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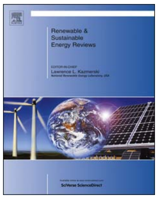

Can biomass energy be an efficient policy tool for sustainable development?

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ABSTRACT

This paper first reviews the potential causality from biomass energy to CO_2 emissions and economic development within relevant literature. Later, the paper examines statistically the impacts of biomass energy consumption on CO_2 emissions and GDP in the US. To this end, paper observes environmental and economic implications of biomass fuel usage throughout energy literature and launches asymmetric causality test to confirm/disconfirm the literature output. The findings of the tests indicate that biomass energy consumption per capita mitigates CO_2 emissions per capita and increases GDP per capita. Eventually, upon its output, this research asserts that biomass energy consumption can be an efficient policy tool for environmentally sustainable development in the US, and, that, hence, biomass production technologies and biomass consumption need to be promoted in other countries as well as in the US. On the other hand, analyses underline the fact that policy makers should consider as well some potential constraints of biomass energy usage such as land use constraints and carbon leakage from biomass production. Therefore, although this paper explores the remedial impact of biomass on environment and growth, one may suggest also that further possible works consider the effects of biomass sources in detail to minimize the some worsening influence of biomass usage on climate change.

1. Introduction

All economic activities require a transformation and this transformation occurs through energy. Energy does not necessarily have a certain substitution level with other factors of production [1] and is of vital importance for all countries [2]. According to IEA [3], 82% of world energy demand is met by fossil energy sources, such as oil, coal, and natural gas. Hence, one may claim that, economies are subject to fossil energy sources. As the increase in global energy demand was greater than the increase in population in the last century [4], the dependence of economies on fossil energy sources induced some political, economic, and environmental concerns [5].

The first concern is that fossil energy supply is restricted. The industrialization, high growth rates of population and urbanization, and the developments in transportation accelerate the use of coal, oil, and natural gas. Global energy demand doubled from 1970 to 2000 and increased by 26% from 2000 to 2010 [3]. A radical change is not expected in this growth trend in the near future [6]. For this reason, fossil energy sources in the world will drain away in the future. For instance, according to the Peak Oil Theory, oil production through conventional methods has reached the maximum level and the half of the world oil reserves has been utilized [7]. As is explained in Li [8], the oil explorations have decreased since mid-1950s and the oil production in 2050 is expected to be 70% as much as the maximum production level in history. These events support the Peak Oil Theory. In a similar way, the production of coal and natural gas will fall short of the demand for coal and natural gas in the future [9]. Therefore, the issue of meeting energy demand is very important with regard to sustainable development [10].

The second concern is associated with energy safety. Energy safety is that different types of energy are continuously utilized at convenient prices without inducing intolerable effects on environment and economy [11]. As energy safety is provided, economies become stronger against energy price shocks [12]. Energy price shocks and flaws in competitive or non-competitive procurement process may break down the trade balances of countries, lead to an inflationary pressures, and decrease the competitive powers of countries considerably [13,14]. Energy safety emerges because of the unbalanced distribution of energy sources across countries and leads to energy dependency in some potential countries. Therefore, providing energy safety is especially important for countries that import energy [15].

The third concern is associated with global warming. Environmental scientists might affirm that global warming and climate

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change have become greatest threat to societies in terms of the 21st century [16]. The CO_2 emissions that emerge because of the usage of fossil sources, such as oil, coal, and natural gas are the main reason of serious environmental problems [17–21]. CO_2 intensity in the atmosphere has increased rapidly especially since the industrial revolution [22–25] and this increase has made the world warmer [26]. Thereby, the usage of fossil energy sources brings about global warming and climate change.

Countries, without doubt, need to consider these concerns about energy supply, energy security and environmental pollution. Policy makers, thus, might be obligated to implement effectively the related energy polices to explore alternative energy sources. Within this period, the biomass sources seem to be a prominent alternative energy source among others available [27–31]. Biomass sources can be transformed to solid, liquid, and gas, and biomass energy (bioenergy) obtained from these sources can be utilized in transportation, heating and electricity generation [32,33]. Besides, fossil diesel and gasoline can be replaced by biofuels [34]. Therefore, bioenergy has considerable environmental and economic advantages as a potential energy source [35]. The link between biomass production/consumption and economic growth and the connection between biomass and CO_2 emissions might be highlighted as follows.

i) Bioenergy might be the most prominent renewable energy source today and in the future in terms of its technical and economic feasibilities [36].
ii) There exist currently several substantial biomass sources in the world and bioenergy can be stored up to meet the future demand for energy [24,37].
iii) Biomass sources can provide countries with less required energy imports from oil exporter countries which do not have political stability [38]. Bioenergy can decrease energy dependency and concerns about national energy security [39]. The replacement of fossil fuels by biofuels might reduce energy imports of countries and, thus, can help countries/regions reduce trade deficits [40,41].
iv) Bioenergy can increase employment in rural areas, may advance agricultural economy, and, so, might be able to reduce poverty in developing countries [42]. Moreover, bioenergy might improve industry and increase economic growth. Hence policy makers tend to promote the usage of biomass in many developed countries [43].
v) Bioenergy can solve environmental problems (such as global warming, climate change, air pollution, and acid rains) by decreasing CO_2 and other pollutant gas emissions [39,44,45].

Due to advantages from (i) to (v), bioenergy has drawn great attention in recent years [33,46] and is observed closely by sustainable energy projections developed by international institutions [36]. Solid and liquid biofuel trade increased especially over the past decade [29], and this increase proves the importance of biomass sources. One may claim, on the other hand, that the usage of biomass energy may increase, as well, CO_2 emissions because the changes in land use and carbon leakages might affect biological diversity and life regions negatively and can risk global food safety as shown in [15,37,47].

Overall, one may state that the world needs sustainable energy policies. Economic performances of countries in the future depend on the procurement of clean, safe, affordable, and eco-friendly energy. Therefore, energy takes part almost at the centre of the all elements of sustainable development [48]. From this point of view, the following questions appear to be highly important: 1- Can biomass production be a policy tool for sustainable development? 2- Is there a causal relationship between biomass production and economic growth and/or development? 3- Can the usage of biomass reduce CO_2 emissions? This paper, then, aims at revealing the relevant answers to 1–3.

Within this scope, this paper examines the relationship between biomass production/consumption and economic growth and the relationship between biomass production/consumption and CO_2 emissions for the period 1982–2011 in the US by employing the asymmetric causality test developed by Hatemi-J [49].

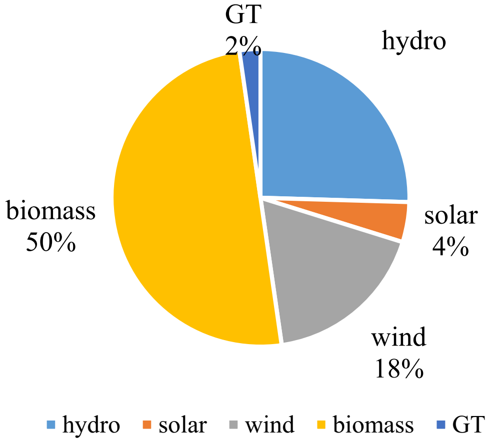

Fig. 1. Renewable energy demand by sources in the US (2014).
Source: EIA [51]

This paper contributes to relevant literature by investigating the dynamic impulses of biomass energy production and consumption on the US economy, through (i) updated literature review, and, (ii) launching a model, to observe if biomass source can be an efficient policy instrument for sustainable development.

Why do we focus specifically on the US? The US accounts for 17% of world energy demand and 18% of global CO_2 emissions [3,50].

Besides, the US procures a considerable part of energy demand through import. According to EIA [51] data, energy consumption of the US is 95.05 quadrillion Btu while energy production of the US is 79.2 quadrillion Btu in 2012. This difference reveals the attention of the US to renewable energy sources. For instance, according to EIA [51] data, in the US, the share of renewable sources in energy demand has continuously increased in the last 20 years and this share reached 10% in 2014. Furthermore, the greatest share in renewable sources belongs to biomass in the US. As seen in Fig. 1, the shares of biomass, hydro, wind, solar, and geothermal (GT) are 50%, 26%, 18%, 4%, and 2%, respectively.

In addition, compared with the other countries, the US produces and consumes more energy from biomass sources. Fig. 2(a) reveals a comparison of electricity generation, biofuels energy production and biofuels energy consumption between the US and the world. Fig. 2(b) shows biofuel production, biofuel consumption, and electricity production based on biomass sources in major countries (the US, Brazil, Germany, and China) and in the world.

As seen in Fig. 2(a), in 2012, the share of the US in electricity generation from biomass sources is 18% in the world. This outcome is given at upper left pie chart of Fig. 2(a). One might consider that this approximate one fifth ratio of the US electricity production in the world is outstanding. However, one might consider, as well, a comparison of the US electricity production with other major countries' electricity generations. The lower bar chart of Fig. 2(b) indicates that the US has greater electricity generation than Germany, China and Brazil have. Moreover, the US produces and consumes almost half of biofuels production and consumption in the world. The biofuels production and consumption of the US in the world, in terms of thousand barrels per day, are 51% and 52%, respectively (Fig. 2(a)). The world's biofuels production and consumption are 1901 thousand barrels per day and 1866 thousand barrels per day, respectively, in terms of 2012 (Fig. 2(b)). The biomass consumptions of US, Brazil, Germany and China are 898, 406, 76, and, 59 thousand barrels per day, respectively, in 2012 (Fig. 2(b)).

