DO COSTS OF RENEWABLE ENERGY INCREASE GENERATION? AN EMPIRICAL TEST ACROSS EURASIAN COUNTRIES

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Abstract. *Currently, renewable energy plays a vital role in the modern global economy to improve affordable soft and cheap energy. Additionally, growth of the population, dependent on import energy and shortage of natural resources, conflicts between countries (Russia and the Ukraine) and sanctions force to solve the energy problems globally. Considering the generation of renewable energy between costs on it, we investigate how much investment on renewables increases dependent respectively. We explore the effect of capital costs from government or investment on renewable energy generation, using data from 72 Eurasian nations for 2019, taking into consideration investment cost variables. We use levelized cost of electricity (LCOE) estimation to tuck up costs of variables which included capital, operation and maintenance. Besides, we include modeling other variables to show the estimating capital variable, and the results were almost unchanged. We use cross sectional secondary data from the sites Global Economy and Our World in Data, report of IRENA and the study reveals the positive relationship with initial investment which refer to improving this type of energy sector. Though, operation and maintenance costs are implicit and not concrete because of different types of plants to generate the energy, for instance, in solar PV labor costs are taken 15% to 20% from the generation in a year, in wind or hydro production of energy are different as well. In operation and maintenance costs are fixed and variable costs that subtracted from generation and equalized per year. According nebulosity, the operation and maintenance costs are omitted in our research. Finally, we checked for robustness standard error tests to avoid heteroscedasticity.*

Keywords: *renewable energy generation, capital, initial investment, LCOE.*

INTRODUCTION

Today energy is an important resource in every nation. The countries conduct various energy policies to distribute daily consumption to avoid shortages. According the goal SDG 7 of United Nation access to affordable energy by 2030, (UNSD, 2021) and models of World Energy Model (WEM), Energy Technology Perspectives (ETP), Global Energy and Climate (GEC) which adopted by International Energy Agency (IEA) to refer transition for renewable energy by 2050.(IEA, 2022) Hence, renewables are developing sector-by-sector and region-by-region to transform from traditional into alternative energy and replace to diversify the energy sector.

Implementation of renewable energy by government and investor impose in differently from both side. Financing from government require subsidizing to equalize for internal or external price of energy. The main cost of renewable energy by government is subsidizing for public power system.(Zhao et al., 2014) Government can subsidy such as interest rate, financing entirely of the project, providing in-tariff policy etc. . In previous years for constructing traditional energy power generation plants have been commissioned 61% state-owned enterprise and 35% from private companies.(Steffen, 2018) Additionally it depends on government budget to allocate expenditure for realization of electricity or energy plants. In terms of government expenditure, investment incentives are the main important indicator to finance Renewable Energy Sources projects respectively. Moreover, projects of RE should be considered with stakeholders and government in different stages (Lam & Law, 2018) and accept Energy Service and Power Purchase Agreements.(Ottinger & Bowie, 2016) But, Power Purchase Agreement in some countries is not implemented and this risk to financing RE projects, the costs which include capital flow can be decreasing concerning investment of private sector that give the result decreasing of development RE plants.(Taghizadeh-hesary & Yoshino, 2020) According financing by government, RE supports by international organizations on the frame of SDG 7(International Renewable Energy Agency, 2022). So, initial capital or investment define the government expenditure and finance flows by international organization (some emerging countries receive).

Considering the cost of renewable energy we can explore the improvement and implementation the projects of RE. Compare with creation RE technology with today's update equipment, it is differ from with price decreasing and installation is cheaper than previous technology and it has increased confidence for using (Ellabban et al., 2014). Especially wind energy supposed one of the low cost technology (Østergaard et al., 2020)(Blaabjerg et al., 2014)

Operation and maintenance cost for RE installation is more sensitive because of different type soft energy, such as, solar PV, wind, hydro, geothermal, biomass etc. .Thus, estimation and analysis reveal some uncertainty.(Wilson, 1984) We used a cross-country dataset of 72 Eurasian countries for the period 2019 and our proxy variable is capital cost the other variables are independent vector variables which reveal the significance to the model.

In our study we take one proxy variable: initial cost for installation RE or capital cost that understanding with government and investor costs, investments from international organization that we use jointly as capital investment. Operation and maintenance (thereafter O&M) cost we omit because of opacity distribution in this case and it derives from capacity of generation installation in total.(Wilson, 1984) According the positive relationship between RE generation and costs, we find that costs are the main indicator and without any investment have not development in this field.

