Energy, renewable energy and growth: Evidence for BSEC countries

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I investigate the relationship between output, energy use and renewables for BSEC countries, using a neoclassical production function with capital and labor as additional variables explaining the output. In this specification, I found a positive linkage between energy use and output respectively growth for most BSEC countries; exceptions are Azerbaijan and Georgia. Regarding renewables, there is no negative relation, that I assumed as initial hypothesis. Contrary, if growth and renewables are linked, the relation is positive. Here again, I found two exceptions, Albania and Turkey. In both countries, an expansion of installed renewable capacity negatively affects growth. The used model is based on OLS and panel OLS with country fixed effects. More advanced models were discarded as they seemed to be misspecified.

1 Introduction

In recent years, politics of many countries focused on reducing energy consumption and on enhancing the deployment of renewable energy sources (RE) within the energy sector. This follows higher awareness for environmental issues, particularly climate change, the following need to reduce carbon emissions and to some extent the intention to reduce dependency on fossil fuel imports and vulnerability to rising fuel prices.

This development has drawn the attention of economic research, as there might be several economic consequences of such policies. One important potential consequence might be the effect of such policies on economic growth, in two aspects: One focuses on the linkage between energy consumption and growth: Several studies have shown that energy use might be an input factor for the growth function. If this is true, policies that aim at reducing energy consumption might have a negative consequence for growth. But there is no consensus in academic literature: While some studies identified a causal relationship running from energy use to growth, or a bi-directional causality, other studies showed reverse causality or no causality at all.

The second aspect is the potential effect of renewable energy use on growth. Although several studies investigated this potential nexus in recent years, theoretical foundation why the source of

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energy should matter for growth is not really elaborated. One potential reason for such an influence could be that renewable energy sources need higher initial investment, while operating costs are low (just as one example, El Fadel, Rachid, El-Samra, Bou Boutros, and Hashisho (2013) discussed those high initial investments). Those investments might tie up capital that is then not available for other, perhaps more profitable investments. If this assumption holds, this would suggest a negative impact of investment in renewables on growth, and this effect should occur when capacity for renewables is expended. On the other hand, studies have shown that investing in renewables might enhance growth, in the form of jobs and private sector development (see for example Kost (2015), de Arce, Mahía, Medina, and Escribano (2012) or Supersberger and Führer (2011)). This would suggest a positive impact running from renewables to growth, and once more, this should occur mainly for capacity expansion, as most of those socio-economic effects are linked to the development of an industry that develops and constructs installations for renewable energy. However, for a positive relation between renewables and growth, one should consider reverse causality: An increase of GDP might increase environmental awareness of the population, and this might direct governments to increase investments or investments incentives towards renewables (this is one basic assumption of the theory of an Environmental Kuznets Curve); and, if growth causes an increase of energy use, a higher GDP would result in higher carbon emissions and for energy importers in higher dependency on those imports. Given international commitments to reduce or stabilize carbon emissions, and given the higher vulnerability of economies that highly depend on fuel imports, both aspects might direct governmental action towards renewables.

This paper wants to contribute to the debate on an energy-renewable-growth nexus in three aspects: First of all, it will focus on the countries in the Black Sea region, defined by membership in the Organization of the Black Sea Economic Cooperation (BSEC). Second, its starting point is a neoclassical production function, taking into account capital and labor as important production factors. And third, it will discuss a potential energy-growth and renewable-growth nexus with multiple considerations: First, that for the investigation of a potential renewable-growth nexus, energy use and renewables should both be used as variables; using only renewables and not energy use might distort the results, as renewables might just serve as proxy for energy. Second, that the results might be sensitive to the used renewable variable, as renewable energy, renewable electricity generation and renewable electric generation capacity might differ in their effects on growth: Renewable electricity might in some way be more "productive", as larger parts of renewable energy might be used for heating or other functions in households; on the other hand, one should then control if a (positive) impact from renewables on growth is not a proxied effect of electrification. And, as already discussed, some of the potential effects of renewables on growth might be more related to capacity expansion than to renewable generation, so that both capacity and generation are taken into account.

Following these considerations, the core of this paper is the estimation of four specifications of a neoclassical production function, all including capital, labor and energy use and then either electricity generation from renewable sources in total values, the share of renewable electricity generation in total electricity generation, the installed capacity for electricity generation from renewable sources or the share of renewable capacity in total installed capacity. The results show that the hypothesis of a negative effect running from renewable capacity to growth is confirmed for two countries, Albania and Turkey; for the latter only if one uses expenditures for research and development as additional variable in the production function. For all other countries and for the panel grouping all countries, there is either no or a positive relation between renewables and growth. Energy use is positively linked with growth for most countries in the region; exceptions are Azerbaijan and Georgia, but causality seems to be bi-directional or running from growth to energy use.