Qin et al. [5] denote that the US will produce 36 billion gallons (136 billion litres) renewable fuels, and that 21 billion gallons (79 billion litres) of this production will be cellulosic ethanol until 2022. Further,

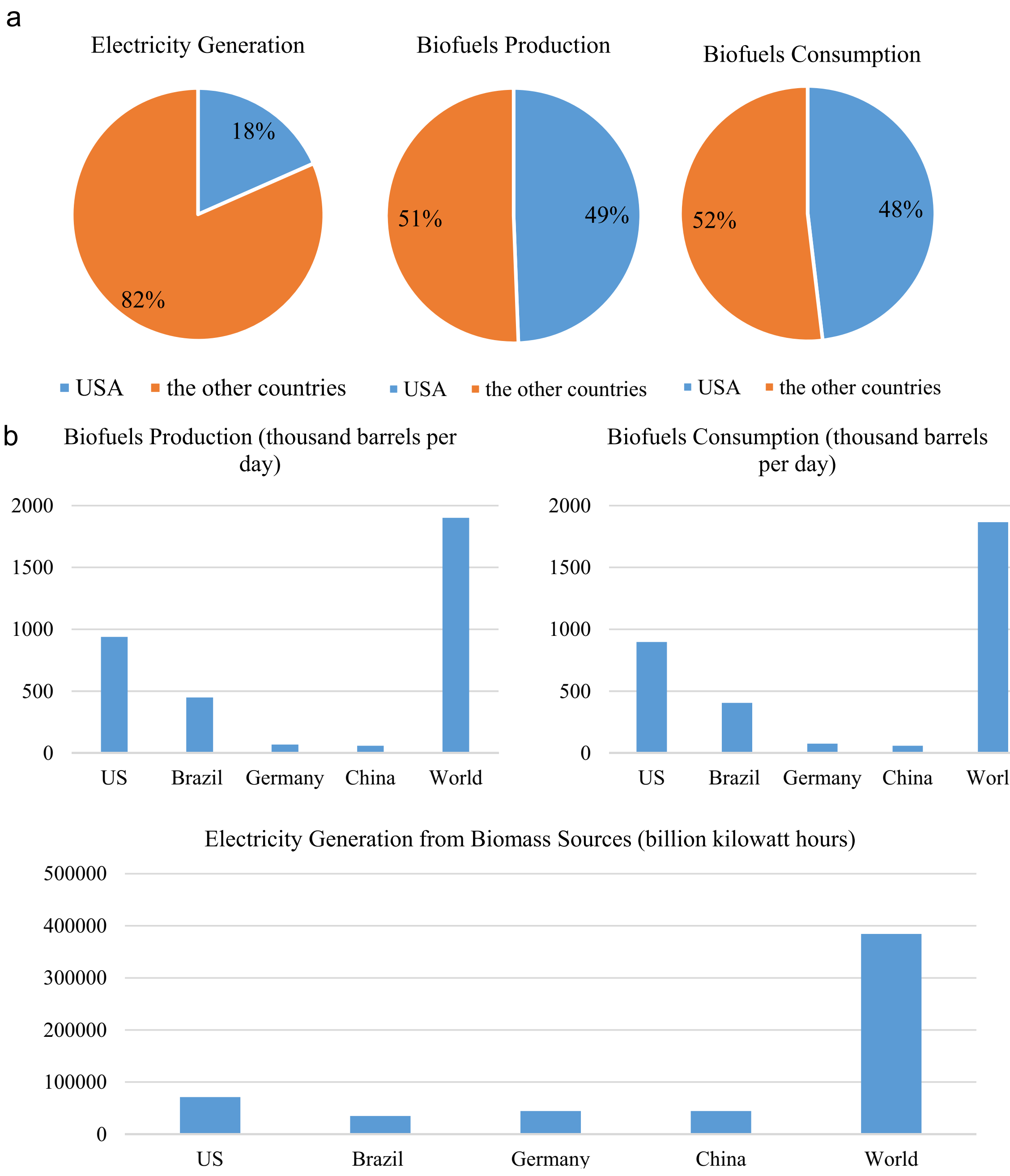

Fig. 2. (a) Biomass and biofuels energy production and consumption in the US and in the World (2012). (b) Biomass and biofuels energy production and consumption in the major countries and in the World (2012). *Source*: EIA [51].

the substitution of oil with biofuels is one of the main goals of the renewable energy policies in the US [52]. In short, it might be argued that biomass production is an important potential policy tool for the US. For this reason, empirical findings of this paper might contribute to the improvement of biomass sources-oriented sustainable development policies and energy policies.

The major countries produce and consume a substantial part of energy obtained from biomass sources. Biomass sources will play an important role in meeting energy demand of the world in the near future. For instance, IEA [3] denotes that the world's primary energy demand will be 14922 mtoe in 2020, and, that 1532 mtoe of this demand will be met by bioenergy. It is expected that the demand for bioenergy will increase by 1.6% on average between 2010 and 2035. It is especially emphasized that the US, which is an oil-importer country today, will become self-sufficient in terms of energy in 2035 due to her increasing productions of shale gas and bioenergy. European Renewable Energy Council [53] announces that, while the share of bioenergy was 6.02% in energy consumption in Europe in 2006, it is aimed to increase this share to 12.7–13.9% in 2020. European Renewable Energy Council [53] anticipates that biofuels will play crucial role in the transportation sector by decreasing CO_2 emissions and, hence, by increasing the energy security. Eventually, it is expected that biofuels will meet 27% of demand for total fuel in 2050 with the substitution of fossil fuels by biofuels [54].

There appears to be small number of articles in the literature searching the relationship between biomass and CO_2 and the correlation between biomass and economic growth. Piroli et al. [55], for instance, assert that there exists a research gap towards the environmental effects of biomass. Salim and Shafiei [56] yield that there are enormous and useful modelling studies about the nexus between energy and economic growth. However, one might notice in general, throughout literature review, that these papers mainly employ the variables of total energy, electricity, fossil fuels and economic growth [43,57]. Therefore, this paper considers a new methodology to observe the dynamics between biomass and economic growth. Tiwari [58] employs this new methodology to examine the relationship between renewable energy consumption and economic growth for the US. However, Tiwari [58] considers total renewable energy consumption instead of biomass energy consumption. Therefore, to the best of our knowledge, this is the first paper observing the causality from biomass usage to CO_2 and economic growth by employing the asymmetric causality test as is in Hatemi-J [49]. This causality test differs from other causality tests by decomposing specifically the impacts of positive and negative shocks within estimated model. Furthermore, this causality test utilizes a bootstrap simulation technique with leverage adjustment in order to generate critical values which are robust to non-normality and heteroscedasticity. Therefore, this paper, beyond an extensive review, will contribute to the related literature through its empirical methodology, as well.

Overall, since this paper focuses on the influence of biomass consumption on GDP and CO_2 emissions, it aims at reviewing the relevant literature in detail. One reaches, however, the mixed output through literature review analysing the sequence of biomass usage on emissions. Some seminal papers yield negative effect of biomass on CO_2 while some other seminal works underline the positive sequence of biomass on the emissions. That's why; this paper launches, as well, some econometrical models to observe the possible negative or positive impacts of biomass usage on CO_2 and economic growth. Therefore, the Section 2 will review the literature regarding the relationship between biomass and CO_2 emissions. Section 3 will review the literature examining impulses of energy/biomass consumption on economic growth. Section 4 will examine the causality, if exists, from biomass to growth and emissions. Section 5 will exhibit the conclusion of this paper with some relevant policy proposals.

2. The literature review: the relationship between biomass energy and CO_2 emissions

Within the relevant literature, there exist some papers exploring mixed effects of biomass usage on CO_2. Accordingly, biomass can decrease CO_2 emissions since fossil sources can be replaced by biomass production which can promote energy crops. On the other hand, land use change, carbon leakage, and green paradox originated from biomass production might increase CO_2 emissions. Therefore, one may state that the net impact of biomass production on CO_2 emissions is ambiguous in the literature. To be able to understand better the nexus between biomass and emissions, one might need to follow the relevant studies given below to explore (i) some possible sources of CO_2 emissions and (ii) the impact of biomass on CO2 emissions.

2.1. *Fossil fuel substitution effect*

Energy obtained from biomass sources can be solid, liquid, and, gas, can be stored up easily, and can be utilized for many fields, such as transportation, heating, and electricity generation [31,37]. Hence, fossil sources can be substituted with biomass sources [59,60]. Biomass produces fewer CO_2 and other pollutant gas emissions compared with fossil fuels [61]. Several works on lifecycle reveal that, if gasoline is replaced by ethanol produced from corn, cellulose, and sugarcane, the greenhouse gas emissions will decrease [62]. Other studies [63,64] confirm [61,62]. One indicates that the usage of ethanol and biodiesel can reduce greenhouse gas emissions by 30% and 50%, respectively, in South Africa [63]. Also, it is denoted that vegetable oil derived fuels can reduce CO_2 emissions by 30–60% [64]. Hence, biomass can decrease CO_2 emissions if fossil sources are replaced by biomass [55,61].

2.2. *Energy crops channel*

Plants are an important part of carbon cycle. A considerable part of carbon is held by soil and it is transmitted to plants through soil. Therefore, all components of plants are included in coal, oil and natural gas [59]. Thus, the structure of biomass sources resembles fossil sources. Thereby, CO_2 emissions that emerge when fuel is produced through biomass sources might be equal to those that emerge when fuel is produced through fossil sources. However, the production of biomass sources generating bioenergy absorbs these CO_2 emissions before they reach the atmosphere [17]. Thus, one may yield that biofuels are carbon neutral [27,65]. As a result, the growth of energy plants and developments in energy crops can reduce net CO_2 emissions by confining a considerable amount of CO_2 emissions in soil and absorbing CO_2 emissions in the atmosphere through photosynthesis [38,66].

