A Global Multiregional Life Cycle Sustainability Assessment of National Energy Production Scenarios until 2050

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Abstract

The global increasing energy demand have made governments more environmental conscious, yet there are also impacts on society and the environment. The triple-bottom-line sustainability assessment and Autoregressive Integrated Moving Average (ARIMA) methods are used for projecting the impacts on environment, economy and society until 2050 by electricity production sectors in Turkey from 12 different energy sources, under Business As Usual (BAU) and Renewable Energy Development (RED) scenarios. In this regard, three sustainability indicators greenhouse gas (GHG) emissions, wages and taxes are quantified based on electricity production from renewable and non-renewable resources using a high country and sector resolution EXIOBASE, which is a global multiregional input-output (MRIO) database. The results showed that in comparison of BAU with RED scenario, GHG emissions associated would be 84% less in RED, wages will be 23% less and taxes would decrease by 22.4% under RED plan by 2050. In addition, energy sources responsible for the highest GHG emissions per kilowatt-hour of electricity produced are found as biomass, coal, waste and oil. However, coal and biomass contributes to high wages and tax on products purchased. This research provides important insights for policy makers to make more informed decisions considering environmental, economic and societal performance of electricity production policies.

Keywords
Life Cycle Sustainability Assessment, Triple-Bottom-Line Accounting, Multi Region Input-Output Analysis, Energy Policy, Electricity Production.

1. Introduction

Over the past decade, world has seen a significant rise in energy demand and population [1], while energy consumption is expected to increase by 34% in 2030 [2]. Policy makers are concerned with devising policy such a way as to mitigate the sustainability challenges which are growing more serious over the years [3]-[4]. European Union has already taken measures to combat the global warming issue by reducing the greenhouse gas emissions [5], devising "Renewable Directives" in 2009 for the member countries and therefore have successfully moving forward to increase dependency on renewable energy from 8.5% to 20% by 2020 [6]. In this effort, Denmark has planned to produce 50% of its electricity need from renewable energy sources [7]. While Sweden is the leading county in the EU in terms of renewable energy use [1], [8]. The country has already achieved the target of 49% of renewable energy in 2014 and is reached 52.6% of total energy consumption by renewable energy sources. Germany aims to produce 45% of its total energy through renewables by 2030 while Turkey has the potential to meet 50% of its energy demand from renewable energy sources [9]-[10]. There have been significant efforts in attempt to reduce carbon emissions; however, sustainability issues are much beyond the climate change. Studies have shown that the de-carbonization policies have resulted in the reduction of carbon emissions but have stressed the scarce mineral resources [11]. Energy consumption not only affects the environment but also influences other pillars of sustainability such as society and economy. Sustainability is often the goal of cooperate sector, government and NGOs but it is hard to classify which one is better towards achieving sustainable goals [12]. There is mesh of challenges that if one indicator is adjusted the others are effected in negative way. For instance if GHG emissions cut by planning energy mix accordingly for electricity production then it is possible that other parameters like gross value added or government revenue will be adversely affected by this change. Since every indicators in different dimensions have relations with each other, therefore there is a need to carefully monitor the impacts associated with domains like social and economic. The Triple Bottom Line approach allows considering this factor [13].

In this study, we analyzed the impacts of different energy mix plans for electricity production in Turkey and using Multi Regional Input-Output table that quantify the impacts associated with energy consumption on GHG emissions, employees' salaries/wages and on taxes. This study is a unique attempt to gauge the energy sector development and its social and economic implications on the living standards. Furthermore, this work will assist the policy makers to view the socio-economic effects while developing energy policies such that they will be able to make more informed decision is setting better energy standards and thus efficiently manage the environmental, social and economic aspects of their regions. In the past, there have been extensive work on quantifying the impact on electricity production form different energy sectors on different ecological indicators.

Quantification of socio-economic sustainable dimensions are addressed by Life Cycle Sustainable Assessment (LCSA) [14]. The LCSA methodology aims to integrate the environmental, social and economic dimensions into a conventional Life Cycle Assessment (LCA) framework [15]. In LCSA framework, environmental and socio-economic impacts are quantified through life cycle of a product, process or a system under study [16][17][18]. Employing the Life Cycle Sustainable Assessment framework, which quantifies the overall social, environmental and economic impacts of economic activities based on multi-criteria decision making and integrating system dynamics of complex dependencies between sustainability indicators [19]-[20]. Including social, environmental and economic aspects in this study is an attempt to diversify the LCSA utility [21]. Since majority of the trade among countries are interlinked, the researchers quantify the impacts associated with production and consumption through a MRIO analysis. This technique to gauge input output socio-economic and environmental impacts of different economic activities is very common in the field of sustainability [22]. For example, Kucukvar et al. [23] used a time-series MRIO analysis to analyze carbon footprints of manufacturing sectors of 40 largest economies covering 1440 economic sectors. In another study, Kucukvar et al. [24] used an environmentally-extended MRIO to gauge Turkish manufacturing sector and global trade related carbon footprints. Wiedmann et al. [25] used MRIO model to determine carbon footprint for UK time series. Druckman and Jackson [26] quantified the carbon footprints of UK household using MRIO model. Ewing et al. [27] determined the water and ecological foot prints using MRIO analysis and there is extensive literature on MRIO usage is available. Hence, MRIO analysis is done to map impacts of carbon emissions, taxes and salaries of Turkey's electricity production at a global scale; taking into account multi-regional supply chain flows [23]-[24].