The reminder of the paper is as follows: The next section will give a short overview on the use of energy and renewables in BSEC countries, followed by a literature review (section 3). Subsequently, the model, data source and econometric methodology is discussed (4; here, I also discuss why I decided to discard the idea of investigating the relationship between output, energy use and renewables more in-depth with a vector error correction model (mainly because several assumptions for a VECM do not hold). This section is followed by the presentation and discussion of the empirical results (5). The last part is a short conclusion (section 6).

2 Energy use and renewables in BSEC countries

Table 1 shows energy use, electricity generation from renewable sources and available capacity for generation from renewable sources for the years 1990 and 2014 (for the former Soviet Republics, complete data is only available from 1992 onwards and for Serbia even later, what will be discussed in section 4.2). All transition economies show a decrease in energy use that mainly happened in the early 1990ies, in the economic crisis of 2010 and for some countries due to some other crisis (like the Kosovo war for Serbia or the Ukrainian-Russian conflicts). In Greece, energy use sharply decreased during the European debt crisis, explaining why the increase in energy use from 1990 to 2014 is that small.

All BSEC countries use renewable sources to generate electricity, and with the exception of Armenia and Azerbaijan, generation from renewable sources increased from 1990 to 2014. In Armenia and Azerbaijan, the decrease of renewable generation is driven by a decrease of generation from hydro power, which might be caused by reduced water levels in Lake Sevan and the ongoing Armenian-Azerbaijanian conflicts. In 1990 (resp. 1992), renewable generation was dominated by hydro power, only Greece, Romania and Turkey reported generation from other renewable sources. In 2014, hydro power is still the most important source of renewable electricity, but except Albania and Georgia, all countries now report generation from non-hydro renewables. The EU members and Turkey outperform both with respect to the increase of renewable generation and to the use of non-hydro renewables: Greece today generates 16.3 per cent of its electricity from non-hydro renewables, followed by Romania (13.3), Bulgaria (6.3) and Turkey (5.0). No other BSEC country reports a share of non-hydro sources of more than 1 per cent (own calculations based on US Energy Information Administration (2017).

For several countries, the increase of installed renewable capacity was smaller than the increase of electricity generation. This shows that for those countries, a larger part of the increased generation might not be driven by new installations, but by a more effective use of the existing ones. For other countries, it seems that they decided to invest in RE technologies they used only

Table 1: Energy use and renewables in BSEC countries

		Energy use		Renewable generation		Generation from non-hydro renewables	Renewable capacity		Non-hydro renewable capacity
		Gt of oil equivalent	% increase	TWh	% increase	GWh	GW	% increase	MW
Albania	1990	2,672.8		2.8			1.7		
	2014	2,335.7	−12.6	4.7	68.8		1.8	7.1	1.0
Armenia	1992	4,130.6		3.0			1.0		
	2014	2,958.7	−28.4	2.0	−34.1	4.0	1.3	30.2	4.0
Azerbaijan	1992	18,193.7		1.7			0.8		
	2014	14,322.4	−21.3	1.5	−13.8	179.0	1.2	44.8	43.0
Bulgaria	1990	28,224.2		1.9			2.0		
	2014	17,898.4	−36.6	7.3	286.3	2,780.0	3.9	97.3	1,756.0
Georgia	1992	8,659.1		6.4			2.7		
	2014	4,389.9	−49.3	8.3	28.9		2.7	−0.6	
Greece	1990	21,440.6		1.8		2.0	2.2		50.0
	2014	23,134.4	7.9	12.2	579.5	7,800.0	7.4	234.3	4,664.0
Moldova	1992	6,845.9		0.3			0.1		
	2014	3,301.5	−51.8	0.3	9.7	15.0	0.1	7.8	5.0
Romania	1990	62,254.7		11.0		2.0	5.7		
	2014	31,688.5	−49.1	26.9	144.9	8,325.0	10.6	85.8	4,336.0
Russia	1992	795,646.3		172.0			43.0		11.0
	2014	710,882.7	−10.7	177.2	3.0	3,670.0	49.3	14.7	518.8
Serbia	1992	15,447.0		9.6			1.8		
	2014	13,258.8	−14.2	10.9	14.2	32.0	2.2	25.8	6.0
Turkey	1990	52,717.3		23.0		80.0	6.8		18.0
	2014	121,541.1	130.6	52.3	127.5	12,083.0	28.0	312.0	4,373.0
Ukraine	1992	219,532.9		7.7			4.7		
	2014	105,683.2	−51.9	10.1	30.9	1,689.0	6.7	43.3	887.0

Source: The World Bank (2017) (energy use) / US Energy Information Administration (2017) (electricity generation and capacity) / own calculations to a smaller part. For Georgia, the slight negative development of installed capacity might just be a consequence of data imprecision, as EIA reported the data rounded to less digits for 1992 than for 2014.

