}} & \dots & \frac{\partial E(ANS_{tN})}{\partial X_{Nk}} \end{bmatrix} \leftrightarrow \begin{bmatrix} \frac{\partial E(ANS_{t1})}{\partial X_{1k}} & \dots & \frac{\partial E(ANS_{t1})}{\partial X_{Nk}} \\ \vdots & \ddots & \vdots \\ \frac{\partial E(ANS_{tN})}{\partial X_{1k}} & \dots & \frac{\partial E(ANS_{tN})}{\partial X_{Nk}} \end{bmatrix} = (1 - \rho W)^{-1} \begin{bmatrix} \beta_k & \dots & W_{1N} \gamma_k \\ \vdots & \ddots & \vdots \\ W_{N1} \gamma_k & \dots & \beta_k \end{bmatrix} \tag{9}$$

Eq. 9 describes a partial derivatives matrix, which illustrates, for example, that if a country “i” alters its renewable energy consumption policy ($X_{1k} = X_{11}$), not only may this country's adjusted net savings change direct effect (every diagonal element of the matrix), but also the adjusted net savings of neighbouring countries or indirect

effect (spillover effect= every off-diagonal element of the partial derivatives of the matrix).

4. Results and discussion

4.1 The local univariate and bivariate Moran’s I test

First of all, we display the Moran’s I test results and estimate the contiguity-based spatial weights matrix. The results are given in Table 2:

Table 2. Summary of spatial-weighting (W)

Matrix	Description
Dimensions	31*31
Links	
Total	80
Min	1
Mean	2.580
Max	5

Source: Authors’ processing using Geoda¹.

The outcome from Table 2 shows that the spatial matrix consists of 31 cross-sectional units that have 80 links between nations, with at least one neighbour and a maximum of 5 neighbours. There are also 2,58 contiguous units on average.

The local univariate and bivariate Moran’s I test is shown in Table 3:

Table 3. The local univariate and bivariate Moran’s I test

Variables	Moran’s I (index)	Moran’s I (p-value)
<i>The local univariate Moran’s I test</i>		
ANS	0.360***	0.008
REC	0.736***	0.001
NREC	0.740***	0.001
GDP	0.115	0.17
<i>The local bivariate Moran’s I test</i>		
ANS-WREC	-0.525***	0.001
ANS-WNREC	0.528***	0.001
ANS-WGDP	-0.371***	0.001

Note: “***”, “**”, “*” refer to the significance level at 1, 5 and 10%.

Source: Authors’ processing using Geoda.

The results of local univariate Moran’s I test demonstrate that while GDP has an insignificant value, there is a spatial pattern among features, a significant spatial autocorrelation, and a spillover effect between 31 countries from The MENA and Sub-Saharan regions. The p-values show a significant value (less than 1%) for adjusted net savings, renewable energy consumption, and non-renewable energy

¹ GeoDa provides techniques for exploratory spatial data analysis along with an easy-to-use interface with interactive visualisation tools. It was developed by the Centre for Spatial Data Science at the University of Chicago.

consumption, while their coefficients indicate a positive spatial autocorrelation. Likewise, the outcomes of bivariate Moran's I test show that the p-value is less than 1%, indicating the presence of a significant spatial autocorrelation, and a spillover effect. However, the coefficient between adjusted net savings and lagged renewable energy consumption (WREC) and between adjusted net savings and lagged GDP (WGDP) appear to be negative, meaning that there is a negative spatial autocorrelation. While, the coefficient between adjusted net savings and lagged non-renewable energy consumption (WNREC) indicates a positive spatial autocorrelation.

4.2 The bivariate local indicators of spatial association

Figure 1 represents BLISA Cluster Map between adjusted net savings and WREC, and shows that they are two countries in the High-High cluster (Senegal and Tanzania) with high adjusted net savings and high WREC at the significance level of 10%, but at 5% there is only Tanzania. This indicate that Senegal and Tanzania share the same high values of the sustainability and renewable energy and are considered as hot-spots countries. Senegal has an average of 42.53% of renewable energy consumption and 8.03% of adjusted net savings, while Tanzania has an average of 80.22% of renewable energy consumption and 13.17% of adjusted net savings, meaning that these countries are working to raise the standard of living and provide more stable energy services to their communities. By doing so, they will be able to achieve sustainable development goal 7, which calls for the provision of affordable, and clean energy. On the other hand, they are only two countries in Low-Low cluster (Tunisia and Oman) at the level of significance of 5%, indicating that these countries are geographically situated in cold-spots, where adjusted net savings and renewable energy consumption are less prevalent and less similar to the surroundings. They are therefore prevented from achieving sustainability standard. For the spatial outliers, we find that there are five countries in Low-High cluster at the significance level of 10%, while six countries in High-Low cluster at the significance level of 10%. Therefore, they are located in areas with high renewable energy consumption and adjusted net savings values and low similarity levels, or vice versa. The rest 16 countries are not in the significant cluster.

