The exploitation of biomass for building space heating in Greece: Energy, Environmental and Economic Considerations

A. Michopoulos[1*], V. Skoulou[2], V. Voulgari[1], A. Tsikaloudaki[3], N.A. Kyriakis[1]

[1]Process Equipment Design Laboratory, Department of Mechanical Engineering, Aristotle University of Thessaloniki, P.O.B. 487, 541 24 Thessaloniki, Greece

[2]Dr. Chemical Engineer, Kilkisiou 1, 661 00 Drama, Greece

[3]Laboratory of Building Construction and Physics, Department of Civil Engineering, Aristotle University of Thessaloniki, P.O.B. 429, 541 24 Thessaloniki, Greece

Abstract

The exploitation of forest and agricultural biomass residues for energy production may offer significant advantages to the energy policy of the relevant country, but it strongly depends on a number of financial, technological and political factors. The work in hand focuses on the investigation of the energy, environmental and financial benefits, resulting from the exploitation of forest and agricultural biomass residues, fully substituting the conventional fuel (diesel oil) for building space heating in Greece. For this investigation, the energy needs of a representative building are determined using the EnergyPlus software, assuming that the building is located across the various climate zones of Greece. Based on the resulting thermal energy needs, the primary energy consumption and the corresponding emissions are determined, while an

[*] Corresponding Author: Tel. +30 2 310 996220, Fax +30 2 310 996087, E-mail address: apmich@auth.gr

elementary fiscal analysis is also performed. The results show that significant financial benefits for the end-user are associated with the substitution examined, even though increased emissions and primary energy consumption have been derived.

Keywords: residual biomass; combustion; emissions; energy consumption; residential buildings;

1. Introduction

Biomass is defined as the biodegradable fraction of waste and residues emerging from agriculture activity, including the vegetal and the animal substances, residues produced by forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste according to the Directive 2003/30/EC [1].

Increasing biomass usage in the European Union (EU) can contribute to the achievement of the Union's strategic targets, concerning environmental protection and safety in energy production and supply [1-3]. Moreover, taking into account that almost the two-thirds of EU's renewable energy sources are residual biomass and waste, it is evident that increasing the share of such sources is becoming quite important for the achievement of the 20% by 2020 goal, according to Directive 2009/28/EC [4]. Furthermore, the latest EU policies promote the minimization of wastes by reusing and recycling; thus the non-edible residual biomass may be well exploited for 2nd generation biofuels and bioenergy production, as directive 2003/30/EC indicates [1].

Towards those amendments, EU established a biomass action plan dealing with the increased dependence on imported energy and the achievement of three main objectives concerning competitiveness, sustainable development and security of supply. According to the latest, three sectors are identified in which the exploitation of biomass should be prioritized: heat production, electricity production and transport (as biofuel). Based on the fact that Southern East European countries produce significant amounts of non-edible residual biomass like tree cuttings, straws, fruit and olive kernels, stalks, etc [5] it is evident that, with the aid of a well-established logistic system [6], biomass can be proved able to cover a significant share of the energy demands of the broader area. In addition, based on the fact that conventionally the energy needs of these countries are mainly covered by imports of fossil fuels, the exploitation of their indigenous, non-edible residual biomass may offer several not only environmental, but also socioeconomic advantages [5,7].

In this viewpoint, residual biomass holds an outstanding position in energy production, as its exploitation presents a number of advantages when compared to the fossil fuels, such as lower fuel cost, decentralize production and minimization of the environmental impacts [8,9]. On the other hand, the main difficulties of biomass exploitation are caused by the need to establish an efficient logistic system, the low energy density, the seasonal production and the variation of quality. However, these difficulties are to a certain extent overcome with the in situ exploitation of residues, cyclic use and pelletization [10].

Generally speaking, biomass exploitation aiming to energy production can be achieved by thermochemical processes such as pyrolysis, gasification and combustion [11,12]. Pyrolysis is mainly applied either for liquid biofuels production, or even carbonaceous materials of high added value e.g. activate carbons [11,13], while gasification is mainly applied for combined heat and power production and for chemicals syntheses in the relevant industry [11,14,15]. On the other hand, combustion of residual biomass seems to have the potential to play a significant role in meeting the heating demands not only in rural, but also in urban areas [16,17]. Towards that direction residual biomass could be considered as an alternative energy source for agro-industry and for the residential buildings sector, in order to satisfy heating demands [18]. However, the wide variability of biomass properties may significantly influence the efficiency of the combustion systems and the environmental impacts emerging from its exploitation [18,19].