Today, most BSEC countries have policy measures in effect to support renewables. Greece started policy towards renewables already in the 1980ies and established its first support scheme in 1994, most other BSEC countries followed in the first half of the 2000s, Bulgaria in 2007, Moldova in 2009 (for Moldova, see eclareon GmbH (2012), for all other countries, International Energy Agency and International Renewable Energy Agency (2016)). For Georgia, neither the joint IEA/IRENA database nor the RES LEGAL database provides information on policies towards renewables. Serbia today has the most ambitious target, 27 per cent of gross final energy consumption from renewable sources in 2020, followed by Romania (24), Greece (18), Bulgaria (16), Ukraine (11) and Azerbaijan (9.7). Turkey (30 in 2030), Armenia (26 in 2025) and Russia (4.5 in 2020, excluding large hydro) have set targets only for renewable electricity (International Energy Agency and International Renewable Energy Agency (2016)). For Albania, Georgia and Moldova, the IEA/IRENA database does not report a RE target.

3 Literature Review

The most recent study on the energy-growth nexus in the Black Sea region I could identify is Koçak and Şarkgüneşi (2017). Their panel includes most BSEC countries (except Armenia, Azerbaijan and Serbia) and Macedonia (FYROM). They found a statistically significant positive coefficient for renewable energy consumption (as percentage of total energy consumption) in a growth model that also includes capital (gross fixed capital formation as percentage of GDP) and the labor force (labor force participation rate 15–64) as explaining variables for per capita GDP growth; all variables are used in logarithms. They investigated causality individually for the countries in their panel, with mixed results: For five countries, they identified a causality running from renewables to growth, a bi-directional relationship for three countries and no causality at all for Turkey.

An older study that includes those BSEC countries who were part of the Soviet Union is Apergis and Payne (2010). They also used a growth model that explains the output (natural logarithm of real GDP in constant 2010 US$) by renewable electricity consumption (net consumption in million kWh), capital (natural logarithm of gross fixed capital formation in constant 2000 US$) and the labor force as inputs. They focused on panel cointegration and found a bidirectional causality between renewable electricity consumption and growth both in the long and in the short run.

Both studies are part of rapidly increasing research on a potential linkage between renewable energy and growth. Sebri conducted a meta-study in 2015 (Sebri (2015)), for that he identified 40 studies on this topic with 153 different settings.[1] His primary result was that the different outcomes of the studies regarding the direction of causality between renewable energy and growth depend on the selected countries, used variables, the time frame and the level of development of the countries selected. He showed that the probability of identifying causality running from

[1] Sebri did not only use peer-reviewed papers, but also some grey literature like working papers.

renewables to growth is higher if a panel includes countries on the same stage of development.

The research on a linkage between renewables and growth is itself a branch of the research on an energy-growth nexus that goes back to Kraft and Kraft (1978). Since their study on the United States between 1947 and 1974, this issue was investigated in many studies for different countries, panels of countries, time frames, model specifications and econometric methods, with mixed results regarding causality between energy and output. So far, there is no consensus about the existence or direction of causality. The so-called "growth hypothesis" (causality running from energy to growth) was found for several settings, but others identified the "conservation hypothesis" (causality from growth to energy), "feedback hypothesis" (bi-directional causality) or "neutrality hypothesis" (no causality).

A relatively recent meta-study on this topic was conducted by Menegaki (2014). He showed, like Sebri (2015) for the renewable-growth nexus, that the results depend on model specification and econometric methods used and countries included. He points out, among other aspects, that a larger number of countries included leads to a higher GDP elasticity, and including capital as additional independent variable results in a lower GDP elasticity.

4 Data and Methods

4.1 Production function

Like Koçak and Şarkgüneşi (2017), Apergis and Payne (2010) and several other studies, I use a neoclassical production function that explains the output by several input factors, including capital and labor. Expanding their models, I use both energy use and renewable electricity consumption as input factors. My consideration is that using only renewable energy or electricity consumption, as done by those authors, might hide a potentially negative effect from renewable energy on growth: The renewable energy variable might serve as proxy for energy use, and if there is a positive relation between energy and growth and a negative relation between renewables and growth, the first might dominate upon the latter or at least neutralize a negative effect if only renewable energy is used as input factor. Some studies have chosen a related specification, using renewable and non-renewable energy as inputs (see Mert, Boluk, and Buyukyilmaz (2015) or Apergis and Payne (2012)), but in my opinion, using non-renewable energy as additional input does not solve the described problem.