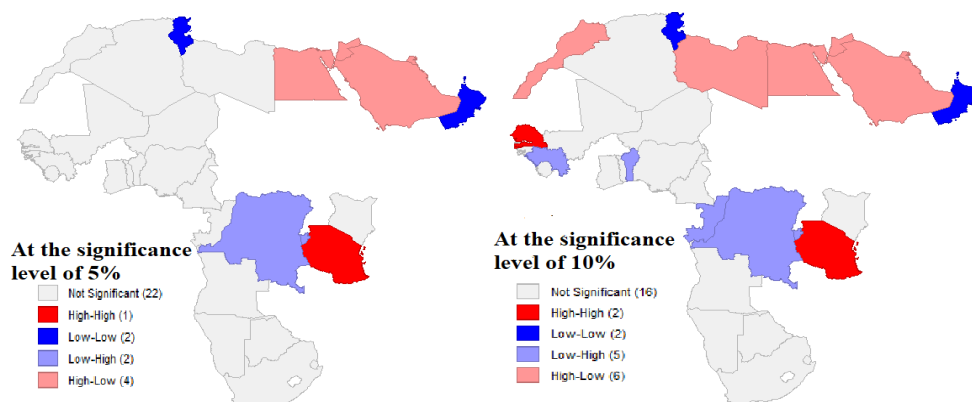


Figure 1. BLISA Cluster Map between ANS and WREC

Source: Authors' own creation using Geoda.

Figure 2 describes BLISA Cluster Map between adjusted net savings and WNREC. At the significance level of 10%, we find five countries which are in High-High cluster, since Kuwait, Egypt, Libya, Jordan, and Saudi Arabia share the highest average of non-renewable energy consumption and adjusted net savings values with their neighbours, we can confirm the positive spatial autocorrelation. Even though these countries can diversify their economies with their oil revenue and use it to fund public projects, services, and public sector employment, they can still achieve high levels of sustainability with fossil fuels and eventually reduce slowly their reliance on oil and gas revenues. However, there are six countries in Low-Low cluster. Two countries in Low-High cluster, and two countries in High-Low cluster at the significance level of 10%. The remaining 16 nations are not in the significant cluster.

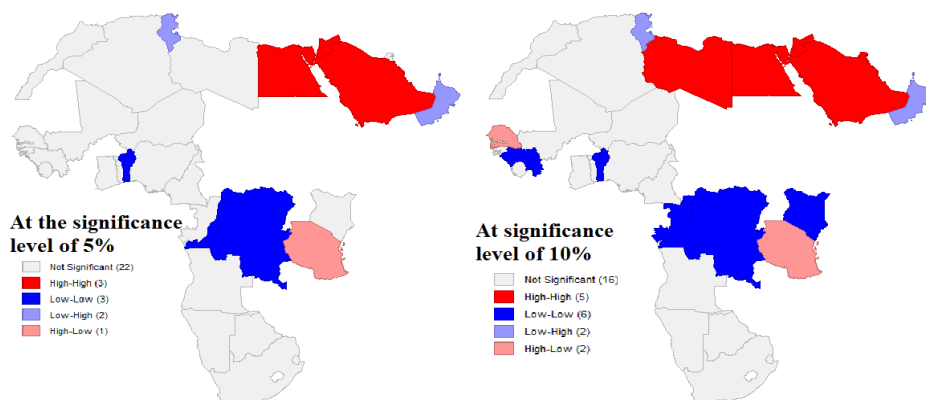


Figure 2. BLISA Cluster Map between ANS and WNREC

Source: Authors' own creation using Geoda.