2. Methodology

To analyze the impacts of electricity production on GHG emissions, employee wages and on taxes from 12 different energy sources in Turkey, MRIO analysis and ARIMA forecasting methods are jointly used. In the first step, Turkish energy demands are studied and electricity generation from different energy sources are quantified through International Energy Agency database [30]. Then, the EXIOBASE database analysis is done based on the socio-economic and environmental indicators selected for this study and then, with the help of scenario analysis, GHG emissions for electricity generation is quantified. ARIMA forecasting is used to project the emissions until 2050 under different energy mix scenarios. Similar computations are done to calculate the impacts of electricity production on employees' wages and on taxes. Fig. 1 further demonstrates the research methodology.

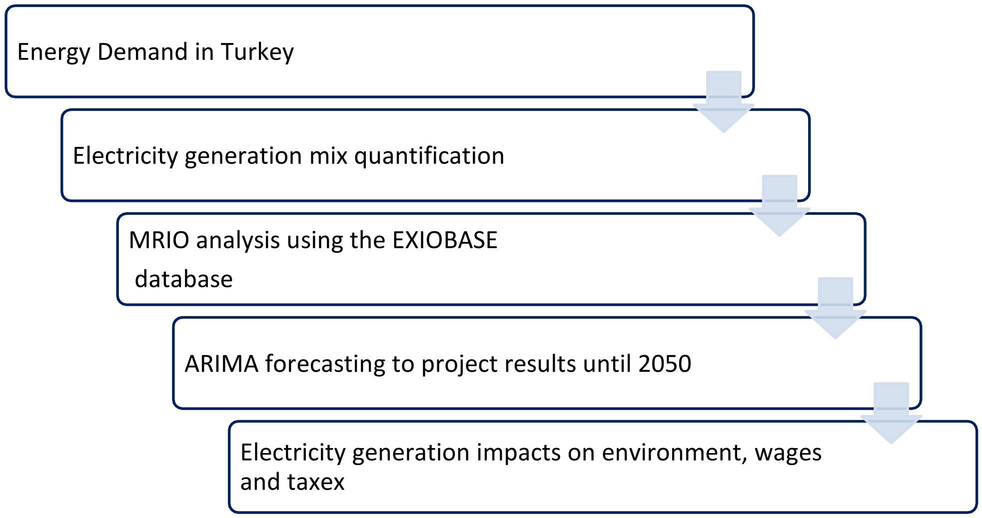

Figure 1. Research Methodology

2.1 Multi Regional input-output Analysis

Although Life Cycle Assessment (LCA) is a renowned method to gauge the environmental impacts and decide on policy matters, Life Cycle Sustainability Assessment (LCSA) techniques are considered more practical and competent [31]. If the socio-economic indicators are also considered in addition the environmental impacts along with enhancing the scope from national levels to multi-national levels for sustainability assessments will broaden the scope of LCA and will transit LCA into Life Cycle Sustainability Assessment (LCSA). LCSA is a cross-disciplinary framework that aims to integrate models instead of methods. This helps in integrating several methodologies and tools to improve sustainability analysis [19].

As LCSA emphasis on enlarging the system boundaries and focus on considering the factors influencing the system under study, single-region input output models have been replaced by multi-regional input output (MRIO) models [19],[32]. Therefore, MRIO analysis are becoming extensively powerful tool in extending the utilities of LCSA frameworks from national economies to global scale [33]. However, several MRIO databases like GTAP, WIOD and EoRA need to have more detailed analysis of interlinked sectors among different countries for refined results [34]. These databases have data representation at an aggregate level, making it difficult to study and analyze at sector level accurately [35].

EXIOBASE, however, covers relatively high-resolution data including 27 European Union countries as well as 16 Non-EU countries along with the rest of the world section. It carries about 200 products, 163 industries, 12 environmental impact categories and socio-economic indicators [36]. It is a very useful environmentally extended, global and multi-regional database designed to be used for policy making [33]. This make EXIOBASE carry relatively detailed accounts of economic sectors and products with respect to intra-country linkages [21]. Furthermore, EXIOBASE covers dimensions like environmental emissions, resource requirements associated with final consumption of several products and utilities, external costs, keeping in view international trade linkages and practices among multi-national scale [37]. In addition, EXIOBASE converts all the data to a standardized detailed classification across all countries. Hence, we employed EXIOBASE for the LCSA analysis is this study. Mathematical formulations of the model have been adapted from existing literature [24], [38]–[40] and relevant results are expressed in the following sections.