Hence, the production function is specified as follows, with Y indicating the output, K the used capital, L the labor force, E the used energy and RE renewable electricity; B_0 is capturing total productivity, β_x the elasticity of variable x:

$$Y = B_0 K^{\beta_K} L^{\beta_L} E^{\beta_E} RE^{\beta_{RE}} \tag{1}$$

"Renewable electricity" (RE) is used either as electricity generation from renewable sources (RE_G), the share of renewable generation in total electricity generation ($RE_{G,S}$), installed capacity for generation from renewable sources (RE_C) or the share of renewable capacity in total installed capacity ($RE_{C,S}$)

To obtain a linear equation that is more suitable to econometric methods, equation (1) was logarithmized, and to eradicate the different size of the BSEC countries, per-capita values are used. This leads to the following specification, where minor letters indicate the natural logarithm of the respective variable in per-capita values:

$$y = \beta_0 + \beta_K k + \beta_L l + \beta_E e + \beta_{RE} re \tag{2}$$

The use of both energy use and renewable electricity raises concerns of multi-collinearity. I tested for this with auxiliary regressions and with a specification of the production function where I only used energy, but not the renewable variables. Auxiliary regressions showed only a weak relation between energy use and renewable electricity, and dropping the renewable variable did not remarkably change the results of the estimations for the energy use. This suggests that multi-collinearity is not a problem here.

4.2 Data

Data on GDP (Y), capital (K) and labor (L) are taken from Penn World Tables, version 9.0 (Robert C. Feenstra, Robert Inklaar, Marcel Timmer (2016)). GDP is the real GDP at constant national prices (in million 2011US$), capital the capital stock at constant national prices (in million 2011US$) and the labor force the number of persons engaged. To obtain per-capita values, those variables have been divided by the total number of population of the respective countries in the respective year, using data from the World Development Indicator database (The World Bank (2017)). The World Development indicators are also the source for per-capita energy use (E, measured in kg of oil equivalent). The use of renewable energy is proxied with renewable electricity, which is obtained from the US Energy Information Administration's (EIA) database (US Energy Information Administration (2017)). I consider two variables for renewable electricity: Generation from renewable sources and available capacity from renewable sources. The consideration is that a potentially negative effect of renewables on growth might arise when capacity is expanded, as those investments might tie up capital, and some arguments for a positive effect of renewable electricity on growth also focus more on capacity expansion than on increasing generation (as already discussed in the introduction). Both variables, renewable generation (RE_G) and renewable capacity (RE_C) are transformed to per-capita values by dividing them by total population. In addition, I specified the same model using the share of renewable electricity generation in total electricity generation or the share of renewable capacity in total installed capacity, calculated by using additional EIA data.

In principle, the data set covers the years from 1900 to 2014. As some countries became independent later, the covered time frame is shorter for some countries, leading to an unbalanced panel. The first year included for a country is the first year mentioned for it in table 1.

For Serbia, only the years 1993 to 2014 are covered, following the break-up of Yugoslavia. EIA data is available only from 2006 onwards (when the State Union of Serbia and Montenegro broke up), as EIA do not recalculate data when countries break up (other than Penn World Tables and World Development Indicators). To extend the time series for Serbia, I estimated renewable electricity generation and installed renewable capacity back to 1993 using the EIA data for the Union of Serbia and Montenegro; to estimated Serbia's part, I calculated the average proportion between Serbia and Montenegro for 2006 to 2008 and then assumed that this proportion was the same for all years back to 1993.[2]

4.3 Methods

The data is first tested for unit roots, both for all countries individually as for the panel. For individual countries, the Dickey-Fuller test and the Phillips-Perron test were used; only the first is reported, as both tests did not give different results. For the panel, the Im-Pesaran-Shin test (IPS) and the Hadri LM test are applied. The both tests have different null hypotheses: IPS tests if all groups contain a unit root, so that the alternative is that at least on group is stationary (but not all). Hadri's null is that all panels are stationary.

I then proceed with the estimation of an OLS model for the individual countries and a panel LS model with country-fixed effects, based on equation 2. As the unit root tests indicate that the data is mainly (but not always) integrated of order 1, the LS models are estimated in first differences. This means that in effect the model shows how an increase of input factors affects GDP growth. The estimates were done for four specifications, two including renewable generation in total numbers or shares, the other two using renewable capacity.