Figure 3 shows BLISA Cluster Map between adjusted net savings and WGDP. Given the heterogeneous distribution of GDP and adjusted net savings as revealed by spatial distribution, we therefore find at the significance level of 10% that no

country remains in the High-High cluster and that only one country (Tunisia) remains in the Cold Spot, while there are 3 countries in Low-High cluster, two countries in High-Low cluster and the rest 25 countries are not in the significant cluster. Therefore, the relationship between GDP and adjusted net savings continues to be quite low, as these nations are still far from achieving sustainable development goal 8, which stipulates 7% annual GDP growth. Benin, Botswana, Eswatini, Kenya, and Morocco achieve more than 7% annual GDP growth in 2021, but if we examine their data or average data during the study period, we find that they were having difficulty maintaining growth rates above 3%.

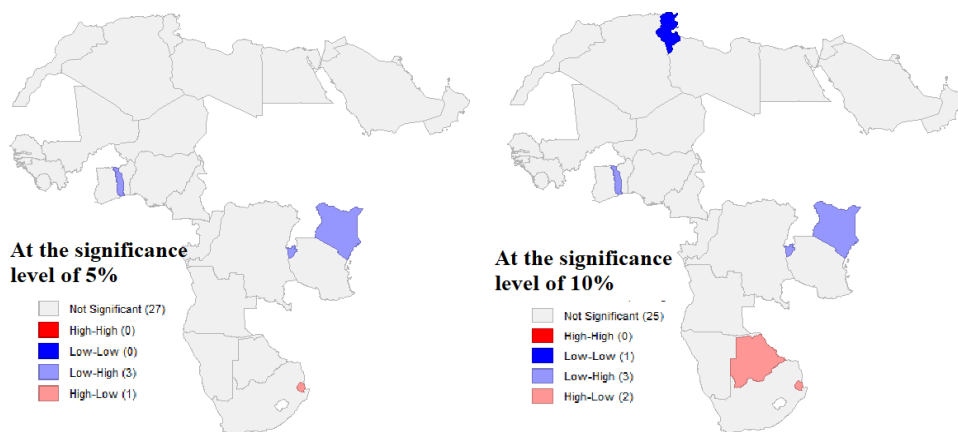


Figure 3. BLISA Cluster Map between ANS and WGDP

Source: Authors' own creation using Geoda.

4.3 The estimation outcomes

Table 4 shows the outcomes of the panel model estimation and Hausman test. The Hausman test shows that the statistic is significant at the level of 5%. The alternative hypothesis of a fixed effect is thus accepted, and we can determine that the best model is a panel with fixed effects. We then estimate three types of panel models with fixed effects (FE): time FE, cross-sectional FE, and cross-sectional and time FE.

Table 4. The panel model estimation and Hausman test

Test Summary	Chi-Sq. Statistic		Chi-Sq. d.f.	Prob.
Hausman	10.915**		3	0.0122
Variable	Pooled	cross-sectional FE	Time FE	cross-sectional and time FE
	Coefficient (Prob)	Coefficient (Prob)	Coefficient (Prob)	Coefficient (Prob)
REC	-1.211***(0)	-0.160 (0.452)	-1.284*** (0)	-9.406 (0.5522)
NREC	-0.960***(0)	0.127 (0.3921)	-1.03*** (0)	-0.019 (0.9008)
GDP	0.280***(0.001)	0.209*** (0)	0.297*** (0.001)	0.190 (0.1534)
C	107.8*** (0)	1.069 (0.938)	114.802*** (0)	-9.406 (0.5522)

Test Summary	Chi-Sq. Statistic		Chi-Sq. d.f.	Prob.
Hausman	10.915**		3	0.0122
R-squared	0.3334	0.76	0.346	0.771
Akaike	7.945	7.010	7.987	7.025
Schwarz	7.971	7.236	8.153	7.390
Hannan-Quinn	7.955	7.097	8.051	7.167
Log likelihood	-2705.155	-2356.461	-2698.544	-2340.625
F-statistic	113.01*** (0)	62.26*** (0)	14.493*** (0)	39.117*** (0)
Breusch-Pagan LM	1354.025*** (0)	1435.43*** (0)	1352.836*** (0)	1440.737*** (0)
Pesaran scaled LM	29.15*** (0)	31.82*** (0)	29.1133*** (0)	31.996*** (0)
Bias-corrected scaled LM	...	31.08*** (0)	-2.082** (0.037)	31.26*** (0)
Pesaran CD	4.57*** (0)	4.22*** (0)	-2.082** (0.037)	-1.722* (0.085)

Note: “***”, “**”, “*” refer to the significance level at 1, 5 and 10%.

Source: Authors’ processing.

