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Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO_2) emissions: Empirical evidence from the panel of biomass-consuming countries

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ABSTRACT

Even though the energy-growth-environment literature put a lot of effort into investigating the impact on carbon dioxide (CO_2) emissions of aggregate energy consumption, aggregate renewable energy consumption and aggregate non-renewable energy consumption, the importance of biomass energy consumption for the environment is not well covered. Besides, the existing studies do not reach a consensus on the validity of the Environmental Kuznets Curve (EKC) hypothesis. Therefore, this study fulfills the gaps in the literature by investigating the impact of biomass energy consumption on CO_2 emissions in the EKC model for the panel of biomass-consuming countries. By using some control variables and applying econometric approaches that take into account heterogeneity and cross-sectional dependence across countries in the panel, we find that the EKC hypothesis is valid and biomass energy consumption decreases the level of CO_2 emissions. These results are supportive of the international notion that investing in biomass energy infrastructure and biomass supply are an appropriate direction the energy policy makers can use in their efforts to reduce environmental degradation in the long-run.

1. Introduction

The amount of carbon dioxide (CO_2) emissions has dramatically gone up in the last decades. More precisely, the world CO_2 emissions went up from 19 million kilotons (mkt) in 1980 to 36 mkt in 2013, implying that it increased by about 80% over this period [82]. Due to large rising in CO_2 and greenhouse gas (GHG) emissions in general, the parties to the United Nations Framework Convention on Climate Change (UNFCC) have attended yearly conferences since 1995 so as to handle increased global emissions to limit global warming. This objective requires great declines in the carbon emission which may be accomplished through a great effort and commitment on the part of the participating countries. Kyoto Protocol is the result of UNFCC, where the participating countries have promised that they would bring down their CO_2 and GHG emissions. In February 2016, an amendment was made to the protocol in Doha,[1] which was ratified by 60 Countries. In November and December of 2015 UNFCC was held in Paris,[2] where the participants of this Paris Protocol promised to keep the global worming under control maximum $2C^0$ above the level of pre-industrial period.

The most important question thus is not whether a reduction in the level of emissions is necessary but – to that it seems there is an overall consensus in society – but "How can countries decrease the pollution?" According to the EEA [35]; one appropriate way to decrease CO_2 emissions is to rise the percentage of non-fossil share in the energy supply mix. In fact several studies have shown that as more renewable energy is consumed the less carbon is emitted [32]. More precisely, renewable energy is found to be an environmentally-friendly type of energy for panel of Organization for Economic Co-operation and Development (OECD) countries [24,28,49,73], panel of North African countries [48], panel of European countries [33,55], panel of 27 advanced countries [5],

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[1] http://unfccc.int/kyoto_protocol/doha_amendment/items/7362.php (accessed on March 8, 2017).

[2] http://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf (accessed March 8, 2017).

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Malaysia [77], Kenya [6], Turkey [26] and Italy [18].

Part of renewable energies, biomass is a relatively newly developed source of energy that will assist in the world's energy sustainability. As Bilgili and Ozturk [25]; p. 132) define it: "Biomass is basically a stored source of solar energy initially collected by plants during the process of photosynthesis whereby carbon dioxide is captured and converted to plant materials mainly in the form of cellulose, hemi-cellulose and lignin. Biomass includes crop residues, forest and wood process residues, animal wastes including human sewage, municipal solid waste food processing wastes, purpose grown energy crops and short rotation forests".

Following the existing literature, this empirical research investigates the effect of biomass consumption on the environment. The investigation of biomass energy in this literature is essential because countries would be strongly suggested to focus on the generation and use of energy from biomass if biomass energy consumption were discovered to be having a statistically significant negative influence on the level of pollution. In addition, biomass energy is forecasted to make up to one-third of the global energy mix by 2050 according to the International Institute for Environment and Development.[3] Bilgili and Ozturk [25] attribute the general trend towards biomass energy to five specific factors: a) biomass is renewable, abundant and easily generated, making it an excellent substitute to oil and thus reducing the countries' oil dependency and imports; b) the biomass generation is labor intensive and thus it can be conducive to poverty reduction and increase of rural employment; c) biomass is easily convertible to thermal energy and electricity; d) it is generally documented that biomass generally aids at the reduction of harmful emissions compared to the alternative energies traditionally used; e) biomass is a positive contributor to energy security.