2.3. *Land use change (direct and indirect)*

A considerable source of CO_2 emissions is the transformation of forest lands into agricultural lands [67]. Increasing raw material necessity to produce bioenergy requires more lands and, hence, farmers employ more forests and grasslands [62]. Accordingly, the production of raw materials to produce bioenergy has a direct impact on the transformation of lands and deforestation [68,69]. Forestlands hold a large amount of CO_2. Hence, the production of raw materials to produce bioenergy can induce deforestation and, then, can cause a large amount of CO_2 to be released [62].

The production of bioenergy can increase CO_2 emissions by affecting the usage of lands indirectly, too. The production of bioenergy can increase demand for biomass sources. This demand can lead to increases in agricultural products that are utilized to produce bioenergy. Consequently, the profits obtained from these products can increase. Increasing demand for agricultural lands might cause forest lands to be transformed into agricultural lands [55]. This transformation might raise CO_2 emissions to raise [55].

2.4. *Carbon leakage and green paradox*

Carbon leakage is an important problem that might undermine some environmental policies [70]. Several papers assert that bioenergy policies might bring about carbon leakage [55,62,70]. The increases in the production of bioenergy can lead to decrease in prices in the world energy market, and, thus, can induce CO_2 emissions through increases in total energy consumption. This mechanism is denominated as carbon leakage [71]. Therefore, the usage of bioenergy can mitigate CO_2 emissions as it can raise also the emissions by promoting the usage of fossil energy [55].

Additionally, Grafton et al. [72] and Grafton et al. [73] remark that the price of fossil sources will fall if the production of bioenergy is subsidized more. This expectation can promote producers to produce more fossil fuel production in the current period. In such a case, subsidies to produce bioenergy might enhance fossil fuel production. This effect is called Weak Green Paradox. If Weak Green Paradox is valid, these subsidies can increase CO_2 emissions, as well.

2.5. *Empirical evidence*

Schwaiger and Schlamadinger [74] examine the effects of increasing fuelwood usage for five European countries (Austria, Finland, France, Portugal, and Sweden) for 2020 with regard to 1995 by considering environmental, socio-economic, and technical aspects. The scenarios yield that fuelwood has significant but restricted possibilities to reduce total greenhouse gas emissions in these countries. Additionally, the scenarios indicate that the greatest decreases in greenhouse gas emissions will occur in Sweden and Finland. Wahlund et al. [75] find out that especially woody biomass is able to reduce CO_2

emissions in Sweden. Gustavsson et al. [76] establish four scenarios for Swedish economy in which up to 400 PJ/year of additional biomass is prioritised (i) to reduce CO_2 emissions, (ii) to decrease oil use, (iii) to mitigate both CO_2 emission and oil use, and, (iv) to produce ethanol to replace gasoline.

Carrying out the third scenario, Gustavsson et al. [76] claim that CO_2 emissions might be extenuated by 12.6 TgC/year and oil usage might be reduced by 230 PJ oil/year. The monetary cost of the third scenario is 45 million €/year lower than the first and second scenarios. The last scenario results in the lowest CO_2 emissions reduction, intermediate oil use reduction, and the highest monetary cost. Utlu [77] obtains that CO_2, carbon, and smoke intensity will decrease by 14%, 17.1%, and 22.5%, respectively if biodiesel is used in transportation sector as a fuel. Senatore et al. [78] explore that biodiesel can reduce net CO_2 emissions by 78% with regard to petrodiesel. Panwar et al. [79] yield that, if 10% of castor oil seed production is converted to biodesel production, CO_2 emissions will decrease by 79.782 t on a yearly basis. Khanna et al. [80] yield that bioenergy obtained from less than 2% of agricultural lands might produce 5.5% of electricity obtained from coal-based power plants in Illinois, USA, and, that this outcome will reduce CO_2 emissions by 11% in fifteen years.

Bento et al. [81] examine the effects of biofuels on greenhouse gas emissions through multiple market model that takes into consideration positive and negative leakages. They yield that biofuels will increase greenhouse gas emissions. Fangsuwannarak and Triratanasirichai [82] reach that palm diesel oil brings about more CO_2 emissions than biodiesel fuel does while it induces fewer CO_2 than pure diesel fuel does. Suttles et al. [83] observe the effects of bioenergy consumption on CO_2 emissions in European Union and in the US through the global computable general equilibrium model and yield that bioenergy consumption can mitigate CO_2 emissions considerably.

One may consider, as well, some econometrical models to measure the statistical significances of biomass energy on CO_2 emissions. Bilgili [84] searches the effects of biomass and fossil fuel consumption on CO_2 emissions for the US by conducting cointegration analyses with structural breaks over the monthly period 1990–2011. He reveals that, while fossil fuels have positive effects on CO_2 emissions, biomass has negative effects on the emissions. Grafton et al. [73] research the effects of biomass subsidies and biomass production on fossil fuel production and CO_2 emissions for the US over the annual period 1981–2011 by employing ordinary least squares (OLS). Eventually, they test the validity of the Weak Green Paradox and the Strong Green Paradox and yield that biomass subsidies and biomass production raise fossil fuel production and CO_2 emissions. In other words, their findings support the validity of the Weak Green Paradox and the Strong Green Paradox. Piroli et al. [55] investigate the effects of the biofuels production on global CO_2 emissions via structural vector autoregressive (VAR) model for the annual period 1961–2009. They exhibit that, while the biofuels production boosts CO_2 emissions in the short run, it detracts CO_2 emissions in the middle and long runs. Finally, Katircioglu [85] examines the correlation between biomass energy consumption and CO_2 emissions by employing bounds test and conditional error correction model in Turkey for annual period 1980–2010. Their results imply that CO_2 emissions are negatively related to biomass energy consumption.

Finally, one might need to observe the most recent works available in the literature considering quantitatively the potential influences of biomass energy usage on CO_2 emissions and/or Greenhouse gas (GHG) emissions in general.

Bilgili [84], confronting biomass consumption with fossil fuel consumption in the US in terms of their influences on CO_2 emissions, explore that, when fossil fuel consumption rises by one quadrillion btu, the CO_2 emissions will accumulate by 64 million metric tons, and, that, as biomass consumption expands by one quadrillion btu, the CO_2 emissions will decline by 46 million metric tons.

Gilbert et al. [86], following current biomass feedstock and ammonia prices in the US, reveal that obtaining ammonia from biomass gasification is economically reasonable and can cause a diminishment in greenhouse gas by 65% in comparison with traditional process to procure ammonia from natural gas. Kuo and Wu [87], comparing the coal fuel and biofuel, search the co-gasification system in terms of energy conversion efficiency and exergy efficiency and exhibit that biomass (torrefied wood) based fuel mitigates CO_2 emission by 38.23%.

Garcia et al. [88], observing several bioenergy alternatives (e.g. for electricity, heat, and mobile power) in Mexico, reveal that 16% of electricity consumption based on fossil fuels might be met by biomass sources, and that, then, greenhouse gas emissions might decrease by 17% by the year 2035. Shen [89], comparing the potential impacts of biomass on particle pollution originated from combustion (e.g. motor vehicles, power plants, residential wood burning), explores that particles from indoor biomass burning might be reduced by 79–85% through promotion of biomass pellets in China.

Sharifzadeh et al. [90], comparing biomass-derived fuels with petroleum-derived fuels in terms of hydrogen-carbon ratio and CO_2 emissions, conclude that biomass conversion technologies might produce prominent amount of carbon dioxide, and, that, however, under some circumstances, biomass production might yield considerably small emissions (12.9% for diesel and 16.5% for gasoline). Then, Sharifzadeh et al. [90] suggest an efficient integrated bio refinery to be able to obtain low CO_2 emission. Trivedi et al. [91] also emphasize an effective-integrated bio refinery employing algea to be able to reach sustainable carbon-neutral green energy. Therefore, Trivedi et al. [91] underline algae based biofuels and chemicals to provide societies with clean environment.

Nishiguchi and Tabata [92], contrasting energy sources from utilized woody biomass and non-utilized woody biomass in Japan, yield that direct combustion and combusting wood pellets are the preferable methods. They further indicate that direct burning might have an impact on 13.7 million tonne of CO_2 emission contraction. Herbert and Krishnan [93], matching the energy sources from biomass and other fuels such as charcoal, liquid petroleum gas and kerosene, state that biomass might result in a prominent effect on reduction in GHG emission. They specifically remark that, i.e., the CO_2 emission decrement by 600 t per unit can be obtained through 100 kWe biomass generating system in the United Kingdom.

Finally, one may point out, as well, the output of Sekhar et al. [94] investigating the responses of mulberry genotypes to the elevated CO_2 concentration. They observe increased water use efficiency in elevated CO_2 grown S13, and, conclude that the drought tolerant, selection-13 (S13) might be considered potential genotype for carbon neutral renewable bio-energy to mitigate increasing atmospheric carbon emission [CO2].

3. Literature review: the nexus between energy/biomass energy and economic growth

The relationship between energy and economic growth has drawn attention since the oil crisis in 1970s [95], and this topic has become a field of interest following the pioneer paper by Kraft and Kraft [96]. Energy consumption is a considerable indicator of development, thus, the topic of relationship between energy consumption and economic growth has called much the economists' attention. Since the findings of relevant literature provide policy makers with information about how to design regarding energy policies, the literature on the energy-growth nexus has continuously expanded [97,98]. On the other hand, the findings of the papers vary with countries, time periods, kinds of energy, and econometric methods [97,99]. When one examines the related literature, he/she will observe that causality analyses are mainly employed to examine the relationship between energy and economic growth. The literature of causality studies follows mainly four hypotheses [97,100,101].