In today's fast paced and highly demanding era, multidisciplinary examining approaches are very crucial to incorporate environmental, technological and economical perspectives in order to ensure sustainable development, especially in energy sector [41]. In this study, we have selected GHG emissions, taxes and wages as three indicators to analyze the environmental, social and economic aspects resulting from energy generation activities based on MRIO analysis in Turkey [42]. The reason behind selecting GHG emissions, taxes and wages as indicators for this study is to gauge the taxed electricity and wages obtained based on carbon footprints from electricity production from different energy sources. This is an attempt to link socio-economic aspects with carbon emissions and to trigger the importance these indicators on the living standards of the people [43].

2.2 Energy development scenarios and forecasting for Turkey

Scenario analysis, which is a useful technique to incorporate the uncertainties in the development of matters of long term policies, is used to anticipate the progress of Turkish energy sector by in coming years [44]. Scenarios reduce the complexities of interpreting the complicated systems like energy systems, which are connected to numerous factors and is depended on variety of external sources [45]. Hence, scenario analysis is a tool to ease the understandings and predict the evolution of such complex systems. Policy makers also use these analysis to screen the real world developments with multi dimensions and take short term and long term decisions accordingly [46], [47].

Therefore, to understand the future developments in the energy sector and to cope with the possible developments in Turkish energy sector, two scenarios have been developed to analyze the electricity generation mix in the country until 2050. Business As Usual (BAU) scenario is developed to simulate the possible implication if the electricity production continues at the present pace and according to the current growth rate. Realistic targets, instead of motivated targets set by the government, are considered in this scenario [48]–[50]. Dependency of Turkish energy sector on coal is expected to rise from 23% in 2015 to 27% in 2030. By 2050, coal power plants are expected to contribute 26% share in the overall energy mix. As far as natural gas is concerned, the government plans to decrease its dependency on the natural gas fired power plants to decrease the import bill, as most of the natural gas is imported in Turkey. Therefore, as compared to 44% contribution in the energy mix in 2015 will decrease up to 14% by 2050. On the other hand, renewable energy sources will experience a steady growth under BAU. Proportion of hydropower energy, however, is expected to reduce from about 26% in 2015 to 23% in 2050. Contribution of wind energy is estimated to increase from 4% to 13% from 2015 to 2030 and this will further increase to 19% until 2030. Solar PV technology will contribute to about 4% by 2020 and will increase steadily to 9% until 2030. It will reach to around 12% by 2050 under BAU scenario.

The second scenario developed is the Renewable Energy Development (RED) plan that considers the environmental friendly policies and international agreements signed by the Turkish government to curb GHG emissions from fossil-fueled power plants. The main purpose of RED plan is to reduce the carbon emission by designing the suitable energy mix of relying more on the renewable sources of energy. Therefore, fossil-fueled power sources like coal and natural gas will be subsided by the less dominant renewable sources of energy sources in Turkey like wind, solar photovoltaic energy [49], [51], [52]. As the name of the scenario suggest, renewable sources of energy will be prioritized over fossil-fueled sources and the government is expected to invest more in wind and solar forms of energy. Wind energy, which contributes around 4% in the energy mix in 2015 is expected to contribute about 20% by 2030 and this contribution will further increase to 26.4% by 2050. Solar energy also will show substantial growth. By 2020, 6% of Turkish electrical needs will be fulfilled by solar energy. This number will double in 2025 and by 2050, 20% of the electricity will be coming from solar PV power plants. On the other hand, Coal and natural gas contributions will decrease. Energy obtained from coal power plants, which was about 23% in 2015, will reduce to just 10% by 2050 while energy obtained from natural gas will also have a decline of about 30% and by 2050, only 9.5% of energy is expected to be obtained from natural gas fired power plants.

The energy mix plans for Turkey in 2050 under BAU and RED plan is shown in Table 1.

Table 1. Turkey's Energy mix in percentages in BAU and RED plan in 2050

Energy Source	Business-as-Usual	Renewable Energy Development
Coal	26	10.5
Gas	14	9.4
Nuclear	4.7	6.2
Hydro	23	21.8
Wind	18.8	26.4
Oil	0.6	0.4
Biomass and waste	0.9	0.2
Solar photovoltaic	11.8	20.4
Solar thermal	0	0
Tide	0	0
Geothermal	0.8	0.7