Appreciating, thus, the importance of the biomass we aim at investigating the effect and dynamic relationships of its consumption with CO_2 emissions, taking into account the macroeconomic conditions of the various countries. The majority of past studies had focused on the impact of renewable energies in aggregate to the emissions profile of one or more countries, and not on specifically the biomass use. Our study also chooses a panel of countries that have exhibited a biomass contribution in the consumption mix, and not just a general group of countries. The reason for that is to, in a way, encourage non-biomass user countries by demonstrating the benefits with regards to emissions already achieved in biomass using countries.

The main objective of this study is to measure the impact of real income and biomass energy consumption on CO_2 emissions for the panel of biomass-consuming countries from 1985 to 2012. In the recent energy literature, the specific effect of biomass consumption to the environment and economic growth has been limited [2,3,22,25,60,62] in comparison with studies examining the effect of aggregate energy consumption or aggregate renewable energy consumption. These studies focused on groups of countries such as the European countries, the G7 or the West African countries without making a distinction between biomass intensive users and not. In our study, we selected a panel of countries where biomass is a contributor to the countries' energy consumption profile. During the literature review, it is noted that in the limited amount of studies dealing with the role of biomass, the majority focused specifically on the impact of biomass to economic growth and not to environmental profile of the country. This study aims at filling these gaps in the literature by examining the impact of biomass usage on the carbon dioxide emissions for the panel of biomass-consuming countries.

In order to evaluate the influence of biomass energy consumption on CO_2 emissions, this study primarily builds on the Environmental Kuznets Curve (EKC) model. According to the assumption of this model, the level of carbon emission increases as the level of real income-gross domestic production (GDP)-increases up to a point; after this point carbon emission decreases with real income [40]. In addition, this study uses the two mostly employed control variables-trade openness and urbanization-to investigate whether or not the results about the impact of biomass consumption and the validity of the EKC hypothesis change with other specifications.

Furthermore, this empirical study employs recently developed heterogeneous panel measurement methods with cross-sectional dependence (i.e. the CADF and the CIPS unit root tests, the LM bootstrap cointegration test, and the group-mean FMOLS) because we find that cross-sectional dependence and heterogeneity exist across countries in the panel, and disregarding the existence of cross-sectional dependence and heterogeneity in estimation methods may produce specious outcomes.

The paper is structured as follows: Section 2 presents and discusses recent literature on the broader theme of energy – economic growth nexus narrowing it down to the few studies on biomass. Section 3 explains the methodological approach and data of the study while Section 4 presents the empirical results. Finally, the last section concludes and discusses potential policy implications of the findings.

2. Literature review

The literature on the relationship between energy consumption, emissions and economic growth has received increasing attention during the last two decades, due to mainly the importance of the climate – energy – economics relationship for the future of the planet but secondly, due to the lack of consensus on the direction and the details of the causal relationship. The related studies suggest four hypotheses for the direction: neutrality, growth, conservation, and feedback. According to the growth hypothesis, energy consumption is a factor in the improvement of economic growth (Energy Consumption → Economic growth); while the exact opposite is argued by the conservation hypothesis (Economic growth → Energy consumption). The feedback hypothesis suggests that there is a bidirectional relationship between the two (Economic growth ↔ Energy consumption) while the neutrality supports that no relationship exists between energy consumption and economic growth.