To address causality in this context, I estimated variations of equation 2 for all countries (and the panel) for which the estimated coefficient either for energy use or renewable generation, respectively renewable capacity, was statistically significant. I then replaced the respective variable by its first lag, and I estimated a model where energy, renewable generation or renewable capacity was explained by the other input factors and the first lag of GDP growth, leading to those equations for a nexus between energy and growth:

$$y_t = \beta_0 + \beta_K k_t + \beta_L l_t + \beta_E e_{t-1} + \beta_{RE} re_t \tag{3}$$

$$e_t = \beta_0 + \beta_Y y_{t-1} + \beta_K k_t + \beta_L l_t + \beta_{RE} re_{t-1} \tag{4}$$

and the following for a nexus between renewables and growth:

$$y_t = \beta_0 + \beta_K k_t + \beta_L l_t + \beta_E e_t + \beta_{RE} re_{t-1} \tag{5}$$

$$re_t = \beta_0 + \beta_Y y_{t-1} + \beta_K k_t + \beta_L l_t + \beta_E e_t \tag{6}$$

The underlying consideration is that if there is causality, it might be persistent, so that a lagged variable should still be able to explain the present outcome, and that reverse causality is then no longer a problem, as leads normally cannot explain earlier variables in LS specifications.

The initial idea of this paper was to proceed with a vector error correction model to explore the relationship between output, energy use and renewable more in-depth. For this, I specified two VEC models, which were estimated individually for the BSEC countries. The first model included all variables: output, capital, labor, energy use, renewable generation or renewable capacity. The second model was smaller, including only output, energy use and renewable generation or renewable capacity, the renewable variables either in per-capita values or in shares.

[2] This assumption more crucial for generation than for capacity, as the first might be more volatile in reaction to different weather, economic or political conditions.

However, as both the unit root tests and specific tests for VEC models showed that for most countries and specifications, a VEC model would be misspecified—as the underlying process is not integrated of order 1, the null of zero cointegration vectors could not be rejected in the Johansen test for cointegration, or the eigenvalues were not within the unit cirle—, I decided to discard the VECM and to stay only with the OLS model.[3]

5 Empirical results

5.1 Unit root tests

Table 2 shows the results for the unit root tests for the used variables. As already mentioned, the results are mixed: Particularly for capital and GDP, I cannot reject the null of a unit root for individual countries in levels and in first differences, so that those variables might follow an I(2) or even higher process. For the labor force, energy use and the two renewable electricity variables, the null of the Dickey-Fuller test might even be rejected in levels, so that for those countries, those variables might follow an I(0) process. Thus, I cannot conclude that all variables are integrated of order one.

Given the results for the individual countries, it is not surprising that the panel unit root tests show similar results: With exception of the capital variable, the IPS test confirms that at least one group is stationary in the first difference for all other variables, and for energy use and the renewable electricity variable, at least one groups is stationary already in levels. On the other hand, the Hadri LM tests always lead to a rejection of its null that all groups are stationary for all variables except renewable generation in the first difference.

Despite empirical results, considerations on economic theory suggests that growth-related variables might follow an I(1) or I(0) process, but there is few reason for I(2) or higher processes. An I(2) or higher process would indicate that growth of the respective variable has a trend to accelerate or decelerate. My model includes a variable that should capture growth in total productivity (β_0) which might be the main explanation for such an acceleration or deceleration. Therefore, I decided to proceed with OLS models in first differences, but I want to underline that the results should be interpreted with care.

5.2 OLS estimations

Table 3 reports the results of our estimations for the model including renewable generation. Here, we can identify a positive relation between growth of energy use and economic growth for ten countries (for Greece, only in the specification with the share of renewable generation, and for Bulgaria, only on a significance level of 10 per cent) as well as for the panel. The estimations for the models including renewable capacity confirm this finding for the energy use, as table 4 shows. Only for Azerbaijan and Georgia, the coefficient for energy use is insignificant in all specifications.

If one uses lagged variables, the coefficient of lagged energy use (equation (in the specification of equation 3) is significant for Turkey and the panel for the models with renewable generation

[3] I considered additionally a VAR, but found the same problems.