3. Results and Discussions

The results extracted show the multipliers, which are the impact of per kWh of electricity generation. This indicate the effect of GHG emissions, taxes and wages for every energy source. Later, the total impacts are obtained by multiplying the predicted energy generation in the country by 2050. Total impacts of GHG emissions, taxes and wages depict the amount of carbon emissions, euros of taxes and wages that are projected by our analysis. Fig. 2 show the multipliers for GHG emissions, tax on products purchased and employees wage for every kWh of electricity produced in Turkey form different energy sources. Generally, GHG emission multipliers are dominating followed by employee wages. Multipliers of tax on products are least among others. It can be ascertain easily that electricity production by Biomass and waste as energy source will yield highest wages for employee for every kWh of electricity produced but will also cause the highest GHG emissions per kWh produced. Similarly, renewable sources like wind, hydro and geothermal have negligible GHG multipliers but they result in substantial employee wages at a cost of minimal taxes. Primarily because countries are legislating to reduce taxes on products associated with renewable energy to promote their growth. Therefore, in order to reduce GHG emissions without sacrificing employees pay or tax on products, Turkish energy policy should rely on increasing the percentage of electricity mix production by geothermal, wind and hydro sources of energy. The Employees' wages and taxes on the products seems to have a strong correlation with each other and corresponding to the sources of energy. This is reasonable that more the employee is paid the more he will pay the taxes. The highest benefit to the employee can be observed if the production of electricity by hydro and wind is given greater share in the energy mix. It will lead towards greater earning with least GHG emissions and considerably lower tax on the products purchased.

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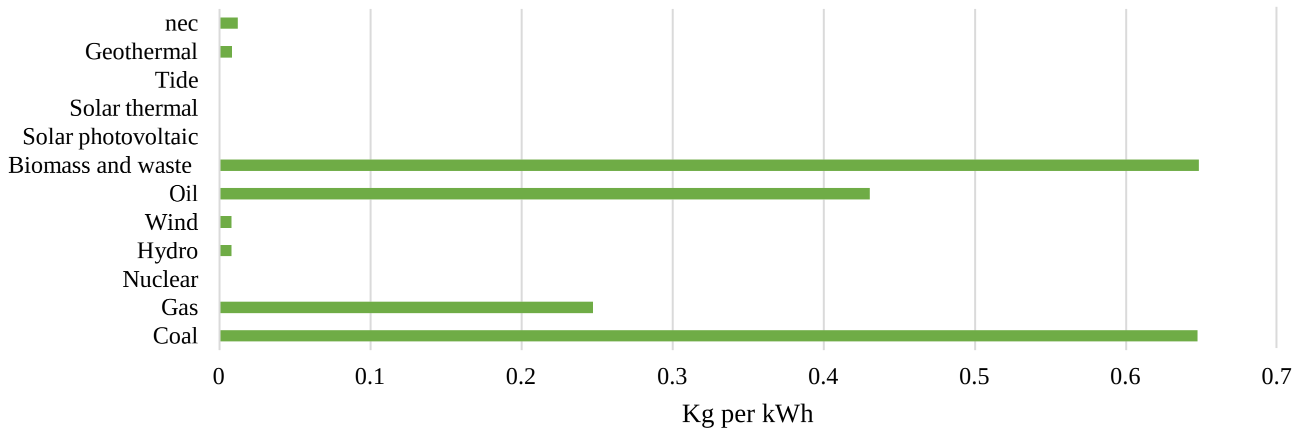
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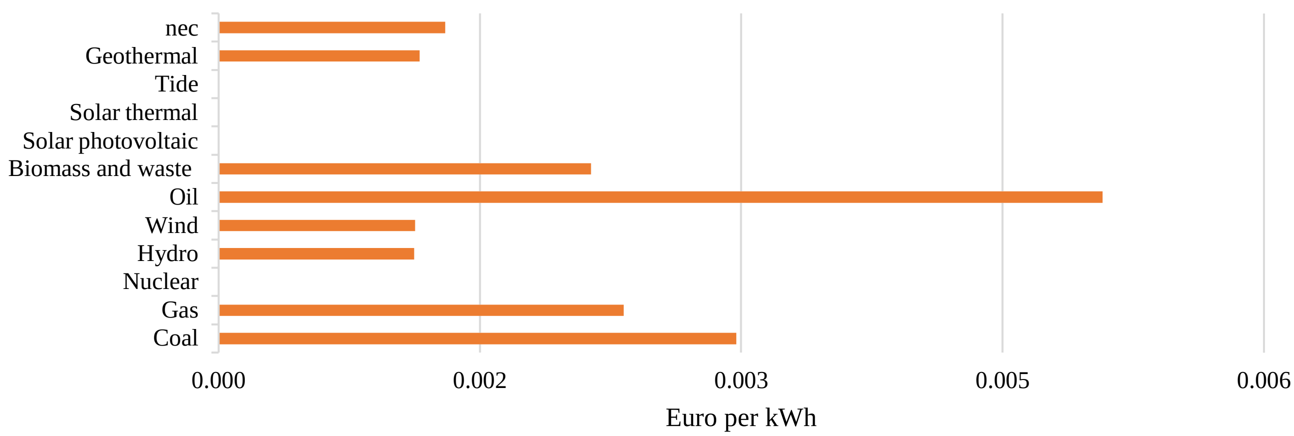
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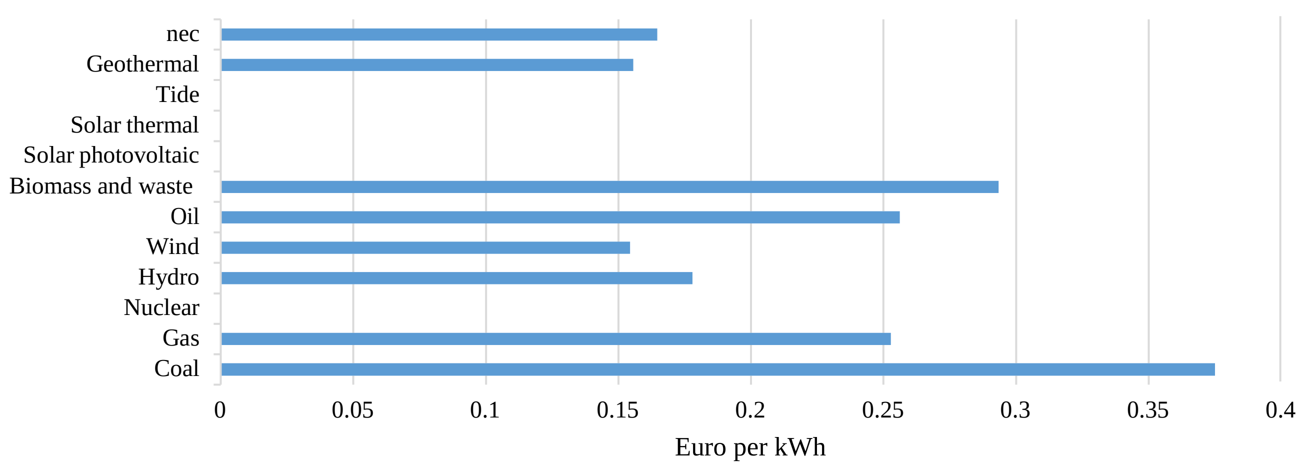
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Euro per kWh