The first hypothesis is the growth hypothesis. The growth hypothesis is valid if there is a unidirectional causality from energy consumption to economic growth. In other words, energy is an important factor for economic growth when this hypothesis is valid. Shiu and Lam [102] investigate the relationship between electricity consumption and GDP over the period 1971–2000 for China. Findings of this paper indicate that there is a cointegration relationship between electricity consumption and GDP and that there is one-way causality from electricity consumption to GDP. Lee [103], employing panel cointegration and panel vector error correction model (VECM), examines the link between total energy consumption and GDP for 18 developing countries over the period 1975–2001. According to the evidence, there is unidirectional causality from total energy consumption to GDP. This result indicates that energy conservation may damage economic growth in developing countries. Odhiambo [104] examines the relevance between total energy consumption per capita and GDP per capita and the rapport between electricity consumption per capita and GDP per capita in Tanzania for the period 1971–2006. He uses Autoregressive Distributed Lag (ARDL) bounds test and a causality analysis. Findings show that the growth hypothesis is valid. Odhiambo [104], therefore, underlines the evidence that energy consumption promotes economic growth in Tanzania. Tsani [105] analyses the liaison between energy consumption and GDP for Greece over the period 1960–2006 by performing a causality test and yields that there happens to be one-way causal relationship from energy consumption to GDP. According to these papers, energy is an important factor for economic growth. Consequently, energy saving policies and energy shocks can affect economic growth negatively.

The second one is the conservation hypothesis. If there is unidirectional causality from economic growth to energy consumption, then, the conservation hypothesis is valid. Sari et al. [106] consider the dependence among total energy consumption, output, and employment in the US over the period 2001–2005 by employing the ARDL method. The discovery of the paper implies that real output and employment are long run key determinants for nearly all measures of disaggregate energy consumption. Sadorsky [107] conducts panel cointegration and panel causality methods to examine the relationship between renewable energy consumption and GDP in 18 emerging economies for the period 1994–2003. The relevant research yields some results which are in favour of the conservation hypothesis. Zhang and Cheng [108] seek for the connection among energy consumption, CO_2 emissions, capital, urbanization, and GDP for China over the period 1960–2007 by utilizing Granger causality analysis. According to the findings of the paper, there is one-way causality from GDP to energy consumption and to CO_2 emissions in the long run. Therefore, Zhang and Cheng [108] state that the government of China can purse conservative energy policies and carbon emissions reduction policies in the long run without hindering economic growth. Ahmed et al. [109], employing the maximum entropy bootstrap approach, consider the relationship between energy consumption and GDP in Pakistan for the period 1971–2011. The output of the paper supports the conservation hypothesis by indicating that a unidirectional causal relationship from GDP to energy consumption becomes available. These entire papers explore that economic growth leads to more energy usage and that energy saving policies do not affect economic growth negatively.

The third one is the neutrality hypothesis. The neutrality hypothesis prevails if there is no causality between energy consumption and economic growth. Acaravci and Ozturk [110], employing panel cointegration and panel causality methods, investigate the trends of electricity consumption per capita and GDP per capita over the period 1990–2006 for 15 emerging economies (Albania, Belarus, Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Macedonia, Moldova, Poland, Romania, Russian Federation, Serbia, Slovak Republic, and Ukraine). They exhibit that panel cointegration tests do not confirm a long-term equilibrium relationship between electricity consumption per capita and real GDP per capita. Overall, Acaravci and Ozturk [110] indicate that the electricity consumption-related policies have no effect on the level of output in the long run for these countries. Nazlioglu et al. [111] examine the nexus between nuclear energy consumption and GDP in OECD countries for the period 1980–2007 by employing a panel causality method considering cross-sectional dependence and heterogeneity. They yield that no causality between nuclear energy consumption and GDP appears in eleven out of fourteen countries. This outcome supports the neutrality hypothesis. Menegaki [112] explores the relationship between renewable energy consumption and GDP in 27 European countries for the period 1997–2007 through random effects model, and, yields that findings are in favour of the neutrality hypothesis. Wolde-Rufael [113] considers the correlation among nuclear energy consumption, capital, labour, and GDP for Tanzania over the period 1977–2007 by employing VAR and causality analyses. The evidence of the paper shows no causality running in any direction between GDP and nuclear energy consumption. This conclusion implies that the neutrality hypothesis might be accepted statistically. Following the symptoms of these papers, one might state that energy policies have little effect or no effect on economic growth.

The fourth hypothesis regarding the nexus between energy/biomass energy and economic growth is the feedback hypothesis. If there appears to be bidirectional causality between energy consumption and economic growth, then the feedback hypothesis exists. In other words, energy consumption and economic growth interact with each other when this hypothesis prevails. Paul and Bhattacharya [114], view the possible channels between energy consumption and GDP in India for the period 1950–1999 by utilizing cointegration and causality methods. They reach the outcome that bi-directional causality exists between energy consumption and GDP. Shahbaz et al. [115] examine the effects of renewable and non-renewable energy consumption on GDP for Pakistan. They employ the data covering the period 1972–2011 and conduct ARDL bounds testing approach, cointegration test approach with one structural break, and Granger causality tests approach based on VECM, respectively. In conclusion, Shahbaz et al. [115] confirm the feedback hypothesis for both renewable energy consumption and non-renewable energy consumption. Chang et al. [116] consider the causality evidence amongst renewable energy consumption and GDP for G7 countries over the period 1990–2011 through a heterogeneous panel Granger causality test. The results of the paper verify the feedback hypothesis. Ozturk and Al-Mulali [117], utilizing panel cointegration and panel causality analyses, search the movements of natural gas consumption and GDP in Gulf Cooperation Council (GCC) countries for the period 1980–2012. They finalize that there occurs a feedback hypothesis. Solarin and Ozturk [118] chase the relevant paths amidst natural gas consumption and GDP in 12 OPEC countries for the period 1980–2012 by performing a heterogeneous panel causality method. The estimations show the evidence of feedback relationship between natural gas consumption and GDP in OPEC members. Based on the conclusions of the researches given above, it might be indicated that energy saving policies and energy shocks have negative effects on economic growth, and these negative effects are reflected on energy consumption.

Some papers in literature obtain mixed results about the impact of energy consumption on GDP and vice versa. Cheng [119], exploring the relationship between energy consumption and GDP in Mexico (for the period 1949–1993), Venezuela (for the period 1952–1993), and Brazil (for the period 1963–1993) through causality analyses, reaches the validity of the neutrality hypothesis for Mexico and Venezuela and the validity of the growth hypothesis for Brazil. Wolde-Rufael [120] investigates the relationship between electricity consumption per capita and GDP capita for 17 African countries over the period 1971–2001 by performing a causality analysis. The empirical evidence shows that there is a causal relationship for 12 countries. Accordingly, for 6 countries; (i) there is unidirectional causality running from GDP per capita to electricity consumption per capita, (ii) there exists a unidirectional causality running from electricity consumption per capita to GDP per capita for 3 countries and, (iii) there is available bidirectional causality for the remaining 3 countries. Huang et al. [121], running panel VAR and panel generalized method of moments, consider the relationship between energy consumption and GDP for 82 countries over the period 1972–2002. According to the results of the paper, i) in the low-income group, there exists no causal relationship between energy consumption and GDP, ii) for the middle-income group (lower and upper middle income groups), economic growth leads to increases in energy consumption, and, iii) within the high-income group, economic growth leads to decreases in energy consumption. Ozturk et al. [122] reveal the transition between energy consumption and GDP in 51 countries for the period 1971–2005 by employing panel cointegration and panel causality analyses. The panel causality analyses find out that there might be long-run Granger causality running from GDP to energy consumption for low-income countries, and, that there is bidirectional causality between energy consumption and GDP for middle-income countries. Tiwari [58] analyses the relationship between different types of energy and GDP in the US for the period 1973–2011 by performing the asymmetric causality test developed by Hatemi-J [49]. According to the indication of the paper, i) causality is valid from GDP to coal consumption, ii) unidirectional causality from electricity consumption to GDP occurs, and iii) there is bidirectional causality from natural gas consumption, primary energy consumption, and total renewable energy consumption to GDP.

All findings of the papers given above provide policy makers with some considerable policy implications and show that energy-growth nexus still deserves further attention. On the other hand, there exist limited papers observing potential influence of biomass on economic growth. Table 1 summarizes the output of literature on the relationship between energy consumption and economic growth. For instance, Payne [123], monitoring the co-movements of biomass energy consumption and GDP for the US over the period 1947–2007 through a causality analysis, confirms the growth hypothesis. Bildirici [124], considering the relationship between biomass energy consumption and GDP in 10 countries for the period 1980–2009 through Granger causality test based on VECM, yields mixed results. On the other hand, Bildirici [43] examines the relationship between biomass energy consumption and GDP for 10 transition countries over the period 1990–2011 by employing Granger causality test based on VECM and finds that the feedback hypothesis prevails.

Table 2
Hatemi-J [49] asymmetric causality test for the relationship between biomass energy consumption and CO_2 emissions.

Null hypothesis	Test statistic	Critical values[a]		
		1%	5%	10%
lnBIO^{+} does not Granger cause lnCO_2^{+}	41.058	19051.426	620.034	133.044
lnBIO^{-} does not Granger cause lnCO_2^{-}	0.417	13801.377	591.063	155.092
lnBIO^{-} does not Granger cause lnCO_2^{+}	0.505	19827.056	716.446	163.511
lnBIO^{+} does not Granger cause lnCO_2^{-}	38919.283[b]	18654.127	553.770	156.424
lnCO_2^{+} does not Granger cause lnBIO^{+}	3.927	20502.743	671.583	140.024
lnCO_2^{-} does not Granger cause lnBIO^{-}	197.007[c]	13237.158	506.544	127.589
lnCO_2^{-} does not Granger cause lnBIO^{+}	0.323	42.577	16.132	9.805
lnCO_2^{+} does not Granger cause lnBIO^{-}	2.480	32.385	13.496	8.448

Notes:
[a] Critical values are obtained through 10000 bootstrap replications.
[b] Illustrates 1% statistical significance.
[c] Illustrates 10% statistical significance.