Shahbaz et al. [75] however argue that the literature still seems insufficient because of the rapidly evolving technology in the sector and changing economic conditions globally. Although the initial studies on the topic focused on generally the relationship of total energy or electricity and economic growth, more recently, the discussion was refueled by the emphasis on sustainable development and environmental-friendly energy resources. Dogan [30] explains that this strand of literature has moved in investigating the relationship more thoroughly by disaggregating the total energy into different types (electricity, coal, natural gas, nuclear, renewables etc). This is firstly appreciating the dissimilar nature of the energy types and their effect to the economy, and also the different approaches to be followed from a policy perspective. This review of the literature discusses studies looking particularly at the nexus between renewable energies, emissions and economic growth and continues with specifically presenting recent studies on the causality between biomass energy consumption, emissions and economic growth.

Trainer [79] was among the first studies that evaluated the role of renewable energies on various economies. The study concluded

[3] The report is available at http://pubs.iied.org/pdfs/G03004.pdf (accessed on March 8, 2017).

that the use of renewable energies will not be detrimental to economic development. It should be noted here, that in the 1990s the cost of switching to renewables was substantially higher than nowadays; but nevertheless economic growth was found to be unaffected. Still in the middle of the 1990s, Byrne et al. [27] evaluated the energy supply mix and policy decisions in China to find that the adoption of solar energy could have positive effects on economic growth. Painuly [61] supported the notion that the utilization of wind energy in countries with available resources such as Netherlands can be conducive to economic growth and development.

Sadorsky [71] showed that in emerging economies, a long-run positive relationship between renewable energy consumption and real income can be confirmed when taking into account population effects. Apergis and Payne [10] confirmed the same statement for the OECD countries within a multivariate framework and a production function theoretical background (including capital and labour) using a Pedroni panel cointegration test. Their results confirm the feedback hypothesis. Frondel et al. [38] explained specifically the important impact on rising employment opportunities by the adoption of renewable energies in total for the case of Germany.

Focusing only in a few countries in Eurasia, Apergis and Payne [11] confirmed a long-run relationship between economic growth, renewable electricity consumption, capital and labour for the period 1992 to 2007. Fang [36] examined the relationship between renewable energy and economic growth for China for the period 1978 to 2008 including the traditional supply side variables (capital and labour) as well as the country's Research and Development (R&D) expenses. The interesting aspect of this study is that it examined the share of renewables to the country's supply mix and not the renewable energy volume and confirming the growth hypothesis.

Menegaki [56] is, to our knowledge, the only study that indeed confirmed the neutrality hypothesis for a group of twenty seven European countries. She explains that the reason for that might be the relatively low contribution of renewables to the supply mix in the period studies and expects that this relationship will change the stronger the renewables role is in the region. Tugcu et al. [80] study's findings showed that by using a production function framework the use of renewable energy is a conducive factor to economic growth for a group of highly advanced and industrialized countries (G7). Using a bivariate framework specifically, Kula [51] confirmed the conservation hypothesis for a selected group of 14 OECD countries. Ocal and Aslan [59] examined particularly the case of Turkey in the period 1990 to 2010 to confirm the conservation hypothesis: unidirectional causality from economic growth to renewable energy consumption. Inglesi-Lotz [43] also supported the advantages of renewable energy deployment for the economic welfare of the OECD countries; while Bhattacharya et al. [20] looking at the 38 top renewable energy consuming countries found out that renewable energy consumption has a positive effect to economic growth only for approximately half of the countries in the sample.

Looking next at studies-admittedly limited—focusing on the role of biomass to economic growth, Berndes et al. [19] through the findings of a survey argued that biomass is the most convenient source of energy for households especially with low initial costs of implementation and hence, better chances in market penetration. Payne [62] after investigating the relationship between biomass energy consumption and economic growth in US showed that a unidirectional relationship running from biomass to economic growth, findings confirmed recently for US by Aslan [13]; while Bildirici [22] confirmed the same results for a panel of mainly developing economies of Latin America. In the same year, Bildirici and Ozaksoy [23] examined a panel of countries and reported mixed results on the direction of the causality, but finding a long run relationship between biomass energy and economic growth for all. Looking at transition economies primarily, Bildirici [21] employed a panel ARDL approach to conclude in different results than the above mentioned studies: the feedback hypothesis was confirmed by the Granger causality test, meaning there was bidirectional causality between biomass energy and economic growth. Ozturk and Bilgili [60] examined a panel of 51 Sub-Saharan African countries by employing a dynamic multivariate panel analysis (openness and population were for example factors that were also included) and concluded that for all, the use of biomass energy contributes positively and significantly to the countries' economic growth.