The results show that the perfect model is the cross-sectional FE due to the low value of the Akaike, Schwarz, and Hannan-Quinn information criteria and the high value of Log likelihood. After the first estimation, we move to the spatial panel model with cross-sectional FE. We estimate with Quasi-Maximum Likelihood (QML) method three spatial model.

Table 5 reveals that both LM test has a statistical accepted sign for the selected model, and relying on Anselin and Rey (1991). The three spatial models with FE and random effect (RE) are shown in Table 5, and it is clear that all model specifications reject the null hypothesis that there is no spatial autocorrelation error term at the 1% significance level. The previous local univariate and bivariate Moran's I index results are consistent with this outcome.

Table 5. SAR, SEM and SDM spatial model

	SDM-FE	SDM-RE	SAR-FE	SAR-RE	SEM-FE	SEM-RE
Spatial rho	0.226*** (0)	0.216*** (0)	0.224*** (0)	0.217*** (0)	0.221*** (0)	0.217*** (0)
Log-Likelihood	-2338.814	-2413.819	-2340.9035	-2415.678	-2341.969	-2416.832
R ²	0.2904	0.2973	0.2861	0.2925	0.268	0.2749
AIC	4693.628	4847.638	4691.807	4845.356	4693.938	4847.663
BIC	4729.828	4892.888	4714.432	4877.031	4716.563	4879.339
χ ²	χ ² (7) = 21.23*** (0.0034)		χ ² (4) = 8.23* (0.0834)		χ ² (4) = 7.49 (0.1120)	

Note: “***”, “**”, “*” refer to the significance level at 1, 5 and 10%. (.) refers to probabilities. In SEM model there is spatial lambda not spatial rho.

Source: Authors’ processing.

Based on the findings, we strongly reject the null hypothesis, with a p-value lower than 1% and χ² test statistic of 21.23. Therefore, the perfect model is spatial

Durbin model with cross-sectional fixed effect (SDM-FE), because it has a high level of R^2 and Log-Likelihood and low value of AIC and BIC.

Table 6 displays the estimation result of the dynamic SDM-FE model with differenced lag (3) or dlag (3), we select this model due to the low value of AIC and BIC. Yu et al. (2008) recommend using the bias-corrected QML method to estimate the SDM-FE dynamic model with both space- and time-lagged dependent variables. The outcomes from table 6 display that the variable WANS or Spatial rho has a positive and significant coefficient ($\rho=0.156$), suggesting the existence of positive spatial spillover effects and a non-random spatial distribution of adjusted net savings in these countries. The signs of renewable energy consumption and non-renewable energy consumption are negative and significant at the significance level of 5%, while the sign of GDP is positive and significant at the significance level of 1%.

Table 6. Dynamic SDM-FE with dlag (3)

	SDM with dlag (1)	SDM with dlag (2)	SDM with dlag (3)			
Spatial rho	0.156*** (0)	0.152*** (0.001)	0.156*** (0)			
Log-Likelihood	-2027.837	-2209.458	-2027.837			
R ²	0.8294	0.3061	0.8294			
AIC	4073.673	4436.916	4073.673			
BIC	4113.98	4477.223	4113.98			
Dynamic SDM						
Variables	Coefficient (Prob)					
REC	-1.218*** (0.007)					
NREC	-1.059** (0.020)					
GDP	0.308*** (0.001)					
WREC	-0.058 (0.893)					
WNREC	0.041 (0.926)					
WGDP	-0.055 (0.470)					
Effect variables	Direct effect		Indirect effect		Total	
	SR	LR	SR	LR	SR	LR
REC	0.104 (0.293)	-1.211*** (0.008)	-0.069 (0.644)	-0.173 (0.720)	0.036 (0.840)	-1.384** (0.041)
NREC	0.168 (0.140)	-1.050*** (0.024)	-0.056 (0.727)	-0.048 (0.922)	0.112 (0.528)	-1.098 (0.109)
GDP	0.313*** (0)	0.317*** (0)	0.075 (0.205)	-0.024 (0.765)	0.388*** (0)	0.292** (0.022)

Note: “****”, “***”, “*” refer to the significance level at 1, 5 and 10%.

Source: Authors' processing.