Concerning the available biomass stocks suitable for exploitation for heating purposes in the Hellenic building sector they are mainly residues coming from the forestry and agricultural and agro-industrial activities as these residues are also characteristic for the country [8]. More specifically, forests cover almost 19% of the country's area while yield an annual production of about 800,000 m^3 of round and industrial wood, as well as 2,000,000 m^3 of fuel-wood. Among other indigenous species (beech, oak, fir, etc) pine is regarded as more characteristic and it is usually exploited for the production of wood for technical use [20]. A high added value by-product of the production of untreated technical wood in 680 sawmills in Greece [21], free of chemical substances, is pine sawdust. Today several forestry industries exploit this high added value by-product, covering at least partially their energy needs. Moreover, the newly developed pellet industry in Greece produces pellets from indigenous and imported residual biomass of mainly woody origin [10,21].

On the other hand, corn cultivation is quite extended in Greece in the frame of the food production industry, for people as well as for animals. In Greece, corn is considered a significant crop, its cultivation being widespread all over the country; the 2009 annual production reached 1.578 $*10^9$ kg, while for 2010 a $1.45*10^9$ kg was foreseen [22]. The residues remaining at fields after the harvesting period of corn crops were considered as the non-edible residues. It is worth mentioning that there is not an established management scheme of such residues; usually they are left rotten at the fields or burned in open air fires at the end of the cultivation season.

Finally, olive kernel is a widespread residue produced by the olive oil industry in Greece, with the majority of the Greek areas presenting intense olive tree cultivation activity. The olive kernel is produced seasonally and in significant amounts. As a result, olive kernel production in Greece reaches 300,000 to 400,000 ton/year [23]. The olive kernel agroresidue is traditionally exploited for covering part of the energy needs of the olive kernel oil factories, local residential heating in islands and greenhouse heating [18,24].

Within this framework, the aim of this work focuses on the evaluation of the energy gain, in terms of primary conventional energy consumption, as well as of the environmental impact of substituting diesel oil with residual biomass for house heating under the

Greek (i.e. South European Mediterranean) climate conditions. In parallel, the economical aspects of installing a burner system fed with biomass residuals instead of diesel oil are examined based on the Net Present Value (NPV) and the ratio of Benefit/Cost (B/C) indices are determined.

2. Description of the Building

The study focused on a typical multi-family building of Greece. In order to define the building's typology, data regarding the description of the building stock in Greece gathered from the Hellenic Statistical Authority was used [25]. For the majority of buildings, the bearing structure is made of reinforced concrete and the masonries (external, internal) are constructed with hollow clay bricks. In urban areas, the majority of contemporary constructions comprises of 3-6 floors above the ground floor. Moreover, a significant percentage of new constructions comprises of 2 or 3 apartments per floor, each of which covers an area of circa 75 m^2 to 90 m^2 [26-28]. Based on the above typology, a representative building encompassing the aforementioned characteristics was designed (Figure 1). It encompasses 5 storeys above the ground floor, the latter housing only the building entrance; the remaining space is used as an open parking space (pilotis). Each floor covers an area of 256 m^2, divided in three almost equal apartments, Figure 1. Apartment 1, (80 m^2) is located at the rear of the building plan. The unheated staircase (28 m^2) separates Apartment 1 from the remaining two Apartments 2 & 3(74 m^2 each), which have similar internal plan and are located on the main building façade, facing the street. All apartments consist of two bedrooms, a living room integrated with the kitchen and a bathroom. Each apartment has a balcony in front of the living room, projected 2.25 m from its external wall. The storey height is equal to 3.0 m, resulting to a total volume of 3,840 m^3 (256 m x 3 m x 5 m), 3,420 m^3 of which are heated. It is assumed that the examined building is free-standing; therefore windows exist on every façade. The main façade is south-orientated and almost 30% of its area is covered with fenestration. The windows of the west and east façades are limited to 12.2% and 9.4% of the relevant façade area, while north windows account for only 4.5% of the respective façade's area.