With regards to the chosen theoretical framework of the study – the EKC hypothesis (the level of carbon emission increases as the level of real income or gross domestic production (GDP) increases up to a point; after this point carbon emission decreases with real income) – we have identified a number of countries employing it but not with a biomass focus [32,34]. To be exact, a study done for a panel of Association of Southeast Asian Nations-ASEAN proved that the EKC hypothesis is valid. [42,52], Italy and Denmark [1], panel of Central and Eastern Europe [14], panel of European countries [50], panel of Middle East and North Africa-MENA [12,37], panel of Central American countries [9], panel of upper-income economies [7], panel of OECD countries [24,49,73], panel of 27 advanced countries [5], Singapore and Thailand [70], Iceland [15], France [8,45], Malaysia [77], Turkey [26,39,72,83], Tunisia [74], Pakistan [58], Vietnam [78], Kenya [6], China [46,47,54] and Spain [16].

All in all, although in the energy literature, the relationship between biomass energy consumption and economic growth has been debated extensively, the effect of biomass usage to the level of emissions is neglected. That is where our paper finds its contribution in the literature.

3. Model and data

The first EKC model that we use is the following:

Model 1: $(CO_2)_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDP^2_{it} + \beta_3 BIO_{it} + \varepsilon_{it}$

To investigate whether or not results obtained from the first model about the impact of biomass consumption and the validity of EKC hypothesis change with other specifications, we also employ the following two models:

Model 2: $(CO_2)_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDP^2_{it} + \beta_3 BIO_{it} + \beta_4 TO_{it} + \varepsilon_{it}$

Model 3: $(CO_2)_{it} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GDP^2_{it} + \beta_3 BIO_{it} + \beta_5 URB_{it} + \varepsilon_{it}$

where i and t stands for countries and year; ε represents error term; β_1, β_2, β_3, $\beta_4$and β_5 are the coefficients on GDP, the quadratic GDP, biomass energy consumption, trade openness and urbanization. In case that $\beta_1 > 0$ and $\beta_2 < 0$, the EKC hypothesis is supported. In addition, β_3 is expected to be negative. In regards to data description, CO_2 emissions are in kilotons; GDP is the real gross domestic product in 2005 US$; BIO is electricity power generated from biomass and waste in kilowatt-hours; TO is the value of trade in 2005 US$; URB is urbanization measured as the ratio of urban population to the total population. Following Bhattacharya et al. [20] and Dogan [29]; this study takes production as proxy for consumption because the production is significant contributor to the environment. The annual data are from 1985 to 2012, and sourced from “the World Development Indicators” and “the US Energy Information Administration” (www.eia.gov). The 22 countries used in this study are Argentina, Australia, Austria, Belgium, Bolivia, Brazil, Switzerland, Chile, Colombia, Spain, France, Guatemala, Italy, Kenya, Luxembourg, Netherlands, New Zealand, Panama, Peru, Portugal, Sweden and the USA. It is important to note that we try our best to use maximum number of observations conditioning upon the availability of variables for the number of countries in the focused group. It is also worth mentioning that we transform the data into their natural logarithm in order to interpret the reported coefficients as the elasticities of the dependent variable (i.e. carbon emissions) with respect to the independent variables (i.e. GDP, the square of GDP, biomass energy consumption, trade openness and urbanization).

According to the descriptive statistics given in Table 1, the USA was the largest emitters of CO_2 in 2005, and had the largest real GDP in 2012. In addition, Panama produced the lowest level of emissions in 1989, and Bolivia produced the smallest real output in 1986. Furthermore, the USA was the largest consumer of biomass energy in 2012 while Panama was the smallest consumer of biomass energy in 1990. While the USA was the most openness country in 2012, Bolivia had the least trade activities in 1985. Last, large standard deviations of the analyzed variables suggest that data points are far from the mean. This simply implies that there is enough variability to work with this panel time-series data whereas there may be heterogeneity across cross-sections for the analyzed variables. We further discuss this issue in the next section.