Our results show that capital cost has a positive relationship with RE generation. Moreover, this study impact to invest on RE generation to achieve for sustainable and affordable energy resources. This finding not only substantially contribute to the extent literature, but also pay attention for policy and decision makers to increase the share of generation RE among Eurasian countries especially nations that dependent to traditional energy. Finally, we use OLS econometrics method and check for robustness standard error tests to avoid heteroscedasticity.

Literature review

Installation equipment of RE plants cost of capital is important for successful energy transition. Analyzing one country's such a case "least likely case sampling"(Steffen, 2018) Germany new power plant investments in 2010-2015 and use empirical logit regression, answer eight potential economic and finance theory concerning projects of RE. Additionally, the study answer the questions how important project finance in developed, low-risk countries and what drivers reasons to use financing in RE.

Using weighted average cost of capital and spectrum of estimation methods for the private cost of capital for renewable energy projects is used and evaluate the empirical evidence from 46 countries for the period 2009–2017.(Steffen, 2019) In this case, the author emphasis the methods that more reliable for estimating the cost of capital for RE projects.

Estimating investment risk and return among 96 countries (Polzin et al., 2019) private finance RE projects reveals that feed in-tariff, auctions, renewable portfolio standards develop and increase risk return. Moreover, these study not only understanding investment return, but also analyzing generic instrument such as credibility that impact investment risk.

Willingness to investment for RE installation is crucial to investors to applicate and transit for successful energy transition. According to this, lack of information about potential investors who finance RE that the research is based large-scale representative surveys that consist of 2260 respondents in Austria and Switzerland.(Ebers Broughel & Hampl, 2018) The study reveals impact of socio-demographic and socio-psychological characteristics on individuals' willingness to invest in community renewable energy projects using logistic regression and test difference between investors and non-investors.

Method and data

To evaluate project in economic finance theory we use net present value for the effectiveness of the project. In RE projects we analyze and give result through LCOE which reveals project payback. LCOE is an estimate of the net present value of the unit cost of electricity (e.g. in $/MWh) over the lifetime of the generation technology.(OECD, 2015)(Bloomberg L.P., 2013)

To estimate cash flow of RE installation we use levelised cost of energy (LCOE) instrument that refer to discounting lifetime cost divided by discounted lifetime generation. Fig.1

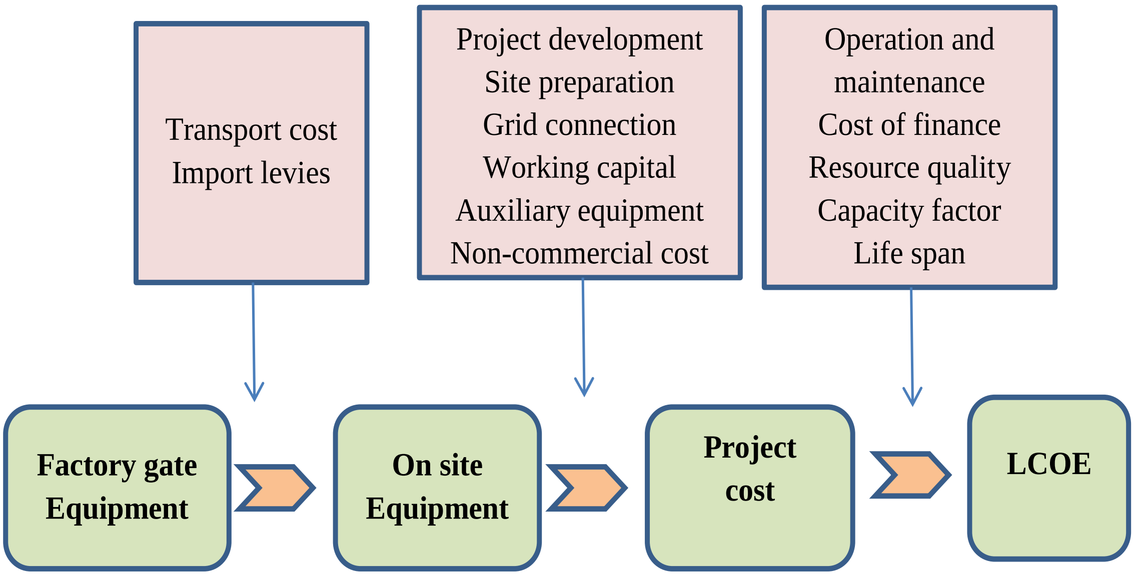


Figure 1. Renewable power generation cost indicators and boundaries.(Santos et al., 2018)