Table 2: Results of unit root tests

Country		y	k	l	e	re_G	re_C
Albania	level	0.213	3.551	**−3.156	−1.555	*−2.843	***−7.844
	first difference	**−3.091	−1.238	***−4.638	***−3.523	***−5.688	***−5.135
Armenia	level	−0.004	1.933	−1.177	***−4.022	−1.787	−1.182
	first difference	**−2.982	−1.297	***−4.935	*−2.688	***−3.984	***−4.500
Azerbaijan	level	−1.428	−1.532	**−3.036	**−3.379	***−4.410	**−3.075
	first difference	2.805	*−2.577	***−5.648	−1.779	−1.318	−2.294
Bulgaria	level	0.494	1.754	−1.399	***−4.004	−0.655	0.627
	first difference	*−2.718	−1.188	−2.243	***−4.204	***−5.656	***−5.093
Georgia	level	−0.354	3.288	***−6.713	**−3.033	−0.990	0.134
	first difference	−2.040	−1.456	*−2.777	*−2.630	***−6.077	***−4.970
Greece	level	−1.159	−1.468	−0.356	−0.943	−1.167	3.587
	first difference	−1.894	−0.620	−2.270	***−4.295	***−5.853	*−2.762
Moldova	level	−1.625	0.398	*−2.746	***−5.184	***−4.017	−1.720
	first difference	***−3.559	−0.990	***−5.191	*−2.814	***−6.816	***−4.229
Romania	level	0.529	2.206	−1.475	***−3.771	−1.300	4.608
	first difference	−2.562	−1.833	***−6.392	**−3.242	***−5.659	−1.965
Russia	level	0.025	4.864	−0.309	*−2.728	−2.355	−0.123
	first difference	−2.257	−2.252	**−3.015	**−3.050	***−5.868	***−4.445
Serbia	level	−0.530	2.044	−0.697	−2.390	**−3.118	−0.300
	first difference	***−3.807	−1.758	***−3.867	***−4.218	***−5.302	***−3.437
Turkey	level	−0.649	−1.209	−0.800	−0.590	*−2.665	1.312
	first difference	***−5.878	*−2.679	***−4.353	***−5.667	***−6.596	**−3.131
Ukraine	level	−1.407	−0.982	−2.016	***−3.611	***−3.993	4.243
	first difference	−2.065	*−2.805	***−3.998	***−4.371	***−5.044	**−3.140
Panel (IPS)	level	4.775	12.158	−0.870	***−4.652	**−2.318	7.360
	first difference	***−4.340	−0.574	***−6.841	***−6.613	***−9.680	***−6.696
Panel (Hadri)	level	***39,090	***37,548	***24,544	***17,526	***12,795	***30,714
	first difference	***4,237	***17,429	*1,375	***3,860	−1,905	***6,273

*, **, *** mark significance for rejecting H_0 of a unit root (ADF test for individual countries) or that all groups contain a unit root (IPS test for the panel) or that all panels are stationary (Hadri test for the panel) on a significance level of 10, 5 or 1 per cent, respectively

and in addition for Ukraine in the models with renewable capacity. This suggests a causality running from energy use to growth. Lagged GDP as independent variable in a model explaining energy use (following equation 4) is significant for Armenia, Turkey and the panel when capacity is used and in addition for Serbia in the generation setting. This suggests a causality from economic growth on energy use, and for Turkey and the panel, causality would then be bi-directional. For all other countries, lagged variables are not significant in both specifications.

Regarding generation of renewable electricity, the absolute value is positively related to growth in Georgia, Moldova and in the panel, and the share of renewable generation for Armenia, Georgia, Greece, Moldova, Serbia, Ukraine and the panel. Only in the panel lagged renewable electricity generation significantly influences present growth, while lagged GDP growth is insignificant in the reversed specification. For Armenia, both lagged variables explain the other present variable, so that bi-directional causality is suggested.

Regarding renewable capacity, there is a significantly positive relation to growth only for Greece and the panel, and both only for the specification in shares. For the panel, causality is suggested to run from growth to the capacity share, while for Greece, none of the lagged variables can explain the others present value. For Albania, the estimated coefficient of an increase in installed capacity is significantly negative, suggesting that investing in renewables hinders growth. Causality is very likely running from renewable capacity to growth here, as there is no good reason to assume reverse causality for a negative relation between those two variables if absolute numbers are used.

The estimated coefficients for capital and labor are in line with economic theory: If the estimated coefficient is significant, its value is positive. For the labor force, there are several negative signs for the coefficient, but none of them is significant, so that they are by assumption zero. That this happens for many countries in the region suggests that growth there is decoupled from the development of the labor force.[4]

The performance of the models is good, measured with the adjusted R^2 and the F value, except for Armenia. This shows that the model seems not to be misspecified.

The results for renewable capacity show that the initial working hypothesis that expanding the use of renewable electricity might hinder growth is not confirmed except Albania. Quite contrary, there is evidence that renewable electricity and growth are positively related, although not in all countries in the region. Even if there is no linkage between renewables and growth, this means that investing in renewables is neutral with respect to growth, so that those investments might be considered for other reasons (like meeting COP21 targets) without affecting the growth rates.

Albania seems to be an outlier with its negative relation between renewable capacity expansion to growth. To deal with this, one should re-think the policy towards renewables and review if there are distorting incentives (as well as for Turkey, where a potential negative effect is identified in the following section).