4.4 Discussion

The results show that there is a negative impact of renewable energy consumption; therefore, this finding is consistent with earlier research by Sari Hassoun and Ayad (2020) and Zhu et al. (2024), which indicates that the "financial crowding out" theory can be behind such outcomes. These developing countries from the MENA and Sub-Saharan regions may have small attention on private investment and a smaller capital stock in the future, which could lower their national saving rates and slow long-term economic growth. Additionally, early-stage energy changes can

put a pressure on national savings before the long-term environmental benefits (lower depletion) fully materialise. From our point of view, this suggests that the use of renewable energy may provide energy while generating tiny air pollution (CO₂ and GHG emissions). This finding indicates that, even though they are detrimental to sustainability, these nations should take advantage of vast and neglected renewable energy resources to speed up the process of mobilising resources. Local private businesses, government programmes, and donor aid may support renewable energy technologies, which are prolific in developing economies to provide services to rural households at lower costs. We can also state that renewable energy can function optimally in rural and underdeveloped areas where it is challenging to produce energy from traditional fossil fuels, like the least sustainable countries of Burundi, Cameroon, Democratic Republic of the Congo, Guinea, Guinea-Bissau, Kenya, Sierra Leone, and Togo. Besides, renewable energy may be less vulnerable to price and value swings that impact consumers of non-renewables like petrol and oil. This could boost the value of adjusted net savings in countries with high levels of sustainability like Senegal, Tanzania, Niger, and Mali. Customers are able to save money for future capital accumulations or increase their energy consumption due to the stable market price and value of renewables. The initial outlay of capital expenditures for the establishment of renewable technologies is higher, as with any development project. But lower energy costs, more services, and more jobs in the renewable energy industries eventually make up for this loss of capital expenditures. However, this result does not stand in with that of Güney (2019, 2021), Islam et al. (2022), Wei and Huang (2022), Noor et al. (2023), Ahmad et al. (2023), Sari-Hassoun and Kahwi (2024), Dradra et al. (2024), and Sari-Hassoun et al. (2025).

On the other hand, it is not surprising that non-renewable energy consumption has a negative impact on adjusted net savings given that energy from fossil fuels produces more air pollution than it does energy. Growing environmental degradation and extensive economic activity are posing health care challenges. In fact, GHG from fossil fuels is strongly linked to significant environmental and social costs. It is arguable that environmental pollutants, make matters worse. Furthermore, fossil fuel sources are highly costly, particularly when it comes to building power development projects. The fact that non-renewable energy has higher outputs or service-related costs than recipients can afford frequently hinders savings. In this case, consumers who use non-renewable energy are usually not eligible for any kind of subsidy, while in developing economies (Morocco, Jordan and Kenya) often provide incentives, for the use of renewable energy technologies, which reduce energy costs. Morocco provides financial aid to companies that generate renewable energy in an effort to lessen the nation's reliance on fossil fuels, and Kenya with its currently Africa's largest wind farm. This outcome is consistent with the findings of Güney (2019), and Sari-Hassoun and Ayad (2020). Therefore, high non-renewable energy usage in MENA and Sub-Saharan nations with significant fossil fuel reserves implies higher natural resource extraction rates and immediately lowers the value of the inventories of remaining resources. For instance, some countries such as Nigeria, Algeria, Saudi Arabia, and Angola depend a lot on fossil fuel rents, and it constitutes

a substantial portion of national income. However, instead of being reinvested in additional productive assets, wealth is being transformed from natural capital to consumable income due to the depletion of these non-renewable resources. Consequently, we can affirm once more that the results on renewable energy and non-renewable energy do not support the sustainable development goals 7 and 13 in these 31 countries from the MENA and Sub-Saharan regions. We can also declare that the shift in developing nations from fossil fuels to alternative sources of energy is a problem with institutional and climate inequality, and that government policies should primarily focus on renewable energy development.

Fortunately, GDP positively affects adjusted net savings, demonstrating that growth in the economic infrastructure supports sustainable development. This finding is significant, because it demonstrates that the economic growth is not always accompanied by environmental degradation and that it is on the right track to promote sustainable development. Since climate change and global warming have more to do with inadequate and ineffective environmental policies to reduce GHG than with economic growth, this result does not advocate for a growth reduction strategy to counter environmental pollution. Rather, it argues that the focus should be on identifying the factors that cause environmental pollution. This outcome is supported by the results of Güney (2021), Sari-Hassoun and Kahwi (2024) and Sari-Hassoun et al. (2025). According to Keynesian consumption theory and the Solow growth model, a great rise of the economic growth does not only enable a higher domestic savings capacity, but increases the propensity to save as absolute income levels rise as well.