4. Methods and empirical findings

The overall approach of our investigation includes testing firstly for potential slope heterogeneity (ignoring such heterogeneity of parameters might lead to a certain level of bias in the estimated parameters) [69]; then for cross-section among the countries of the panel (especially looking at indicators such as GDP, possible interdependence between countries through various channels such as trade, innovation and technology etc should be taken into account) [67] and then proceed with testing the series univariate characteristics (CADF and CIPS [68]) and existence of cointegration (Pesaran (1999, [67] and [64,65], concluding with the estimation of the long-run parameters to eventually quantify the magnitude of the impact of biomass consumption to CO_2 emissions.

We use the method developed by Pesaran and Yamagata [69] in order to check whether or not slope coefficients are homogenous. We specifically estimate the delta ($\tilde{\Delta}$) and the adjusted delta ($\tilde{\Delta}_{adj}$) and the results show that there is strong evidence to reject the null hypothesis of slope homogeneity and confirm the existence of slope heterogeneity at 1% level of significance (see Table 2).

Table 1
Descriptive statistics.

	Mean	Std. Dev.	Minimum	Maximum	Observations
CO_2	11.12	1.65	7.83	15.57	616
GDP	25.97	1.79	22.32	30.28	616
BIO	6.77	1.78	2.71	11.18	616
TO	25.41	1.68	21.47	29.09	616
URB	4.21	0.35	2.74	4.58	616

Note: Variables are valued in their natural logarithm.

Table 2
Results from heterogeneity tests.

test	GDP (GDP^2)	BIO	TO	URB
$\tilde{\Delta}$	56.28*	47.14*	53.06*	41.12*
$\tilde{\Delta}_{adj}$	59.03*	49.88*	56.04*	42.83*

Note: * denotes the statistical significance at 1% level.

In addition to testing heterogeneity, this study also carries out the Pesaran's CD-test [67] to find out whether cross-sectional dependence exists within each panel data. As shown in Table 3, the test shows evidence to reject the null hypothesis of cross-sectional independence at 1% level of significance. This result implies that we should take into account that the variables used are cross-sectionally dependent in the panel.

4.1. Panel unit root tests

In the presence of the issues of cross-sectional dependence and heterogeneity in the panel, the CADF and the CIPS panel unit root tests due to Pesaran [68] are used to determine the univariate characteristics of the series and define whether classic Ordinary Least Squares (OLS) – type of approach is going to be employed or cointegration methodological approaches.

Table 4 presents results from the panel unit root tests showing that all variables included in the model are I(1)- integrated of order one and hence, we need to consider and test for possible cointegration in our estimation of the long-run relationships.

4.2. Panel cointegration tests

Since the Pedroni panel cointegration test developed by Pedroni [63,66] is applicable for heterogeneous panels, it is firstly employed to investigate possible cointegration relationship between carbon emissions, real income, and the square of real income, biomass energy consumption, trade openness and urbanization. In the results of Table 5, there is enough evidence to reject the null

Table 3
Results from cross-sectional independence test.

	CO_2	GDP (GDP^2)	BIO	TO	URB
CD-test	31.55*	77.02*	54.62*	75.44*	64.90*
p-value	0.00	0.00	0.00	0.00	0.00

Note: * denotes the statistical significance at 1% level.

Table 4
Results from panel unit root tests.

	CADF		CIPS	
	Level	Δ	Level	Δ
CO_2	−1.80	−2.94*	−2.35	−5.39*
GDP (GDP^2)	−1.71	−2.89*	−1.28	−3.26*
BIO	−2.23	−3.10*	−2.32	−5.24*
TO	−2.05	−3.12*	−2.34	−4.11*
URB	−2.39	−3.73*	−3.36*	−5.88*

Note: * denotes the statistical significance at 1% level. Δ is the difference operator.