[4]Capital and labor force are not in the focus of this paper. Regarding the labor force, it might be interesting to exploit additional data, like the average hours worked, to study this question more in-depth.

Table 3: Estimation results for renewable electricity generation

	β_K	β_L	β_E	β_{RE_G}	$\beta_{RE_{G,S}}$	β_0	Obs	R^2	F
Albania	0.763	−0.373	***0.519	−0.005		−0.005	25	0.5434	***8.14
	0.888	−0.398	***0.519		−0.334	0.315	25	0.5485	***8.29
Armenia	0.324	−0.384	0.157	−0.014		0.046	22	0.1271	1.76
	−0.128	−0.795	***0.706		***0.750	**−0.193	23	0.6327	***10.47
Azerbaijan	***1.900	**3.865	−0.236	−0.087		−0.067	22	0.4961	***6.17
	**1.903	*3.499	0.085		−0.525	−0.008	23	0.5132	***6.80
Bulgaria	***0.657	0.302	*0.231	0.012		*−0.022	25	0.6416	***11.74
	***0.643	0.324	*0.220		0.047	−0.024	25	0.6387	***11.60
Georgia	***4.563	**0.795	−0.147	*0.144		***−0.058	22	0.8047	***22.63
	***3.754	***1.222	−0.127		***0.601	***−0.532	23	0.9087	***55.75
Greece	1.120	**0.634	0.280	0.017		−0.011	25	0.6513	***12.21
	**1.816	**0.577	**0.410		*0.246	**−0.050	25	0.6949	***14.66
Moldova	1.450	0.285	***0.700	*0.208		*0.033	22	0.4683	***5.62
	2.202	−0.229	***0.749		***3.224	**−0.193	23	0.612	***9.68
Romania	**0.681	0.025	***0.615	0.046		0.016	25	0.6878	***14.22
	**0.666	−0.025	***0.596		0.155	−0.029	25	0.6905	***14.39
Russia	0.515	**0.881	***0.843	0.155		0.008	22	0.7724	***18.82
	**1.843	*0.646	***1.115		***2.088	***−0.409	23	0.8418	***30.26
Serbia	***2.762	0.061	***0.482	0.132		−0.012	22	0.5150	***6.58
	***3.592	0.164	***0.493		*0.881	*−0.291	22	0.5824	***8.32
Turkey	*0.743	−0.159	***0.614	0.053		−0.016	25	0.7073	***15.50
	0.689	−0.159	***0.730		0.000	−0.015	25	0.6668	***13.01
Ukraine	*3.954	0.128	***0.987	−0.005		0.024	22	0.5924	***8.63
	**3.988	0.402	***0.937		*1.932	−0.103	23	0.6666	***12.00
Panel	***1.066	0.194	***0.362	**0.034		−0.002	279 (12)	0.428 / 0.288 / 0.398	***13.49
	***0.948	0.373	***0.514		**0.371	***−0.115	286 (12)	0.509 / 0.317 / 0.202	***44.90

*, ** and *** mark significance for rejecting H_0 that a coefficient is zero at a significance level of 10, 5 or 1 per cent, respectively

Table 4: Estimation results for renewable electric capacity

	β_K	β_L	β_E	β_{RE_C}	$\beta_{RE_{C,S}}$	β_0	Obs	R^2	F
Albania	0.691	−0.340	***0.500	**−0.144		0.004	25	0.6263	***11.06
	0.830	−0.396	***0.511		−0.490	0.430	25	0.5639	***8.76
Armenia	0.250	−0.301	**0.169	−0.125		*0.053	22	0.1393	1.85
	0.202	0.134	***0.448		0.574	−0.147	23	0.4185	***4.96
Azerbaijan	***1.892	*3.343	−0.235	0.178		−0.066	22	0.4790	***5.83
	**1.483	*3.222	0.014		1.951	−0.37	23	0.5478	***7.66
Bulgaria	***0.645	0.322	*0.220	0.005		−0.021	25	0.6378	***11.57
	***0.635	0.329	*0.218		0.042	−0.028	25	0.6396	***11.65
Georgia	***4.364	*0.625	−0.105	0.810		**−0.060	22	0.7784	***19.44
	***4.477	***1.523	−0.131		0.006	−0.057	23	0.8493	***32.00
Greece	0.984	**0.911	*0.302	0.149		−0.014	25	0.6583	***12.56
	**2.520	**0.545	**0.325		*0.398	**−0.137	25	0.6992	***14.95
Moldova	1.840	−0.039	**0.716	−0.030		0.028	22	0.3494	**3.82
	0.180	−0.116	**0.835		0.604	−0.029	23	0.4511	***5.52
Romania	*0.640	0.032	***0.613	0.049		0.017	25	0.6690	***13.12
	*0.590	0.006	***0.604		0.099	−0.011	25	0.6758	***13.51
Russia	0.448	**0.843	***0.896	0.958		0.003	22	0.7805	***19.67
	0.940	**0.849	***0.813		2.550	−0.535	23	0.7866	***21.27
Serbia	**2.508	0.125	***0.485	0.192		−0.010	22	0.4921	***6.09
	**3.443	0.036	***0.461		−0.338	0.064	22	0.5080	***6.42
Turkey	0.689	−0.156	***0.744	0.042		−0.017	25	0.6696	***13.16
	*0.727	−0.181	***0.713		−0.076	0.015	25	0.6741	***13.41
Ukraine	**3.721	0.184	***1.062	0.992		0.003	22	0.6509	***10.79
	**3.214	0.241	***1.035		1.850	−0.152	23	0.6373	***10.67
Panel	***1.085	0.174	***0.357	−0.060		−0.001	279 (12)	0.424 / 0.330 / 0.398	***18.94
	***0.997	0.457	***0.463		*0.212	*−0.070	286 (12)	0.477 / 0.513 / 0.341	***42.07