Bilgili and Ozturk [2] review the conjunction between biomass energy consumption and GDP by following panel dynamic ordinary least squares (DOLS) for G7 countries over the period 1980–2009. They find evidence in favour of the growth hypothesis. Ozturk and Bilgili [125] inspect the tie between biomass energy consumption and GDP in 51 Sub-Sahara African countries for the period 1980–2009 by utilizing panel DOLS. They verify the validity of growth hypothesis.

The share of biomass in the world renewable energy demand is almost 76% [3]. Therefore, the papers investigating the relationship between biomass and economic growth within the relevant literature become prominent with regard to developing biomass energy policies.

Table 1
The outcome of some seminal papers in literature on the relationship between energy consumption and economic growth.

Author	**Country**	**Period**	**Methodology**	**Conclusion**
Kraft and Kraft [96]	USA	1947–1974	Granger causality	conservation
Eden and Jin [126]	USA	1974–1990	Granger causality	neutrality
Oh and Lee [127]	Korea	1970–1999	Granger causality	feedback
Ang [128]	France	1960–2000	Vector Error correction models (VEC)	growth
Narayan and Smyth [129]	G7 countries	1972–2002	VEC	growth
Zhang [130]	Russia	1970–2008	Granger causality	feedback
Dagher and Yacoubian [131]	Lebanon	1980–2009	Hsiao, Toda-Yamamoto and VEC	feedback
Nasreen and Anwar [132]	15Asian countries	1980–2011	VEC	feedback
Reynolds and Kolodziej [133]	Soviet Union	1987–1996	Granger causality	conservation (oil) growth (natural gas and coal)
Wolde-Rufael [134]	India	1969–2006	Toda-Yamamoto causality	growth (nuclear)
Payne and Taylor [135]	USA	1957–2006	Toda-Yamamoto causality	neutrality (nuclear)
Apergis and Payne [136]	25 OECD countries	1980–2005	VEC	feedback (coal)
Apergis and Payne [137]	67 countries	1992–2005	VEC	feedback (natural gas)
Park and Yoo [138]	Malaysia	1965–2011	VEC	feedback (oil)
Ghosh [139]	India	1950–1997	Granger causality	conservation
Yoo [140]	Korea	1970–2002	VEC	feedback
Akinlo [141]	Nigeria	1980–2006	VEC	growth
Abosedra et al. [142]	Lebanon	1995–2005	Granger causality	growth
Shahbaz and Feridun [143]	Pakistan	1971–2008	Toda Yamamoto	conservation
Shengfeng [144]	China	1953–2009	VEC	growth
Payne [145]	USA	1949–2006	Toda-Yamamoto	neutrality
Menyah and Wolde-Rufael [146]	USA	1960–2007	Granger causality	conservation
Apergis and Payne [147]	6 countries	1980–2006	VEC	feedback
Lin and Moubarak [148]	China	1977–2011	VEC	feedback
Bilgili [149]	USA	1981–2013	wavelet coherence	growth

As Bildirici [43] remarks that there exist, indeed, limited number of papers which investigate this relationship within available literature.

4. Estimation results from asymmetric causality test

The definition of data, estimation methodology and priori unit root tests are given in Appendix A and B section in detail. Table 2 presents the results of Hatemi-J [49] asymmetric causality test for the US for the period 1982–2011.

Based on the results, one might indicate that an increase in per capita biomass consumption mitigates the per capita CO2 emissions. Or, one might indicate equivalently that the null hypothesis stating that a positive biomass energy consumption per capita shock does not Granger cause a negative shock in CO2 emissions per capita can be rejected at 1% significance level. Table 2 outcome confirms Bilgili [82], Piroli et al. [53], and Katircioglu [83]. Table 2 also exhibits that a reduction in CO2 emissions per capita results in a reduction in biomass consumption per capita. Or, one might equivalently reject the null hypothesis that a negative shock in CO2 emissions per capita does not Granger cause a negative shock in biomass energy consumption per capita at 10% significance level. This outcome verifies, as well, [53,82,83] indirectly.

According to Table 3, a rise in biomass consumption per capita induces a boost in GDP per capita. In other words, as seen in Table 3, the null hypothesis that lnBIO+ does not Granger cause lnGDP+ can be rejected at 10% significance level. Hence one may conclude that, the growth hypothesis exists between biomass energy consumption per capita and GDP per capita for the US over the period 1982–2011. This evidence supports Payne [123], Bilgili and Ozturk [2], and Ozturk and Bilgili [125]. Table 3 outcome, on the other hand, cannot reject the hypotheses that positive or negative shocks in GDP do not Granger cause negative or positive shocks in biomass usage. This later evidence does not alter the evidence of growth hypothesis but calls for future potential papers that might investigate why a change in GDP does not readjust the biomass consumption.

Overall, the estimations conducted in this paper reveal that an increment in biomass consumption will give rise to (i) a diminishment in CO_2 emissions and (ii) an expansion in GDP in the US. Consequently, one might claim that biomass energy production/consumption policy can be an effective instrument to keep sustainable development through high employment with clean environment.

Table 3
Hatemi-J [49] asymmetric causality test for the relationship between biomass energy consumption and GDP.

Null hypothesis	Test statistic	Critical values[a]		
		1%	5%	10%
lnBIO^{+} does not Granger cause lnGDP^{+}	325.397[b]	14840.523	507.253	135.789
lnBIO^{-} does not Granger cause lnGDP^{-}	65.015	22169.753	600.569	146.301
lnBIO^{-} does not Granger cause lnGDP^{+}	5.170	17002.406	686.539	165.303
lnBIO^{+} does not Granger cause lnGDP^{-}	0.866	11405.895	539.950	129.411
lnGDP^{+} does not Granger cause lnBIO^{+}	46.881	15219.180	777.512	202.455
lnGDP^{-} does not Granger cause lnBIO^{-}	3.559	13753.687	438.451	114.629
lnGDP^{-} does not Granger cause lnBIO^{+}	1.728	15.504	6.042	3.678
lnGDP^{+} does not Granger cause lnBIO^{-}	0.737	12.545	5.569	3.613

Notes:
[a] Critical values are obtained through 10000 bootstrap replications.
[b] Illustrates 10% statistical significance.

5. The practical implications underpinning the estimation output: Social goals and economic mechanism

The main output of this paper is that biomass energy consumption per capita mitigates CO_2 emissions and increases the GDP per capita in the US. This statistical evidence, might, however, might need to be underpinned by some practical facts. Then, apart from the statistical evidence, one may ask why an increase in production/consumption of biomass energy could practically reduce the usage of fuel oil. One may answer this question by monitoring two main issues: (i) the social goals of demand side and supply management policies, and, (ii) the economic feasibility of biomass production.

5.1. The social goals of demand side and supply side management policies

One may consider some management policies to explain why biomass usage might diminish the usage of fuel oil. One, therefore, may state that demand and/or supply side management mechanism emphasizes the social goals aiming at establishing economic mechanism that can achieve the stated social objectives [150]. There exist two common social goals of the societies: (a) higher levels of welfare, and, (b) clean environment. As the population of the World grows significantly, the efficient and sustainable usage of natural resources becomes the main target of the societies.

To this end, United Nations [151] underlines the importance of modern energy services to reach urban sustainability and food and nutrition security. The United Nations Conference on Sustainable Development [151] states that, in order for societies to be able to reach sustainable development, there needs to be requirement of global actions to reach further economic and social progress through the targets of growth, employment, and, strengthening environmental protection. Therefore, in order for societies to achieve the economic growth together with the clean environment, the linkage between sustainable development towards economic development and environmental protection is specifically underlined at United Nations [151] as depicted in Fig. 3.

The United Nations' implementation of Agenda 21 given in Fig. 3 actually is not a new program, but has been following mainly the outcome of United Nations Conferences/Programs held in Rio in 1992 and Kyoto in 1997 and 2005 [151]. The targets' consequences from sustainable development to economic growth and clean environment, might, of course, are subject to change from country to country.

The US' implementation of the United Nations agenda, for instance, came up with Energy Policy Act (EPACT) incentives of 1992 and 2005 [152] and Biomass Research and Development Act of 2000 [153]. EIA [152] reveals the prominent impact of EPACT tax incentives launched in 1990s and during 2000s to stimulate energy usage from fossil energy to renewables of wind and biomass. Hence, EPACT of 2005 intends to implement (i) Federal renewable energy production tax credit, (ii)

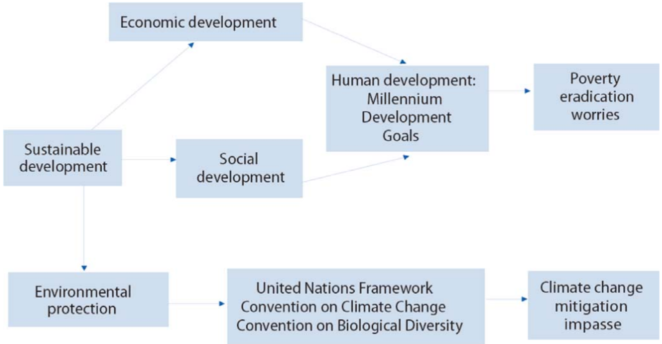

Fig. 3. The United Nations' implementation of Agenda 21.
Source: United Nations [151]

grants for forest biomass utilization and (iii) grants for forest biomass utilization research and development [154,155]. Further, Biomass Research and Development Act considers the efficient coordination between the United States Department of Energy and United States Department of Agriculture to achieve the efficient energy usage from biomass [153,155]. The EIA Demand Side Management Program [156] considers, as well, the implementation of effective demand side management (DSM) policies to encourage the electricity usage of economic agents from biomass by following EIA-DSM's program which periodically analyses the pattern of electricity usage of households and industries in the US [156]. One may claim that all relevant programs eventually intend to conduct the policies that might bring about higher economic growth /development together with lower CO_2 emissions from the usage of energy sources/natural endowments. To this end, policymakers may suggest that industries and households employ renewable energy endowments in their production and consumption behaviour to mitigate the current and future possible global warming level.