Hence, Fig.1 we derived the formula of levelised cost of energy and clarifying with generation of power from the installation.

$$\sum P_{MWh} * MWh * (1+r)^{-t} = \sum [(Capital_t + O\&M_t + Carbon_t) * (1+r)^{-t}]$$

According of this formula, we find on the left-hand side the discounted sum and on the right-hand side the discounted sum of costs and there are:

P_{MWh}= The constant lifetime remuneration to the supplier for electricity;

MWh = The amount of electricity produced in MWh, assumed constant;
$(1+r)^{-t}$= The discount factor for year t (reflecting payments to capital);
$Capital_t$= Total capital construction costs in year t;
$O\&M_t$= Operation and maintenance costs in year t;
$Carbon_t$ = Carbon costs in year t;

P_{MWh} is a constant over time, it can be brought out of the summation, and equation can be transformed into:

$$LCOE = P_{MWh} = \frac{\sum[(Capital_t + O\&M_t + Carbon_t) * (1+r)^{-t}}{\sum MWh * (1+r)^{-t}}$$

P_{MWh} is annual generation of Renewable Energy of each country which we use in our study and it covers 72 nations. The data for each country we drag from the site Global Economy.(Economy, n.d.) It reveals RE generation in billion kilowatts in hour for 2019.

$Capital_t$ is Public RE finance flows plus International financial flows to developing countries in support of clean energy research and development and renewable energy production, including in hybrid systems (concerning SDG 7.a.1).(International Renewable Energy Agency, 2022)

$O\&M_t$ is fixed O&M costs were added to each year in the cash flow model.

$Carbon_t$ – Carbon price is common to all countries over the lifetime of all technologies. Many countries do not have an explicit carbon price. In these cases, USD 30 can be taken to be the shadow price of carbon, and not a cost that would be borne by investors.

In our model we only take Capital cost, O&M costs are implicit and not concrete because of different types of plants to generate the energy, for instance, in solar PV labor costs are taken 15% to 20% from the generation in a year, in wind or hydro production of energy are different as well. In operation and maintenance costs are fixed and variable costs that subtracted from generation and equalized per year. Carbon cost applies when during construction factor use traditional or fossil fuel.

The basic econometric model has the following specification:

$$RE\_gen_i = \alpha_0 + \alpha_1 Capex_{cost} + \beta X + \varepsilon_i$$

where RE_gen is the dependent variable. Capex is the main independent variable. The vector X includes political-economic determinants of sustainable energy power. The X defines also as a part of variables Energy Transition Index (ETI)(WEF, 2018) (Singh et al., 2019) (see appendicies) that adopted by World Economic Forum. Additionally, to check of robustness test we add the variables related to ETI which denote Transition readiness enabling dimensions, there are trade openness and human development index. Trade openness define exports plus imports as percent of GDP and its squared term to account for the power generation Kuznets curve (indicating of degradation then improving of RE generation (Dinda, 2004). To avoid from heteroscedasticity we estimate the regression model with the ordinary least squares method and robust standard errors.

Results

Table 2 shows mail regression results. In Model 1, the RE_gen is first regressed on Capex_cost only. The coefficient is positive and statistically significant at the one percent level. The results indicate that a one million USD increase in Capital yields 101439 kilowatt hours (it equals 101, 44 megawatt hours) increase in Renewable power generation. We can give an example China in this case, the more invested to RE sector, the higher power generation from it

(International Renewable Energy Agency, 2022). It is important to note that capital of nations explains 99.19 percent of variation in cross-country differences in environmental performance.

In Model 2, we add variable of investment freedom index which shows insignificance in this model. The one type of renewable energy generation like solar plays the main role in RE field (Alrikabi, 2014) (Abdin et al., 2013) and we add variable of solar electricity generation in Model 3. The result is significant and positive relationship at the one percent level and it indicates when solar electricity increase one billion kilowatt hours the all type of renewable power generation power increase in 2.12 billion kilowatt hours respectively.