Table 5
Results from Pedroni cointegration test.

	Model 1		Model 2		Model 3	
	Statistic	p-value	Statistic	p-value	Statistic	p-value
Common AR coefficients (within-dimension)						
Panel v-statistic	−1.51	0.93	−1.04	0.85	−2.47	0.99
Panel rho-statistic	−0.20	0.41	0.51	0.70	1.20	0.88
Panel PP-statistic	−4.24*	0.00	−5.16*	0.00	−3.06	0.00
Panel ADF-statistic	−4.83*	0.00	−5.44*	0.00 -	3.83	0.00
Individual AR coefficients (between-dimension)						
Group rho-statistic	0.83	0.79	1.98	0.97	2.13	0.98
Group PP-statistic	−6.38*	0.00	−6.80*	0.00	−5.82*	0.00
Group ADF-statistic	−5.56*	0.00	−5.40*	0.00	−6.06 *	0.00

Note: * denotes the statistical significance at 1% level.

hypothesis of no cointegration for Model 1, Model 2 and Model 3 at 1% level.

On the other hand, the Pedroni panel cointegration test has drawback of assuming cross-section independence although it takes into account heterogeneity in the panel. Thus, we further carry out the LM bootstrap panel cointegration test developed by Westerlund and Edgerton [81] robust to both cross-sectional dependence and heterogeneity across sample countries.

According to the LM bootstrap panel cointegration results (Table 6), there is no sufficient evidence to reject the null hypothesis of cointegration at 1% level since the respective p-value is far greater than the significance level. In other words, there is a long-run relationship between CO_2 emissions, biomass energy consumption, real income, trade openness and urbanization. These results confirm the findings by Payne [62] for US, Bildirici [22] for Latin American countries, Bildirici and Ozaksoy [23] for a panel of European countries and Bildirici [21] for a group of transition economies.

4.3. Panel long run estimator

Pedroni [64] suggests that the group-mean estimators produce consistent estimates in case that heterogeneity exists in the cointegrated panel data. Therefore, the group-mean FMOLS due to Pedroni [64,65] is carried out to obtain consistent and reliable long run coefficients on the independent variables and quantify, thus, the magnitude of the impact that biomass consumption has on the emission levels.

The variables are transformed into their natural logarithm and so, the reported coefficients in Table 7 are equivalent to the elasticities of CO_2 emissions with respect to real income, quadratic real income, biomass energy consumption, trade openness and urbanization. In the three models, the effects of real output and the square of real output on carbon emissions are positive and negative, respectively. This implies that the EKC hypothesis is supported for the specific panel of biomass-consuming countries. More precisely, the (partial) marginal effect of real income on the level of emissions is calculated by $\beta_1+2^*\beta_2^*GDP$, and thus the (partial) marginal effect of real output on the pollution is positive at early stages of economic development; but, it increases and eventually becomes negative as the analyzed countries shifts to higher stages of economic growth. Moreover, the elasticity of biomass energy consumption is negative, implying that the higher the consumption of biomass in an economy the lower the level of emissions. The size of the coefficient is relatively small possibly due to the relatively restricted (compared to other fuels) share of biomass in the overall energy mix. It is important to note that the validity of the EKC hypothesis and the negative of biomass energy consumption on the pollution are the same across Model 1, Model 2 and Model 3; in other words, the main findings are robust because they do not change with different specifications.

Table 6
Results from the LM bootstrap panel cointegration test.

Test	Model 1		Model 2		Model 3	
	Statistic	Bootstrap p-value	Statistic	Bootstrap p-value	Statistic	Bootstrap p-value
LM bootstrap	2.72	1.00	3.07	1.00	3.64	1.00

Note: The bootstrap test statistics are computed by using 5000 replications. The null hypothesis claims the presence of cointegration in the panel for all units while the alternative hypothesis claims that there is no cointegration at least for a cross-section unit.

Table 7
Results from the group-mean FMOLS.