Figure 2. Multipliers for every kWh of electricity produced in Turkey. (a) GHG, (b) Tax on products, (c) Employee wage

3.1 Business as Usual Scenario (BAU)

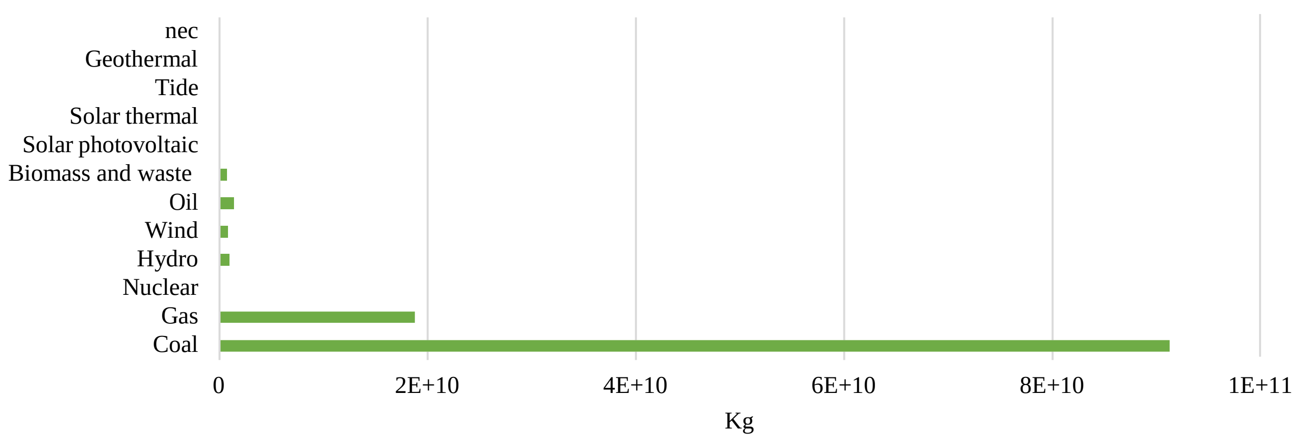
Fig. 3 shows the overall total impacts on selected indicators due to electricity generated by different energy sources in Turkey in 2050 under Business-As-Usual scenario. It can be observed that electricity produced by coal and gas will have the greatest influence in the entire chosen three indicator from different domain. GHG emission will touch around 10^8 tones; total taxes on the products purchased will be around $4*10^8$ Euros while employees' wages will be more than $4*10^{10}$ Euros.

Comparing the multiplier results of Fig. 2 (a) and the total impacts under BAU, coal, natural gas, biomass and liquid oil sources have GHG multipliers on the higher side. However, as the amount of electricity obtained form these sources vary in quantity, the projected total GHG emissions are very less in Biomass and Liquid oils. While as the government is projected to rely on coal resources and continue to import natural gas for generation purposes, their total emissions are dominating in the BAU scenario.