VARIABLES	Description	Mean (std dev)	Source
RE_gen	Renewable power generation, billion kilowatt hours	60.11 (240.2)	Our World in Data(*Our World in Data*, n.d.)
CAPEX_cost	Capital (USD million)	56,029 (235,843)	IRENA
ifindex	Investment freedom index	63.57 (22.70)	Global Economy
solar_elec	Solar electricity generation, billion kilowatt hours	4.827 (14.98)	Global Economy
elect_cons	Electricity consumption, billion kilowatt hours	244.8 (874.1)	Global Economy
coal_cons	Coal consumption, thousand short tons	124,163 (596,960)	Global Economy
innovation_in	Innovation Index	40.44 (11.83)	Global Economy
trade_open	Exports plus imports as percent of GDP	96.51(45.89)	Global Economy
hdi	Human Development Index	0.800 (0.108)	Global Economy

Table 1. Variables used: descriptions, descriptive statistics and sources

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
CAPEX_cost	.00101439***	.00101079***	.00092827***	.00070961***	.00071839***	.00071706***
ifindex		-.15387133	-.0901063	.12876339	.10707966	.07539827
solar_elec			2.1212738***	1.3667596***	1.2911712***	1.2727844***
elect_cons				.0782914***	.04127762**	.03855869*
coal_cons					.00005195***	.00005629***
innovation_in						.08559051

_cons	3.2760809	13.732184	5.8887899	-8.3198802	-4.6175047	-5.7848153
R2_a	.99196628	.99194871	.99791243	.99883063	.99904341	.99902737
aic	648.28936	519.17566	402.83755	374.76189	365.59587	367.27774
bic	652.84269	525.25172	410.48564	384.322	377.06801	380.6619