*, ** and *** mark significance for rejecting H_0 that a coefficient is zero at a significance level of 10, 5 or 1 per cent, respectively

5.3 Robustness checks

The results presented in the previous subsection suggest that energy use and renewables might enhance growth. But one might doubt if the positive effect captured by the renewable variable is really an impact of the use of renewable electricity on growth. It might be that the variables for renewables proxy effects from other variables.

One of those effects might be that electrification might have a positive effect on growth, regardless of the source of electricity. This might arise as electrification might be correlated with digitalization or the use of other more effective technologies. I tested for this by estimating additional models that either included both, renewable electricity generation and total electricity generation (or capacity, respectively), or renewable electricity was replaced by electricity. None of those specifications changed significantly the results for those countries where the estimated coefficient for renewables was significant, neither for the panel estimation.

A second aspect might be that investing in renewables is a sign for the openness of an economy to new technologies and perhaps as well for foreign investments. In this case, renewables would proxy this effect. To test for this, I specified several models that includes expenditures for research and development and FDI inflows as additional variables besides those specified above. There was one important change: For Turkey, including R&D expenditures leads to a significant and negative coefficient for renewable capacity. This suggests that Turkey might be the second country in the region where investing in renewables negatively affects the growth rate (besides Albania, see above).

6 Conclusion

According to my results, economic growth and energy use are closely linked in most BSEC countries, except Azerbaijan and Georgia. The test for causality I performed is ambiguous. It seems that growth and energy use develop parallel, but one cannot identify which of the two forces the other to change. In some way, this suggests a bi-directional relationship. For Turkey and the Ukraine, there is evidence that causality is running from energy use to growth. The same evidence shows up for the panel.

Those results suggest that economic policy in the region should be concerned of the energy use. One should as well keep in mind that investments in energy efficiency might be beneficial if they are properly developed, as they can reduce dependency on fuel imports and vulnerability from rising fuel prices. But badly designed and ambiguous policies that just aim at reducing energy consumption without considering economic effects might have negative consequences for the economies, following my results.

Regarding renewable electricity, I could not confirm the initial hypothesis that an expansion of renewable capacity might have a negative effect on growth, as investments in renewables might tie up capital. Quite contrary, there is a positive relationship between renewable electricity and growth for several countries. For the panel, causality is suggested to run from renewable electricity generation to growth and from growth to the share of renewable capacity. For Armenia, causality seems to be bi-directional between growth and the share of renewable generation. For the other countries where renewable generation is significant (for generation in absolute values, Georgia and Moldova; for the share of renewable generation, Georgia, Moldova, Greece, Russia and Ukraine, for the share of renewable capacity, Greece), the tests for causality are once more ambiguous.

There are two important exceptions from this result: For Albania, an expansion of installed renewable capacity has a negative impact on growth, and for Turkey, the coefficient for renewable capacity becomes significantly negative if one includes R&D expenditures as additional explaining variable. For the latter, the negative effect is covered, as renewable electricity seems to serve as proxy for the adaption of innovations, and the second has a positive impact on growth. For both countries, this negative effect that showed up in my results should be explored more in-depth. Given that the effect occurs only on those countries, while in all other countries, there is either no or a positive effect suggests that the negative effect measured might be a result of the specific situation of the two countries. At first glance, this could be a result of a bad designed policy towards renewables that might set the wrong incentives for investments in renewables. If this is confirmed by further research, the policy towards renewables should be revised, but not abandoned: Given the results for the other countries in the region, a well-design policy towards renewables might be beneficial.

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