Nowadays, due to the New Greek energy regulation [29], there are strict restrictions for the thermal transmittance of the building elements, especially for the coldest climatic zones. These requirements have contributed to the current trend of positioning the thermal insulation on the exterior side of opaque vertical building elements, rather than on the core of the masonry, which was accustomed before. The insulating material (usually XPS) is attached to the masonry and the concrete elements with the help of special adhesives and hookers and then it is covered with synthetic plaster reinforced with a plastic mesh. The floor of the 1st storey, which is above the open space of the ground floor, is insulated with extruded polystyrene below the concrete slab. The floor is paved with marble with the use of cement mortar above a 0.04 m layer of lightweight concrete. The building roof is flat, thermally protected with extruded polystyrene, which lies above water protection layer and is covered with gravels. The consecutive layers of the materials constituting each building element and their thickness are presented in Table 1. The thickness of the thermal insulation used in each building element has been calculated in order to comply with the recent building energy performance regulation of Greece [29]. The thermal conductivity values of the materials listed in the regulation [30] were taken into account for the calculation of the thermal transmittance of each building element (U-value, i.e. the heat flow rate though the building element divided by the area and by the temperature difference of its surrounding environments), which is presented in Table 2.

The U-value of each window has been calculated with regard to its geometry and configuration, in order to comply with the requirements of the current building energy performance regulation for each climatic zone, which sets a maximum value for thermal transmittance equal to 3.0 W/(m^2K), 2.8 W/(m^2K) and 2.6 W/(m^2K) for climatic zones B, C, and D respectively. For all locations, it was assumed that the frame is made of aluminium with a thermal break (U_{fr} = 2.60 W/(m^2K)) with an average width of 0.10 m. The glazing ranged from double conventional (U_{gl} = 2.70 W/(m^2K)) for Zone B, double with low-e coating (U_{gl} =1.8 W/(m^2K)) for Zone C, to double with low-e coating filled with argon for zone D (U_{gl} =1.3 W/(m^2K)).

3. Definition of the Design Conditions

3.1 Description of the Greek climatic conditions

Greece extents in latitude from the 35th to the 41st parallel, with ground morphology from sea level up to 2,900 m. One of the most important topology characteristics is the total length of the coastal line, exceeding 13,600 km. As a result, the climate conditions cover a relatively wide range and may change drastically in relatively close distances. Legislatively, the country is divided in 4 climate zones, according to the most recent regulations [31], shown in Figure 2.

Zone A includes the southern parts of the country and the climate is characterized as hot with high humidity. The heating requirements of the buildings in this zone are limited, the absence of central heating being not rare. Obviously, the cooling needs are the highest of the country.

Zone B includes the parts of the southern Greece excluded from Zone A, parts of western Greece and the central Ionian and Aegean seas islands. The weather conditions of the zone are mild, and the residential buildings present roughly equal heating and cooling demands.

Zone C includes the majority of central and north mainland areas, characterized by relatively cold winters and mild summers. Consequently, the energy needs for heating are clearly higher than for cooling.

Finally, Zone D includes some areas of Western and Eastern Macedonia, presenting the most severe winters in the country and milder summers. As a result, the energy needs for heating are the highest while cooling is practically not needed.

3.2 Selection of the representative Cities

For the investigation of the energy, environmental and financial benefits resulting from substituting diesel oil with biomass in central heating installation, three cities were chosen, as representative of climate zones B, C and D; zone A was excluded from the evaluation due to the limited heating needs. The selected cities, i.e. Andravida located in Zone B, Kavala in Zone B and Kastoria located in Zone D (Figure 2), feature climate characteristics as close as possible to the respective climate zone, mainly in terms of the heating and cooling degree days (HDD and CDD) respectively

3.3 Design conditions and design heating loads of the building

The basic climatic design parameters listed in Table 3, were retrieved from the ASHRAE database [32] for the cases of Andravida and Kavala, since it was considered as more reliable due to the long recording period. The ASHRAE database does not include Kastoria, therefore for the specific city the required climate data were retrieved from the Greek Regulation. The design heating and cooling loads were calculated, using the Elite Chvac® software.

According to the calculation results, the total heating load of the building in Andravida (Zone B) is 35.5 kW, with 49.2% of it being ventilation losses, 40.1 kW in Kavala (Zone C), with 49.3% ventilation losses and 45.6 kW in Kastoria (Zone D), with 47.5% of it being ventilation losses. The total cooling load was calculated at 31.2 kW in Andravida, appearing at the time slot 17:00–20:00 in July, at 28.9 kW in Kavala, appearing at the time slot 17:00–20:00 in August and 23.3 kW in Kastoria, appearing at the time slot 17:00–20:00 in July.