Legend: * p<.1; **p<.05; *** p<.01

Table 2. Capital and Renewable power generation: main results

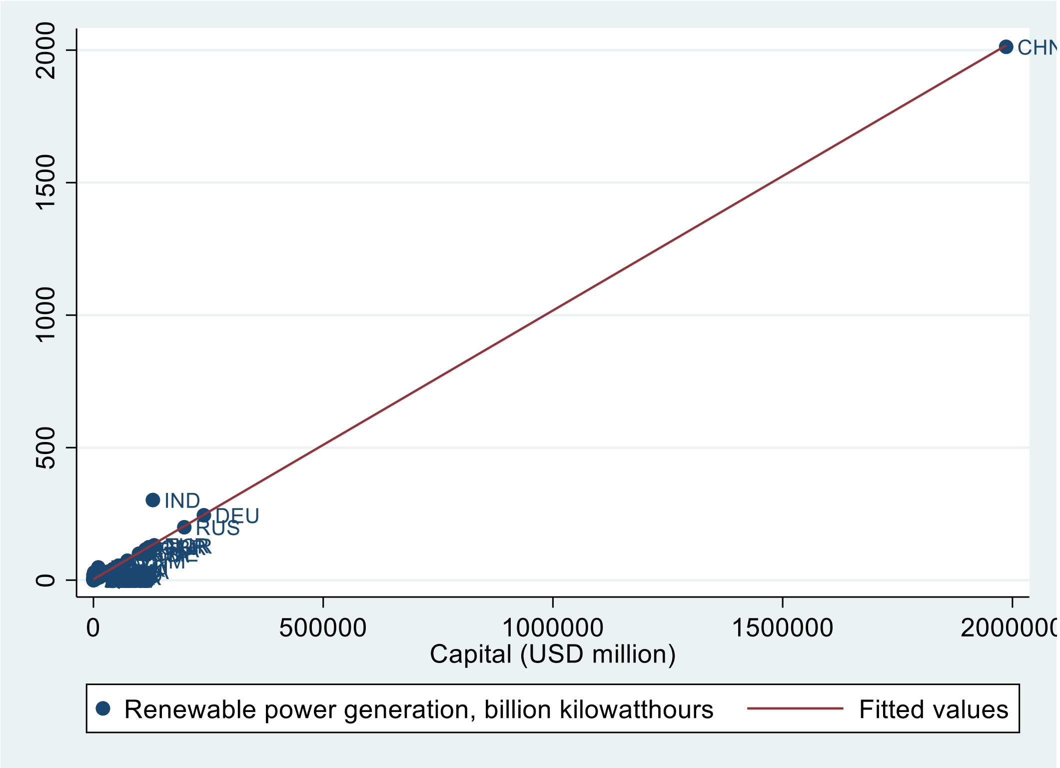
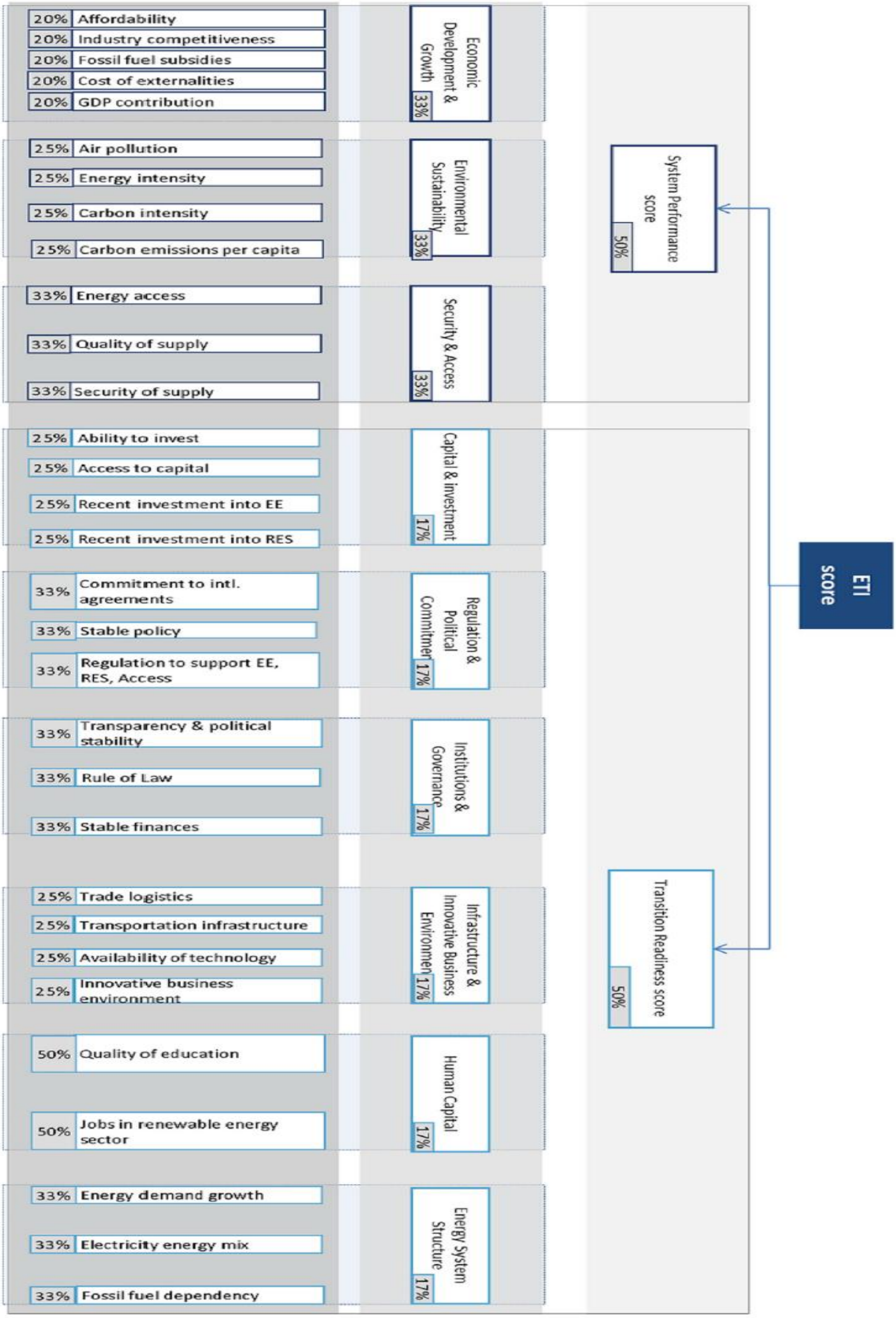


Figure 2. Scatter plot between RE power and capital

The impact of capital on renewable energy generation is investigated further in Model 4 and 5, where electricity and coal consumptions are included in the regression. Electricity and coal consumption have a positive relationship with renewable power generation, but when we add coal consumption the demand for this type of energy sources is increased to compare with electricity consumption. While electricity consumption increases one billion kilowatt hours, the RE generation increases 0.078 billion kilowatt hours. So, coal consumption is associated with 0.00005 billion kilowatt hours increase in the RE. There is a huge discrepancy between electricity and coal consumption. Electricity at any situation is important in current economy and it yields from RE and traditional energy referring to using energy sources by diversified (Islam et al., 2022). Hence, sustainable and affordable RE is being developed; traditional energy as fossil fuel, coal, oil, gasoline consumption is being decreased that is shows in our study as well by declining coal consumption.