Regressors	Model 1		Model 2		Model 3	
	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
GDP	11.03**	2.36	6.53*	1.65	8.51**	1.92
GDP^2	−0.22***	−2.56	−0.12*	−1.70	−0.16**	−2.01
BIO	−0.04**	−2.32	−0.06***	−3.98	−0.05***	−2.65
TO	–	–	−0.02	−0.66	–	–
URB	–	–	–	–	0.69	0.21

Note: ***, **,* denote the statistical significance at 1%, 5% and 10% levels, respectively.

5. Conclusions and policy implications

Without any doubts, energy is nowadays considered an important factor of production, but its generation and consumption is related to detrimental consequences to the environment, resulting in climate change. As discussed in this paper but also in recent energy literature, the type of energy generated and its characteristics is even more important. Taking into account the environmental commitments of the countries through international climate change agreements, it is imperative now more than ever to look at alternative sources of energy that are more environmentally friendly than the historically used ones. Their adoption is made easier now due to the technological advancements in the sector and the decrease in the cost of renewable energy installation.

The purpose of this paper is to estimate the impact of biomass energy consumption and real income on the level of emissions for the panel of biomass-consuming countries for the period 1985–2012. The contribution of the study is mainly to the applied literature where thus far, most studies have looked at the importance of renewable energies as a whole. Here, a chosen panel of countries that have appreciated somehow biomass, shown by its inclusion in their energy mixes, was investigated to provide motivation to non-users of biomass by quantifying its effect on the emission levels. The theoretical framework is founded within the EKC hypothesis while using tests that take into account slope homogeneity, cross-dependence, the series' univariate characteristics and existence of cointegration, before estimating the specific long-run parameters. To investigate whether or not the validity of the EKC hypothesis and the effect of biomass energy consumption on the pollution change with other specifications, we use two variables-trade openness and urbanization-as control variables.

Based on the results of the tests, the panel is characterized by heterogeneity in slope parameters and cross-dependency of the countries. The results confirm the existence of long-run relationship among the variables. An important outcome is the validity of the EKC hypothesis for the panel of biomass-consuming countries. Equally important is the interpretation of the elasticity of biomass energy consumption to emissions: the negative sign indicates that the use of biomass energy is contributing factor to the mitigation of emissions in the countries. These findings are in accordance with Payne [62]; Bildirici [22]; Bildirici and Ozaksoy [22]; and Bildirici [21] Possible limitations, that would lead to potential future research, would be the lack of more exogenous variables to capture other types of differences between the various countries, such as the exact structure of the economy.

Internationally, energy and environmental policy makers make an effort to identify and implement appropriate interventions to break the increasing trend of CO_2 emissions. However, taking into account the global pressures to economic growth, various stakeholders aim at most efficient solutions, minimizing the costs involved while at the same time ensuring the social benefits. The findings of this exercise are supportive of the international notion that investing in biomass energy infrastructure and biomass supply are an appropriate direction the energy policy makers can use in their efforts to reduce emissions in the long-run.

From a policy perspective hence increasing the biomass share to the energy mix has a number of positive impacts (for importance of biomass, see first section) but most importantly, allows the country to improve its environmental status, comply with its international climate change commitments, and improve energy sustainability, energy security, and reduction of energy dependency. Simultaneously, the initial installment costs for biomass generation are low, and educating users to substitute other forms of energy will be easier compared to other alternatives. As Gumartini [41] discusses, access to clean and affordable energy is a current problem especially in developing countries amongst rural and poor households, as well as a basic need for reaching a certain level of living standards. Although, hence, commercial energy needs a well-established infrastructure to reach all households, so a traditional type of energy such as biomass can be promoted easier.

Highly linked with the biomass generation is the expansion and improvement of agricultural production systems, which in its turn is associated with improving the living standards of rural population. Energy policy makers should also direct their efforts on Research and Development (R&D) activities towards developing more efficient agricultural production techniques in order to assist with realizing the substantial potential of energy crops [44]. Based on this, future research needs to focus more on the return on investments of biomass both at private and public level, as well as the specific effect on the rural households and particular economic sectors.

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