5.2. The economic feasibility of biomass production

This subsection explores the economic feasibility of biomass production, that might stimulate the producers to invest more in biomass energy sources, by observing empirical facts and/or anticipated figures of (a) possible reduction in costs of biomass, (b) R & D investment and total investment in biomass industry, (c) the subsidies making biomass more competitive, (d) possible reduction in supply chain cost of biomass, and, (e) competitive advantage: Reduction in biomass value chain costs. All these relevant practical facts about biomass production in the US and/or in EU yield an economic mechanism that provides reader with a comprehensive explanation about the potential relative increase in biomass production in comparison with fuel oil production in the US.

5.2.1. Reduction in costs of energy production through biomass source

Biomass is a complex source that can be processed through many ways, can be transformed into several products and can present multiple energy options. Biomass can be produced in forestry, agriculture, trade, and industry. For instance, many solid wastes, such as grains, oil crop plants, chaff, fertilizer, residuals in wood industry, organic wastes etc., can be used as raw materials for biomass. These wide raw material options can be processed through (i) mechanic ways, such as chipping, cleaving, pelleting, briquetting, pressing, (ii) thermal and chemical ways, such as drying, gasification, pyrolysis, esterification, and (iii) biological ways, such as alcohol and methane fermentation. As results of these procedures, (i) solid fuels, such as pellets and charcoal, (ii) gaseous fuels, such as hydrogen, biogas, and wood gas, and (iii) liquid fuels, such as ethanol, methanol, Fischer-Tropsch liquids, oil from plants, oil from pyrolysis and esters can be obtained. In addition, biomass conversion can be utilized in (i) heat fields, such as single stove, central heating, and heating plant and (ii) electricity & heat fields, such as steam turbine, gas turbine, steam & gas turbine, Stirling engine, combustion engine and fuel cell [157]. Due to all these economic and technical advantages, fossil fuels, which are the main source of CO2 emissions, can be substituted with biomass energy.

In addition, due to continuously growing biomass production technologies, there exist markets for several biomass fuels. The economics of biomass power generation depends on continuous and safe procurement of raw material. For this reason, the share of feedstock cost in total cost of electricity generation from biomass is about 40–50%. Feedstock cost is decreased especially by waste management technologies. Gasification Technologies, feedstock conversion system technologies, and anaerobic systems technologies are expected to reduce the capital cost by 22%, 12–16%, and 17–19%, respectively [158]. In a similar way, according to the European Climate Foundation [159], the cost of biomass raw materials will decrease by 25% in Europe in 2020.

When the production costs of gasoline and biofuels used in the transportation sector are compared, it will be seen that the production costs of gasoline, corn ethanol, corn Stover, and sugar cane (Brazil) are 0.0120, 0.0180, 0.0236, and 0.0101 (USD/MJ), respectively. The costs of biodiesel waste and biodiesel vegetable oil are 0.0103–0.0158, and 0.0159–0.0203 (USD/MJ), respectively. According to these figures, ethanol produced from sugar cane can compete with gasoline in Brazil. The cost of electricity produced from coal and biomass is 0.0110–0.0140 and 0.0140–0.0190 (USD/MJ), respectively. The cost of electricity from biomass is almost equal to the cost of electricity from coal [160].

Another biomass-based fuel that draws attention economically is ethanol. Due to continuous improvement in pre-treatment, enzyme application, and fermentation technologies, the cost of bioethanol production per litre decreased from 1.22 USD to 0.31 USD. If the technological improvement targets are completely achieved, the cost is expected to be 0.20 USD in a few years. Hence, substitution of gasoline with bioethanol seems to reasonable [161]. This substitution might mitigate CO2 emissions stemming from the transportation sector.

Economic theory considers not only production costs but also environmental externalities of energy sources. Therefore, environmental externalities of energy sources should be considered as well as the production cost of energy sources. Hence, the price of the energy source can exactly reflect social costs. Within this scope, Owen [162] calculates the external costs of several electricity generation methods in European countries. Accordingly, the external costs of coal, oil, natural gas, and biomass are 2–15, 3–11, 1–4, and 0–0.075 Eurocents per kilowatt-hour, respectively. Owen [162] remarks that external costs' estimations of European countries are compatible with those of the US. Therefore, one can argue that biomass sources might be more effective than fossil sources when production costs include externalities [163].

5.2.2. R & D investments in bio sources

Rausser et al. [160] reveal that the R & D expenditures and incentive policies of governments result in commercial advances for biofuels and other renewable energy sources. Besides, private sector increases R & D expenditures and investments in reply to these expenditures and incentive policies. For instance, while R & D investments for biomass of the US Department of Agriculture (USDA) and the US Department of Energy (DOE) were 5 million USD and 92 million USD in 2002, respectively, their relevant investments were 28 million USD and 220 million USD in 2010, respectively. These government and private investments and incentives increase productivity by stimulating innovation in renewable energy. Hence biomass sources can compete with fossil sources. In addition, the Energy Independence and Security Act of 2007 in the US aimed at increasing renewable fuel standards to 36 billion US gallons by 2022 from 4.7 billion US gallons mandated in 2007. To achieve this target, the act provides 500 million USD on a yearly basis for production of biofuels during the period 2008–2015. The policy makers denote, in general, that the lifecycle of greenhouse gas emissions would decrease by 80% if the target can be achieved.

5.2.3. The subsidies making biomass more competitive

Subsidies are also important for the competition of biomass sources with fossil fuels. For instance, the US has implemented energy and agricultural policies supporting conversion of corn into ethanol since 1970s. The total subsidies for production of ethanol were 9–11 billion USD in the US in 2008, and reached 18–22 billion US during 2009–2012. With regard to EIA, in the US, subsidies for biofuels will be 67 billion USD in 2035 while this figure was 22 billion USD in 2010 [164].

5.2.4. Reduction in supply chain cost of biomass production

A supply chain is the path of a product from supplier to consumer.

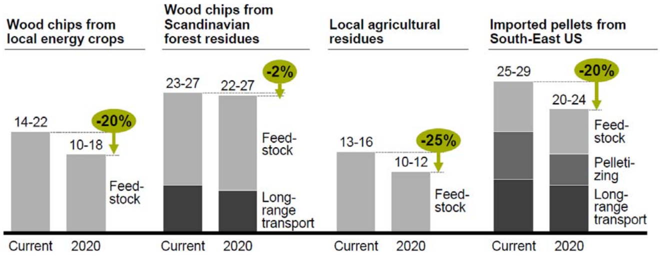

Fig. 4. Cost reduction for biomass fuel delivered to power and heat plants.
Source: European Climate Foundation [159].

This path comprises the chain from natural resources, raw materials to final commodity.

The Fig. 4 denotes the cost reduction in supply chain up to 25% for biomass fuel delivered to power and heat plants in continental Europe. From 2010–2020, the cost of biomass fuel delivered to power and heat plants are expected to (i) reduce in the wood chips from local energy crops by 20%, (ii) mitigate in wood chips from Scandinavian forest residues by 2%, (iii) be lower in local agricultural residues by 25%, and, (iv) decrease in imported pellets from South-East US by 20%. The 25% cost reduction from 2010 to 2020 is expected to arise from increased scale, better technology, and improved harvesting and gathering techniques in biomass production [159].

5.2.5. *Competitive advantage: Reduction in biomass value chain costs*

Value chain concept indicates that a product produced by a company gains additional value at each step of several activities. Within the framework of value chain, a company aims at focusing on the sources of competitive advantage [165]. Eventually, this competitive advantage through specific activities of a representative company is expected to reach lower costs. The Fig. 5 reveals the costs' estimations of the 5 archetype biomass value chains from 2010 to 2020 in continental Europe.

If value chains are scaled up, (i) the cost of co-firing in hard coal condensing plant of SE US pellets is expected to reduce by 15%, (ii) the cost of SE US pellets in converted large condensing plant is estimated to decrease by 15%, (iii) the cost of chips from energy crops in new dedicated condensing plant is expected to mitigate by 20%, (iv) the cost of chips from Scandinavian forest residue in new dedicated CHP (combined heat and power plants) is anticipated to decline by 15%, and, (v) the cost of local agricultural residue in new dedicated CHP plant is anticipated to decline by 40% [165].

6. Conclusion

This paper mainly reviews the literature of biomass energy regarding its influence on environment and economic growth. Considering the mixed evidence of the literature, the paper, later, launches an econometric model to investigate the effects of biomass energy consumption per capita on per capita CO_2 emissions and per capita GDP. By employing the data ranging from 1982 to 2011 for the US, the paper follows ADF, PP, LS unit root tests, and Hatemi-J asymmetric causality test framework [49]. According to the empirical findings, a positive shock in biomass energy consumption per capita Granger causes (i) a negative shock in CO_2 emissions per capita and (ii) a positive shock in GDP per capita. One may claim, then, that, as biomass energy consumption per capita increases in the US, the CO_2 emissions per capita will fall and the GDP per capita will escalate. Thereby, one might eventually state that the use of biomass energy not only helps societies struggle with global warming and climate change but also provides countries with energy dependency and energy safety.