4. Definition of the Energy Analysis Parameters

The energy requirements of the building in the three cities were determined with the aid of the EnergyPlus software. The building was divided in 11 independent thermal zones per floor. Accounting the common-use part of the building (staircase and entrance lobby) as an additional zone, a total of 56 zones resulted. For each thermal zone, the ambient conditions (diurnal distribution of winter and summer temperature requirement, ventilation rate, lighting power, person presence, appliance usage etc.) of the Greek Regulation [33] were taken into account, supplemented by the ASHRAE recommendations [32].

Since it is of residential use, the building was assumed to be in use 24 hour per day all year around. On a daily basis, the 24:00–06:00 period was assumed to be of lower operation, the rest of the day being of normal operation. Table 4 lists the indoor simulation parameters.

Regarding the climate details, the typical meteorological year (TMY-2) given by the meteorological database METEONORM ver. 5.102 for each of the cities was used.

5. Results and Discussion

5.1 Energy Analysis

Figure 3 presents the heating energy demands, as they resulted from the simulation of the building in the three cities. The annual energy demand in Andravida (Zone B) is 5,775 kWh, increasing to 18,500 kWh in Kavala (Zone C), reaching 24,700 kWh in Kastoria (Zone D).

These demands were reduced to total energy demand, assuming the minimum efficiency required by the Greek Regulations [29,31] for the heat emission and heat distribution systems, 89.0% and 96.0% respectively. From the total energy requirement, the final energy need was calculated, using diesel oil and locally produced residual biomass, assuming the minimum, power dependent, boiler efficiencies according to EN-303.2 [34] and EN 303.5 [35]. The primary energy need in each case was determined from the final, using the legislated reduction factors (1.1 for diesel oil, 1.0 for biomass [31]). The results are shown in Figure 4.

As it can be clearly seen in Figure 4, the primary energy consumption with residual biomass is in all cases higher than with diesel oil, the difference starting from 3.8% in Zone B, reducing to 3.2% in Zone D. These differences are attributed to the efficiency of the biomass boiler, which, according to the relevant standards [34,35], is about 10% lower than that of the equivalent diesel boiler. This deviation is also confirmed by recent experimental work on biomass boilers [36].

5.2 Environmental Impact

Forest residues, pine sawdust in the form of pellets, agricultural residues (corn stalks) and olive kernels were assumed as feeding materials for a central heating system for covering the energy consumption needs at the Andravida and Kavala sites.

Respectively, the residual biomass selected for Kastoria is assumed to consist of forest residues, pine sawdust pellets, and agricultural residues (corn stalks), since there are no olive trees in the area, because of the cold climate [37]. It is reminded that, in the framework of this study, the exploitation of the non edible residual biomass is examined only locally.

The residual biomass is assumed to be exploited with an inherent moisture content lower of 20% w/w after short term storage in open air spaces and under the

Mediterranean climatic conditions. The ultimate and the proximate analyses of the selected residues are presented in Table 5. The selection was based on the availability of such residues, suitability of their physicochemical characteristics, particle diameters and rheological characteristics in order to be suitable for automatic feeders, sufficient bulk density, low moisture, C/N ratio over than 30 and attractive heating value [8], for enabling their combustion [38].

Moreover, as the availability of such residual biomass seems to be an issue of great importance for implementing any energy production scenario in a country, the selection of residues that are produced locally [39] and in a proper form, sawdust as raw material for pellets production, crushed kernels and chopped cereals stalks has been considered and compared with oil in terms of a cost – benefit analysis.

For the estimation of the environmental impact from the exploitation of the three characteristic biomass types in Greece for heating of buildings, the CO_2 and SO_2 emission factors were determined. Based on the chemical analysis of the three residual biomass types, presented in Table 5, the lower heating value (LHV) of each type was determined (Table 6) and then, based on the carbon and sulfur content, the CO_2 and SO_2 emission factors were calculated, presented in Table 7. The SO_2 emission factor for the diesel oil was determined similarly (0.1% w/w, [41]), while for CO_2 the value suggested by the Greek legislation was adopted [29].

Regarding the remaining of the pollutants (CO, PM, NO_x and NMVOC), to our knowledge dedicated Greek emission factors have not been published yet. The CORINAIR database includes emission factors for small household boilers (of less than 50 kW power) burning wood, wood waste (residual biomass) and liquid fuels (diesel oil) [42]. Table 7 summarizes the emission factors available for this study.