Similarly, taxes multipliers in Fig. 2(b) demonstrates impact of per kWh of electricity from respective energy source, and Fig. 3(b) shows the total taxes that are projected to be resulting from the electricity generation by 2050. Coal, as explained earlier, is dominating BAU scenario, therefore, this will yield highest taxes. Followed by natural gas, hydro energy and wind energy. It is worth noting that solar energy is not resulting on additional taxes, primarily because the governments are trying to promote the use of this form of energy by giving enormous amount of subsidies and encouraging people and companies to invest in solar energy sources.

On the other hand, coal, biomass, wind, liquid fuel, natural gas are going to yield high wages as shown in Fig. 2(c). However, their overall total impact is presented in Fig. 3(c) in which coal power plants are expected to yield the highest wages followed by hydropower, natural gas and wind. This show the impact of energy source on people's socio-economic livings. Therefore, is confirmed that wind and hydro will be the optimum sources of energy in this regards. The employees' wages will be considerably higher than the taxes on products purchased and GHG emission will be negligible from electricity production by wind and hydro.

(a)



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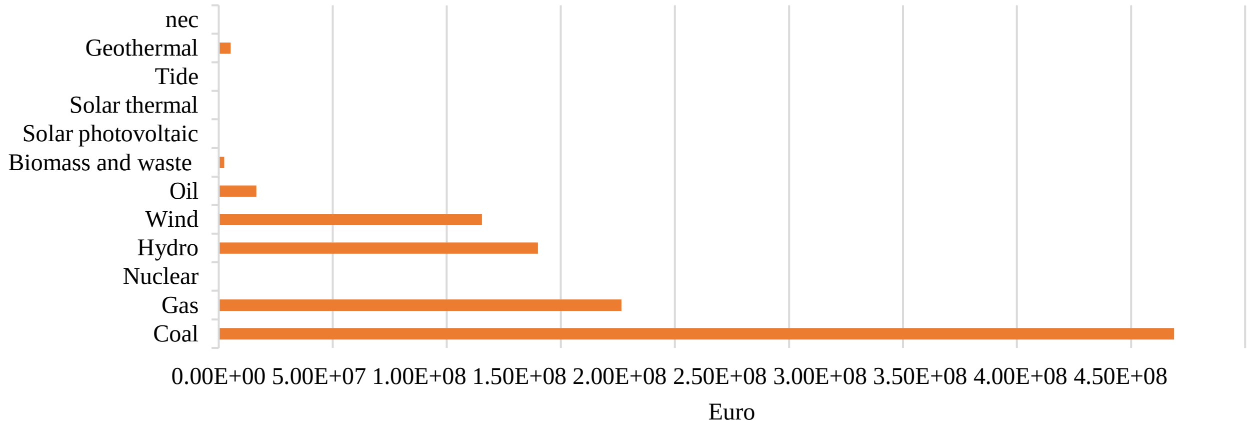

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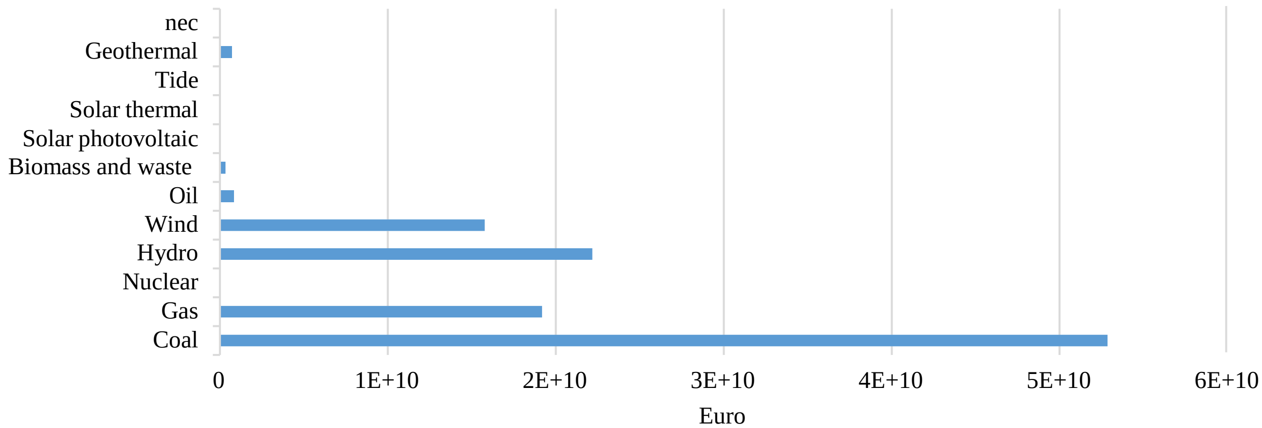


Figure 3. Total impact for every kWh of electricity production in Turkey under BAU scenario in 2050 (a) GHG, (b) Tax on products, (c) Employee wage