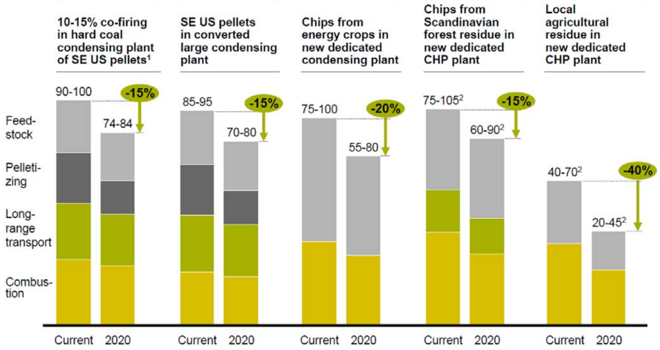

Fig. 5. The reduction in costs of the 5 archetype biomass value chains.
Source: European Climate Foundation [159].

Additionally, biomass sources might increase growth rates of countries as fossil sources can be replaced with biomass sources. Further, biomass sources have great potentials since i) biomass sources can be converted to solid, liquid, and gas, ii) biomass energy can be employed in transportation, heating, and electricity generation, iii) fossil sources can be substituted with biomass sources, and iv) only 7% of biomass sources in the world are currently utilized as Narayan [24] points out. For these reasons, through considerable increment in biomass energy production/consumption, World will need less fossil energy and, hence, can improve fossil energy-based problems. Within this scope, this paper mainly suggests that policy makers follow efficient usage of biomass sources to provide societies with sustainable development through high employment and clean environment.

Further, this paper exposes the practical implications underpinning the estimation output of this paper. The paper reveals, therefore, some practical facts, through social goals and economic mechanism, to explain why biomass usage could reduce fuel oil usage and hence CO_2 emissions in the US. The social goals considers the United Nations' decisions and implementations to mitigate the global warming and relevant economic mechanism comprises practical facts of (i) possible reduction in costs of biomass, (ii) R & D investment and total investment in biomass industry, (iii) the subsidies making biomass more competitive, (iv) possible reduction in supply chain cost of biomass, and, (v) competitive advantage: Reduction in biomass value chain costs. They all exhibit the relative increase in investments in biomass production to gain social and economic benefits of the renewable source of biomass.

One may initiate some discussion lines considering main suggestion and/or outcome of this paper as follows: (i) There is available an intensive literature to review the impact of CO_2 on global warming and economic growth. However, the evidences from literature are not identical, (ii) there exists very little empirical evidence from the literature supporting this paper's output revealing positive effect of biomass sources on environment and/or climate change. This paper, further, analyses the biomass-environment nexus by decomposing the negative and positive shocks in biomass usage for the US. Therefore, there needs to be some potential future works for other countries, as well, by following relevant decomposition analyses, (iii) although this paper reaches mainly a desirable effect of biomass on environment, one should bear in mind that the biomass production/consumption might lead to some ecological concerns. First, the biomass production requires more forestlands to be converted to agricultural lands. This deforestation case might cause a great amount of CO_2 emissions and, hence, can produce undesirable effects on biological diversity and natural life. Second, the increasing biomass production may decrease price of fossil energy and, thus, might increase fossil energy consumption. This case is denominated as Carbon Leakage in literature. In such a case, biomass can increase CO_2 emissions (Green Paradox). Third, the serious risks associated with food safety might emerge if extreme agricultural lands are employed to produce bioenergy, and, if, in this case, food prices can increase excessively.

In conclusion, upon the outcome obtained through analyses of possible structural breaks and throughout asymmetric causality analyses from biomass to air pollution and GDP in the US, this paper suggests that policy makers consider producing and consuming more the biomass sources to mitigate CO_2 emissions and to enhance the welfare. This paper may suggest as well that policy makers need to observe more future empirical evidence searching the net impact of biomass sources within the scope of sustainable development policies and constraints of biomass sources. Therefore, this paper invites further possible researches that might launch alternative case studies, field surveys, and mathematical and/or econometrical models to inquire into the effects of biomass sources on global warming and economic growth in detail.

Appendix A. Data and estimation methodology

A.1. Data

This paper follows time series data for the US. The annual data cover the period 1982–2011. The variables are GDP per capita (constant 2005 USD), CO_2 emissions per capita (metric tons), and biomass energy consumption per capita (used extraction of biomass in kt), respectively. First two variables are obtained from the World Bank Database [166], and, the data for biomass is extracted from the Global Material Flow Database [167]. All variables are employed in logarithmic forms. Hence $\ln CO_2$, lnGDP, and lnBIO refer to logarithmic forms of CO_2 emissions per capita, GDP per capita, and biomass energy consumption per capita, respectively.

A.2. Estimation methodology

Specifying the order of integration of variables is the first step in time series analyses since one may experience, otherwise, spurious regression problem when regarding analyses employ conventional ordinary least squares (OLS) estimations.

Unit root tests developed by Dickey and Fuller [168, hereafter ADF] and Phillips and Perron [169, hereafter PP] are commonly utilized in econometrics literature. The main shortcoming of ADF and PP tests is that they do not take into account possible structural breaks in series. However, potential researchers should consider the possibility that time series might bear structural break(s) to estimate the parameters unbiasedly and efficiently.

Lee and Strazicich [170] suggest an endogenous two-break Lagrange multiplier (LM) unit root test (hereafter LS) allowing for breaks under both the null and the alternative hypotheses and assert that their methodology is extended from the LM unit root test produced by Schmidt and Phillips [171].

The methodology of the LS unit root test can be summarized here in below.

$$y_t=\delta' Z_t+e_t, e_t=\beta e_{t-1}+\varepsilon_t \tag{1}$$

where Z_t is a vector of exogenous variables and $\varepsilon_t \sim$ iid N $(0, \sigma^2)$. Two structural breaks are considered as follows. Model A allows for two shifts in level and is described by $Z_t=[1, t, D_{1t}, D_{2t}]'$, where $D_{jt}=1$ for $t \geq T_{Bj}+1$, $j=1,2$, and 0 otherwise. T_{Bj} denotes the time period when a break occurs. Model B searches the structural breaks, if exist, in trend. Model C includes two changes in level and trend and is described by $Z_t=[1, t, D_{1t}, D_{2t}, DT_{1t}, DT_{2t}]'$, where $DT_{jt}=t-T_{Bj}$ for $t \geq T_{Bj}+1$, $j=1,2$, and 0 otherwise. This process considers breaks both under the null hypothesis ($\beta=0$) and the alternative hypothesis ($\beta < 1$). In model A (a similar argument can be developed for model C), depending on β, the hypotheses are pointed as follows.

$$\text{Null} \, y_t=\mu_0+d_1B_{1t}+d_2B_{2t}+y_{t-1}+\upsilon_{1t} \tag{2}$$

$$\text{Alternative} \, y_t=\mu_1+\gamma_t+d_1D_{1t}+d_2D_{2t}+\upsilon_{2t} \tag{3}$$

where υ_{1t} and υ_{2t} are stationary error terms. $B_{it}=1$ for $t=T_{Bj}+1$, $j=1,2$, and 0 otherwise, and $d=(d_1, d_2)'$. In model C, D_{jt} terms are added to Eq. (2) and DT_{jt} terms are added to Eq. (3), respectively. Eq. (2), indicating the null hypothesis, includes dummy variables B_{jt}.

The LS unit root test statistic is obtained by the following Eq. (4) as is given in Strazicich et al. [172].

$$\Delta y_t=\delta' \Delta Z_t+ \phi \tilde{S}_{t-1} +\sum \gamma_i \Delta \tilde{S}_{t-i}+u_t \tag{4}$$

where $\tilde{S}_t=y_t-\tilde{\psi}_x-Z_t\tilde{\delta}$, $t=2,\ldots,T$. $\tilde{\delta}$ is a vector of coefficients in the regression of Δy_t on ΔZ_t, $\tilde{\psi}_x=y_1-Z_1\tilde{\delta}$, and y_1 and Z_1 show the first observations of y_t and Z_t, respectively. Δ is the difference operator. The term u_t is contemporaneous error term and is assumed independent and identically distributed with zero mean and finite variance. $\Delta \tilde{S}_{t-i}$, $i=1,\ldots,k$, terms are included to correct for serial correlation. Z_t is vector of exogenous variables defined by the data generating process. The null hypothesis is described by $\phi=0$, and the LM test statistic is characterized as $\tilde{\tau}$.

To endogenously determine the location of two breaks ($\lambda_j=T_{Bj}/T$, $j=1,2$), the LS unit root test uses a grid search as follows [170].

$$LM_\tau=\inf_{\lambda} \tilde{\tau}(\lambda) \tag{5}$$

The breakpoints are determined at data points where the test statistic is minimized. Critical values for Model C depend on the location of breaks. If LM test statistics are greater than critical values in Lee and Strazicich [170], the null hypothesis is rejected, and the rejection of the null hypothesis indicates a stationary process.