In Model 6 reveals that the results for capital remain unchanged when innovation index is included in the regression. Innovation index is statistically insignificance. So, in this analysis the Column 5 is suitable for our case and statistical criteria are shown in Table 2. Additionally, the regressions reported that positive link between capital and RE generation controlling for investment freedom index, solar electricity generation, electricity and coal consumption, innovation index as well. We test robustness of these findings in the next sub-section.

Appendices



Robustness tests

To test the robustness of the link between capital and RE generation, we put on questions. We study whether this effect remains intact if the linkage between trade openness and human development index is taken into account. In previous, we find that Column 5 from Table 2 regression is statistically acceptable to clarify research and capital for each nation explains percent of variation indicator is higher than others. Therefore, to check robustness test we take regression variables Column 5 and add two variables: trade openness and human development index. Trade openness related to RE sources that indicate environmental sustainability (W. Wang et al., 2022) and impact for installation equipment concerning to RE generation. Trade openness that denote exports plus imports as percent of GDP has an inverted U-shape effect on the RE generation. It shows the EKC hypothesis (Dinda, 2004). In our research trade openness suggests that in the early stages of exports plus import as percent of GDP increase and RE generation degradation, but beyond some level of exports and imports as percent of GDP levels trade growth leads to increase of renewable power generation. But in our study trade openness is not significant in Column 1.

VARIABLES	**(1)**	**(2)**
CAPEX_cost	.00071608***	.00070807***
ifindex	.13984778*	.06332757
solar_elec	1.2400886***	1.2501079***
elect_cons	.03882***	.04293302**
coal_cons	.00005686***	.00005325***
trade_open	-.10937479	-.11911956
trade_open squared	.0002896	.00034767
hdi		4.8112008
_cons	1.0692231	2.7642054
R2_a	.99903507	.99918646

Legend: * p<.1; **p<.05; *** p<.01

Table 3. Capital and Renewable power generation: robustness tests

Column 2 shows the impact of variable human development index which introduce how it influence for the RE power generation. In previous scholar research investigate the impact of renewable energy consumption to HDI and economic growth (Z. Wang et al., 2018). Additionally, HDI is an inclusive indicator for measuring the standard of living that explains more detailed economic development than the gross domestic product (Kaewnern et al., 2023). We add HDI for each country to know the impact for RE generation and to test robustness of the connection between capital and renewable power generation. Though, second variable HDI is insignificance, we investigate that relationship between capital and renewable energy generation remain the same. Column 2 in Table 3 shows the robustness tests of the regression and adjusted R^2 is higher as well.

To conclude, renewable power generation is linked to capital, and this link remains strong when we control for various measures of economic and inclusive indicators, and energy consumptions.

Discussion and conclusion

This study contributes to the literature on renewable energy resources and its generation by initial investment of government, investors and international organizations, a composite measure that assesses comprehensive progress toward affordable energy sustainability across national boundaries. Using the statistics from IRENA (International Renewable Energy Agency, 2022) cost for each Eurasian countries, we provide novel evidence that nations with capital for renewable better on affordable energy sustainability, even after controlling for economic indicators and different type of energy consumptions variables. Although, the data for each country has omitted and is not enough our study with robustness test prove that capital is the main source to improve the renewables generation.

Moreover, recent studies valuable evidence for the direct importance of Eurasian countries living standard of life to cheap, affordable energy sources hence, this refer to ecological sustainability (Liao et al., 2023) as well. Most scholars paid attention link between environmental, GHG and CO2 emissions in their research but the main role to develop the renewable is financing the installation equipment on it, and it is primary issue to improve across Eurasian countries. Additionally, in this continent includes low, lower middle and upper middle income group countries and this empirical estimates provide policy suggestions. Our econometric results show renewable power generation will improve as a function of capital even after controlling for conventional determinants of RE generation. Additionally, Model 5 explained that solar electricity generation as a part of renewable and plays the main center of generation of renewable; while electricity consumption is always important current circumstances and if renewable power generation is developed, coal consumption will be a little relatively other type of energy consumption. This at least partially explains recent progress in high capital such as China that shifts attention from rapid RE generation. The econometric model supplies robust evidence that capital is entitled to more consideration in the formation of energy policy.

We believe that this study serves as a foundation for future explorations establishing evident causality between initial investment development and energy sustainability. Future prospective studies should also investigate low, lower middle and upper middle income group Eurasian countries nexus using other proxy variables for capital and renewable power generation.

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