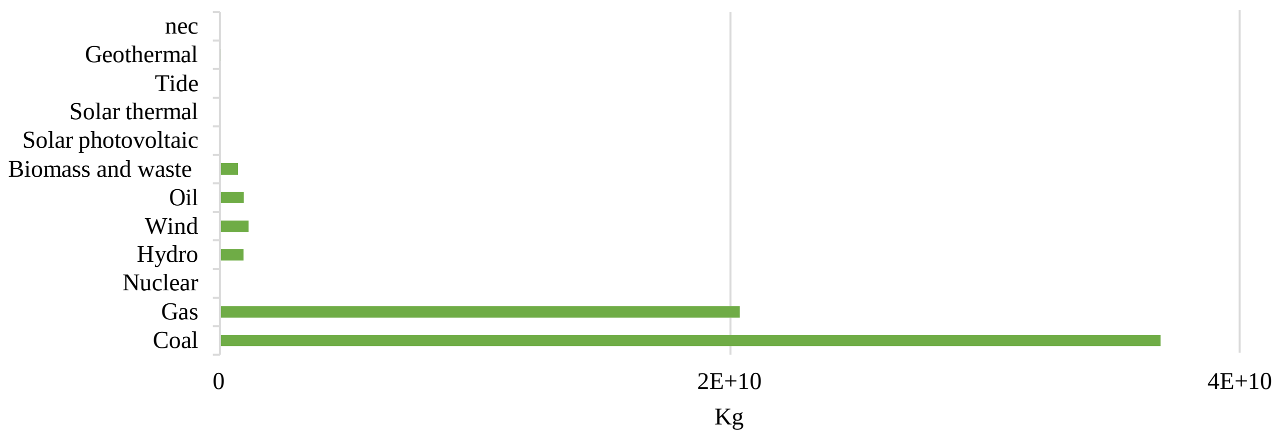
3.2 Renewable Energy development scenario (RED)

Fig. 4 shows the RED plan's total impact on the GHG emissions in Kilograms as well as the Taxes and employees' wages in Euro by 2050. In this scenario, since the percentage mix of electricity production from wind and hydro is greater the employees will get the highest wages and GHG emission will be lower on electricity production by wind And Hydro. Overall GHG emissions from coal in RED scenario are estimated to be about 40% less as compared to BAU is 2050, hence proving that the government will reduce its dependency on coal energy under RED scenario. Emissions from renewable sources are slightly higher because they will be utilized more, but even the relative GHG emissions are negligible as compared to the emissions by coal or natural gas.

Tax burdens under RED scenario are projected to be considerably lesser compared to BAU scenario. Coal energy will yield about 1.5 times fewer taxes as compared with BAU scenario; primarily because of government's reduced utilization of coal sources. On the other hand, natural gas in RED scenario will only save about 8% in terms of taxes while hydro power will result in a saving of 5% as compared with BAU. In contrast, wind energy will result in about 28% higher taxes in RED scenario; majorly due to the sharp development in the wind farms in the years to come. Overall, there will be substantial savings in taxations if the energy sector plans as per the RED scenario.

Wages and impact on people's living standards will also have a positive impact under RED scenario compared with BAU scenario. Similar to as taxes, employee wages related to coal energy sector will have a decrease of around 150%, again because of the reason that the coal energy will be less relied upon. Employee wages for natural gas workers will have an increase of about 8% while people linked with hydro sector will have less wages in RED scenario by 5% compared with BAU. However, as wind energy dependency is projected to increase, employee wages of people linked in this sector are expected to increase by about 28%, which is a considerable increase under RED scenario. On the contrary, RED scenario will not only result in less GHG emissions but is also expected to yield less taxes and will contribute in higher wages over the years as compared with BAU.

(a)



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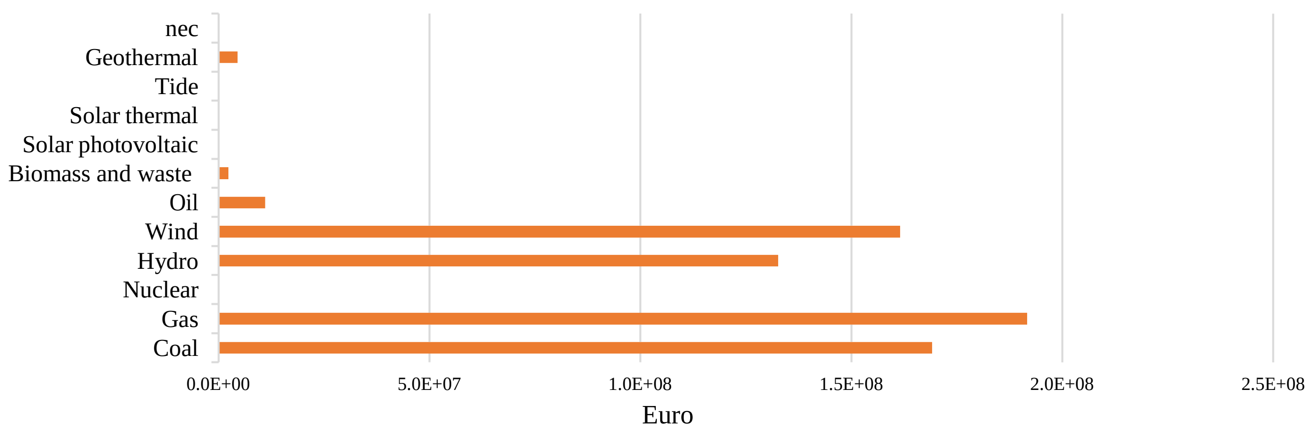