On the other hand, to study the direct, indirect (spillover) and total effect, we employ the same analysis, as Chica-Olmo et al. (2020) study. In order to properly understand the model's coefficients, the direct, indirect (spillover), and overall impacts of each explanatory variable have been determined. A change in an explanatory variable will have a spillover effect, which implies that it will not only affect the country's adjusted net savings, but also the adjusted net savings of its surrounding countries. In our case, the direct and total effect of renewable energy is not significant in the short-run, but significant in the long-run. In the short-run and long-run terms, however, the spillover effect is negative and insignificant. For instance, a 1% increase in renewable energy lowers the adjusted net savings level of neighbouring countries by 0.069% in the short-run and by 0.173% in the long-run, suggesting that the generation of renewable energy has an unfavourable and negligible spillover effect on sustainability as a whole. As a result, the renewable energy consumption policies of one country will not impact the sustainable development of its neighbour. In the long-run, the indirect effects of renewable energy consumption make up about 12.5% of the total effects $((-0.173/-1.384) * 100)$. This emphasises how insignificant policy decisions have an impact on renewable energy consumption in neighbouring countries' sustainability.

The non-renewable energy consumption variable produces the same results but differs in its total impact, which is negligible over the long and short terms. Consequently, there is a negative and insignificant contagion between neighbouring

countries, leading to spatial independence. The findings from renewable energy consumption and non-renewable energy consumption demonstrate that neighbouring nations have very different policy frameworks and do not typically copy one another for a variety of reasons, including the existence of regional synergies. However, GDP has a positive and significant direct and total effect the both in short and long run, but it has an insignificant spillover effect.

5. Conclusions

We study the impact of renewable energy consumption, non-renewable energy consumption and GDP on adjusted net savings in 31 MENA and Sub-Saharan nations during the period of 2000 and 2021. We establish that there is a positive and significant spatial autocorrelation ($\rho=0.156$), meaning that the spatial distribution of adjusted net savings is not random. The GDP sign is positive and significant, but the renewable energy consumption and non-renewable energy consumption signs are negative and significant. This indicates that these countries are prepared to create new value added based on creative systems, with an emphasis on GDP and the growth of the primary economic sectors.

The situation for these 31 developing countries is further made worse by renewable energy consumption and non-renewable energy consumption's detrimental effects on adjusted net savings. As a result, encouraging clean energy policies and focusing on energy efficiency is essential. Governments should give the energy transition a top priority by enacting laws that support it, investing in infrastructure, and offering incentives for clean technology. A good and accuracy regulations provide a strong foundation for the creation of an all-encompassing plan for the switch to renewable energy and increase national energy portfolios. Furthermore, these regulations can also stimulate creativity and make it easier for cutting-edge technologies to advance, while offering a clear path for the development of the energy industry. This allows a number of nations to draft and implement progressive legislation with specific objectives for raising the share of renewable energy, reducing emissions, and enhancing energy efficiency. It can also foster innovation and facilitate the advancement of cutting-edge technologies while providing an obvious path for the growth of the energy sector.

However, it is not an easy task for policymakers to take sustainability, economic diversification, and the energy transition into account, particularly with middle-income countries that produce oil and gas. Expanding the clean energy sector can also result in substantial job and economic opportunities, but it will be important to determine whether these can be pursued in the same localities where the use of fossil fuels is decreasing. These 31 developing nations can create support for workers and communities, diversify their economies, and create new revenue streams by redistributing their earnings and gains from other industries. In addition to the economics of the areas and communities that are likely to be impacted by the transition, policymakers also need to understand the size and scope of who will be most impacted by filling in data gaps about the skills, wages, and demographics of

oil and gas workers. Nigeria is present in our analysis, and it formed an alliance between the Environmental Rights Action-Friends of the Earth Nigeria and the Nigerian Labour Congress, one of the biggest trade unions in Africa, aims to inform employers and the government about the need for a fair renewable energy and economic diversification for workers in the agriculture and petroleum industries.

Unfortunately, the mechanisms and channels by which renewable energy consumption, non-renewable energy consumption, and GDP affect adjusted net savings are not described in detail in this study; rather, it only examines the direct and indirect effects of these factors on adjusted net savings. Subsequent studies may try to characterise other elements. Additionally, sustainable development covers a variety of topics, for example, the human development index (HDI) which covers aspects of health, life expectancy, education, and standard of living. Future studies could include more nations and years, or they could analyse sustainable development separately for the developed and developing worlds. The impact of the COVID-19 pandemic on sustainability was not considered in the paper due to data availability issues. Therefore, it would be worthwhile to look into how the pandemic and institutions have affected sustainable development in later studies.

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