Since the seminal paper of Granger [173] on causality, testing the causality between the relevant variables has drawn great attention. In his original paper, Granger [173] defines causality as "We say that Y_t is causing X_t, if Y_t at time t helps to forecast the future values of X_t. However, as is explained in Hatemi-J [49], positive and negative shocks have not been decomposed so far in causality tests. it is assumed most likely that positive and negative shocks have same impacts in previously published papers on causality. In other words, these papers postulate the notion that the causal impact of a positive shock is the same as the causal impact of a negative shock. Hatemi-J [49] states that positive and negative shocks may have different causal impacts and, thus, he develops an asymmetric causality test. Let us assume that we aim at observing the causal relationship between two integrated variables y_{1t} and y_{2t} and let y_{1t} and y_{2t} follow random walk processes as in Eqs. (6) and (7).

$$y_{1t}=y_{1t-1}+\varepsilon_{1t}=y_{10}+\sum_{i=1}^{t}\varepsilon_{1i} \tag{6}$$

$$y_{2t}=y_{2t-1}+\varepsilon_{2t}=y_{20}+\sum_{i=1}^{t}\varepsilon_{2i} \tag{7}$$

where t=1,2,...,T, the constants y_{10} and y_{20} are the initial values, and the variables ε_{1i} and ε_{2i} indicate white noise disturbance terms. The subsequent notation is used to identify positive and negative shocks: $\varepsilon^{+}_{1i}=\max(\varepsilon_{1i}, 0)$, $\varepsilon^{+}_{2i}=\max(\varepsilon_{2i}, 0)$, $\varepsilon^{-}_{1i}=\min(\varepsilon_{1i}, 0)$, $\varepsilon^{-}_{2i}=\min(\varepsilon_{2i}, 0)$, respectively. Then, one can state $\varepsilon_{1i}=\varepsilon^{+}_{1i}+\varepsilon^{-}_{1i}$, and $\varepsilon_{2i}=\varepsilon^{+}_{2i}+\varepsilon^{-}_{2i}$. It follows that

$$y_{1t}=y_{1t-1}+\varepsilon_{1t}=y_{10}+\sum_{i=1}^{t}\varepsilon^{+}_{1i}+\sum_{i=1}^{t}\varepsilon^{-}_{1i} \tag{8}$$

$$y_{2t}=y_{2t-1}+\varepsilon_{2t}=y_{20}+\sum_{i=1}^{t}\varepsilon^{+}_{2i}+\sum_{i=1}^{t}\varepsilon^{-}_{2i} \tag{9}$$

Finally, the positive and negative shocks of each variable can be defined in a cumulative form as $y^{+}_{1t}=\sum_{i=1}^{t}\varepsilon^{+}_{1i}$, $y^{-}_{1t}=\sum_{i=1}^{t}\varepsilon^{-}_{1i}$, $y^{+}_{2t}=\sum_{i=1}^{t}\varepsilon^{+}_{2i}$, $y^{-}_{2t}=\sum_{i=1}^{t}\varepsilon^{-}_{2i}$. Each positive together with negative shock has a permanent impact on the underlying variable. The next step is to launch the tests for the causal relationship by following positive and/or negative shocks of the variables. The Eq. (10), for instance, reveals the case of testing for causal relationship between positive cumulative shocks.[1] On the assumption that $y^{+}_{t}=(y^{+}_{1t},y^{+}_{2t})$, the test for causality can be implemented by employing the following vector autoregressive model of order p, VAR (p):

$$y^{+}_{t}=v+A_1y^{+}_{t-1}+\ldots+A_py^{+}_{t-1}+u^{+}_{t} \tag{10}$$

where y^{+}_{t} is the 2×1 vector of variables, v is the 2×1 vector of intercepts, and u^{+}_{t} is a 2×1 vector of error terms. The matrix A_r represents a 2×2 matrix of parameters for lag order r (r=1, ..., p). The optimal lag order can be determined using either conventional information criteria such as the Schwarz Bayesian Criterion (SBC) and the Akaike Information Criterion (AIC) or the information criterion suggested by Hatemi-J [174,175]. This information criterion is defined as follows:

$$\text{HJC}=\ln(|\hat{\Omega}_j|)+j2^{-1}T^{-1}(n^2\ln T+2n^2\ln(\ln T)), j=0, \ldots, p \tag{11}$$

where $\ln(|\hat{\Omega}_j|)$ denotes the determinant of the estimated variance-covariance matrix of the error terms in the VAR model using lag order j, n is the number of equations in the VAR model, and T is the number of observations. After determining the optimal lag order, the null hypothesis that kth element of y^{+}_{t} does not Granger cause the ωth element of y^{+}_{t} is tested.[2] This null hypothesis is defined as

$$H_0\text{: the row } \omega\text{, column } k \text{ element in } A_r \text{ is equal to zero for } r=1, \ldots, p \tag{12}$$

Some denotations are used to define a Wald test:
$Y:=(y^{+}_{1}, \ldots, y^{+}_{T})$ (n×T) matrix,
$D:=(v, A_1, \ldots, A_p)$ (n×(1+np)) matrix,
$Z_t:=\begin{bmatrix}1\\ y^{+}_{t}\\ y^{+}_{t-1}\\ \vdots\\ y^{+}_{t-p+1}\end{bmatrix}$ ((1+ np)×1) matrix, for t=1, ..., T,
$Z:=(Z_0, \ldots, Z_{T-1})$((1+np)×T) matrix, and.
$\delta:=(u^{+}_{1}, \ldots, u^{+}_{T})$ (n×T) matrix.

Now, the VAR (p) model can be defined more compactly as follows:

$$Y=DZ+\delta \tag{13}$$

The following Wald test statistic can be utilized in order to test the null hypothesis of non-Granger causality defined as H_0: $C\hat{\beta}=0$:

$$\text{Wald}=(C\beta)'[C((Z'Z)^{-1}\otimes S_U)C']^{-1}(C\beta) \tag{14}$$

where β=vec(D) and vec indicates the column-stacking operator, ⊗ refers to the Kronecker product, and C represents a p×n(1+np) indicator matrix with elements ones for restricted parameters and zeros for the rest of the parameters. S_U is the estimated variance-covariance matrix of the unrestricted VAR model that is estimated as $S_U=\frac{\hat{\delta}'_U\hat{\delta}_U}{T-q}$, where q is the number of parameters in each equation of the VAR model. When the assumption of normality holds, the Wald test statistic in Eq. (14) has an asymptotic χ^2 distribution with the number of degrees of freedom that is equal to the number of restrictions to be tested (in this case, it is equal to p). Some data may not be distributed normally and there might be autoregressive conditional heteroscedasticity (ARCH) effects for some data. To fix these problems, the bootstrap simulation technique might be conducted. If the calculated Wald statistic is greater than the bootstrap critical values, the null hypothesis of non-Granger causality is rejected [49].

Appendix B. Results of unit root tests

Table B1 reports the results of ADF and PP unit root tests and Table B2 depicts the output of the LS unit root test. Accordingly, the test statistics for the first differences reject the null hypotheses and indicate that series are stationary in first differences. Then, the series are integrated of order 1,

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[1] To carry out tests for causality between negative cumulative shocks, the vector $y^{-}_{t}=(y^{-}_{1t},y^{-}_{2t})$ is utilized. Other combinations are possible.

[2] Hatemi-J [49] remarks that an additional unrestricted lag is included in the VAR model to take into account the effect of unit root as Toda and Yamamato [176] suggest.

Table B1
ADF and PP unit root tests.

Variable[a]		ADF test statistic		PP test statistic	
		Intercept	Intercept and trend	Intercept	Intercept and trend
lnCO$_2$		−0.146	−0.520	−0.310	−0.214
lnGDP		−2.081	−1.942	−3.351[c]	−1.307
lnBIO		−1.102	−5.651[b]	−2.984[c]	−6.197[b]
ΔlnCO$_2$		−4.508[b]	−5.331[b]	−4.482[b]	−5.589[b]
ΔlnGDP		−3.024[c]	−3.558[d]	−2.876[d]	−3.393[d]
ΔlnBIO		−10.154[b]	−9.917[b]	−27.978[b]	−28.607[b]
Critical	1%	−3.679	−4.309	−3.679	−4.309
values	5%	−2.967	−3.574	−2.967	−3.574
	10%	−2.622	−3.221	−2.622	−3.221

Notes:
[a] Δ is the first difference operator.
[b] Illustrates 1% statistical significance.
[c] Illustrates 5% statistical significance.
[d] Illustrates 5% statistical significance.

Table B2
LS unit root test.

Variable[a]	Model	Test statistic	Break dates	λ values	Critical values[b]		
					1%	5%	10%
lnCO2	A	−2.464	2005, 2008		−4.54	−3.84	−3.50
	C	−4.420	1990, 2004	$\lambda_{1,2}$=(0.4, 0.8)	−6.42	−5.65	−5.32
lnGDP	A	−2.622	2001, 2006		−4.54	−3.84	−3.50
	C	−4.858	1989, 2001	$\lambda_{1,2}$=(0.4, 0.6)	−6.45	−5.67	−5.31
lnBIO	A	−4.357[d]	1993, 2002		−4.54	−3.84	−3.50
	C	−6.159[d]	1991, 2005	$\lambda_{1,2}$=(0.4, 0.8)	−6.42	−5.65	−5.32
ΔlnCO2	A	−5.955[c]			−4.54	−3.84	−3.50
	C	−6.808[e]		$\lambda_{1,2}$=(0.2, 0.8)	−6.33	−5.71	−5.33
ΔlnGDP	A	−4.800[c]			−4.54	−3.84	−3.50
	C	−5.353[e]		$\lambda_{1,2}$=(0.4, 0.8)	−6.42	−5.65	−5.32
ΔlnBIO	A	−6.079[c]			−4.54	−3.84	−3.50
	C	−8.079[c]		$\lambda_{1,2}$=(0.4, 0.8)	−6.42	−5.65	−5.32

Notes:
[a] Δ is the first difference operator.
[b] Critical values are obtained from Table 2 in Lee ve Strazicich [170].
[c] Illustrates 1% statistical significance.
[d] Illustrates 5% statistical significance.
[e] Illustrates 10% statistical significance.

[I(1)].

Table B2 reveals the estimated structural breaks of the US economy. The breaking dates of the LS unit root test might be expected to correspond to some considerable periods for the US economy. The breaks occurred in the 1990s might denote 1990–1991 recession of the USA due to restrictive monetary policy and business cycles [177,178]. The breaks clustering around 2000s might refer to early recession occurred in EU for the period 2000, 2001 and appeared in the USA for the years 2002, 2003 [179,180] due to high unemployment rates. Additionally, the housing bubble-financial crisis that occurred in the US economy may account for the break in 2008.

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