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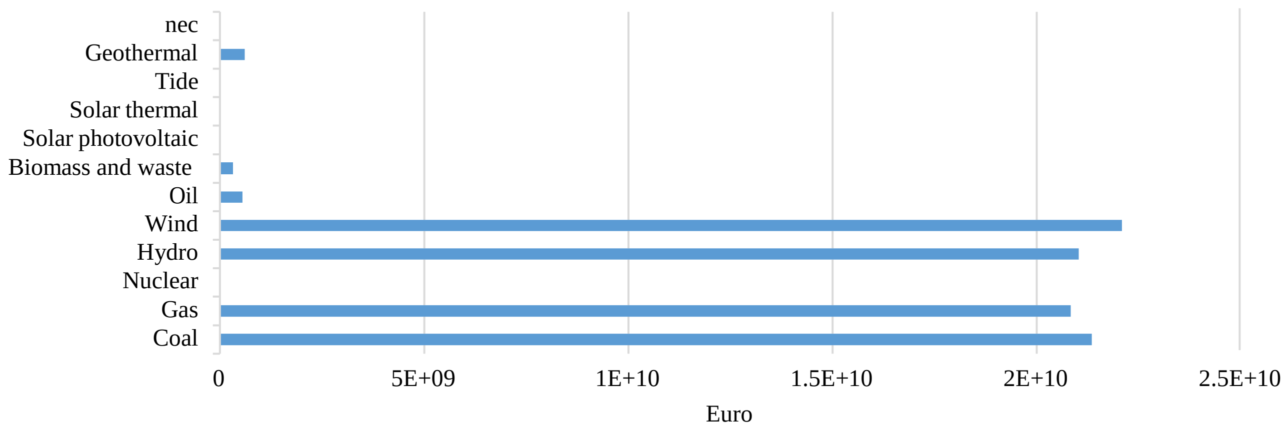

Figure 4. Total impact for every kWh of electricity production in Turkey under RED scenario in 2050 (a) GHG, (b) Tax on products, (c) Employee wage

4. Conclusion

Our analysis results suggests that RED scenario is most environmental friendly in terms of carbon emissions and will have more positive impacts on social and economic aspects in the country in years to come. Under BAU, fossil-fueled energy sources result not only in higher GHG emissions but also enforce extremely high taxes on the public as compared to the RED scenario. Primarily because of the fact that in BAU, the government in inclined towards coal and natural gas energy sources [10]. Hence, the pick of the results are listed below:

- Considering all the three indicators Turkey should focus more on producing electricity by wind and hydro sources as this will result in the least GHG emissions and the highest employee wages yet the minimum tax on the product purchased.

- Since very little energy is produced from biomass and waste, therefore, a high GHG emission is avoided BAU scenario but also the amount of employees' wages and taxes on the products will go down from this energy source. Over all the BAU scenario does not seems to be a good fit when it comes to GHG emissions and the taxed paid on the products purchased. Next section will simulate the total impact in RED scenario by 2050.

- In comparison with the BAU scenario the total GHG emissions in RED is 82.2% less while to total taxes paid on products are 23% less and the total employee wages decreases by 22.44 %. All the indicators have decreased in RED scenario but GHG emission have decreased quiet significantly.

Therefore, Turkey should increase its electricity production on wind and hydro energy to decrease the GHG emissions without compromising on employee's wages and having moderate taxes on products purchased. Investments should be made on developing wind and hydro energy while shift from the dependency of coal and gas will prove to be very useful. In addition to this government should also increase reliance on geothermal energy to produce electricity since it have very low GHG emissions per kWh and high wages. Other non-renewable sources of energy like oil have a string affect in contributing to GHG emissions.

As part of future work, this study can be extended to further indicators to comprehensively carry out LCSA of energy generation in Turkey and other economically emerging countries of the world. In order to make the analysis more close to the current developments, time series analysis and similar techniques can be used instead of using only EXIOBASE 2007 database only. Furthermore, multi-criteria decision making (MCDM) approached can be employed to assess the performance of energy sources based on carbon emissions and socio economic indicators [53]. This work can also be extended to more indicators related to socio-economic and environmental accounting that will result in substantial development of TBL analysis [54]. To capture the details of the entire supply chain more effectively, hybrid LCSA and uncertainty analysis can be useful, as it will minimize uncertainty related misinterpretations of the results [55].

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