In order to calculate the CO_2 emissions for the alternative fuels examined in this study, the energy consumption of the typical building for each climate zone has been converted to final energy consumption, as it is presented above, and then using the lower heating value for each fuel the annual required quantity of the fuels has been calculated. Then by multiplying the CO_2 emission factor of Table 7 with the quantity of each fuel, the annual CO_2 emissions were calculated. These results are shown in Figure 5.

Clearly, in all climate zones, the diesel oil CO_2 emission is lower by roughly 40%, compared to that of any biomass fuel. It should be noted, however, at this point that the CO_2 emission resulting from biomass residues exploitation is considered as neutral, in case of sustainable grown of biomass, as they constitute part of the closed CO_2 cycle.

Respectively to CO_2, Figure 6 presents the SO_2 annual emission, which is significantly higher for biomass fuel, ranging from 56% to 322% - depending on the residual biomass specie, compared to that of the diesel oil. These increased emissions may be attributed (a) to the increased sulfur content of the biomass fuels, since they are used as received, i.e. assuming no de-sulfurization, and (b) to the lower energy content of residual biomass in terms of energy density, which increases the fuel consumption per unit of energy produced in order to cover the same energy demands as with oil.

Regarding the other pollutants (CO, NO_x, NMVOC and PM), the significant differences between the emission factors of diesel oil and biomass fuels, listed in Table 7, suggest even larger differences of emissions, taking into account the increased fuel consumption in the residual biomass case. It has to be noted however that (a) the reliability of the emission factors of Corinair is limited and (b) there are technological solutions of advanced biomass combustion systems (e.g. systems based on catalytic combustion) that can produce significantly lower emissions [43], and these systems are not included in Corinair database. Therefore, no attempt will be made to compare results for CO, NO_x, NMVOC and PM.

5.3 Economic Analysis

The fiscal analysis of using residual biomass for heating of buildings is based on the differences of installation cost (boiler / burner cost), service life of the system, fuel cost and discount cash flow rate.

Based on today's real values of the Greek market, and for systems of the power range of this work, the installation cost difference is estimated to be 2,000 €, regardless of the location of installation.

The service life of the systems is usually expected in the 15 – 20 years, mainly depending on the maintenance level and on the fuel quality. For the purposes of this study it was assumed at 15 years (worst case scenario).

The market price of diesel oil and biomass fuels is depended on a number of parameters of local (e.g. biomass availability), national, e.g. taxation policy, which may differentiate between oil and biomass, and international, e.g. oil availability, local wars etc., origin. Additionally, there are obvious interrelations, e.g. the biomass producer's price increases with the increase of oil price, not necessarily representing the costs' increase.

For the purposes of this study, the consumer prices for diesel oil and biomass residues were considered equal to the free market prices prevailing today, i.e. 1 €/L for diesel oil, 0.25 €/kg, 0.15 €/kg, and 0.08 €/kg for forest residues (pine sawdust pellets), agricultural residues, (corn stalks) and olive kernel, respectively. Moreover the discounted cash flow rate is set to 7%, according to the Hellenic economic practice.

The net present value (NPV), the cost-benefit analysis (B/C ratio) indices and the turnover period of the investment were determined and results are presented in Table 8. It can be clearly seen that the length of the turnover period reduces with the increase of the energy consumption (up to 8.6 years for Andravida in zone B, 2.2 years for Kavala in zone C and 1.7 for Kastoria in zone D). However, in the same climatic zone it decreases with the increase of LHV/price ratio, becoming longer in the case of forest residues, reduced for olive kernel and minimum for agricultural residues. Similar behavior is observed for the NPV and the B/C indices. More specifically, from the cost-to-benefit analysis it results that for all areas and for all biomass types the substitution of diesel oil with biomass is financially beneficial (B/C>1) and that the profitability of the investment increases with (a) the increase of the energy consumption, for the same type of biomass, (b) with the increase of the LHV/price, for different biomass types. Finally, the NPV index verifies that the substitution is financially beneficial, especially for the northern part of the country, where the energy needs for heating are more significant.

5.4 Social Impact

The energy, environmental and economic effects resulting from the substitution of diesel oil with three different types of biomass, aiming at covering the heating energy demands of the Greek buildings, were studied, analyzed and evaluated in the previous sections. More specifically, and at a national level, the use of biomass as a solid fuel in the domestic sector is expected to grow rapidly during the upcoming years. The recently established Ministerial Decision [44] revised the already existing legislative framework concerning heating in domestic buildings and from now on the biomass utilization is permitted even in the major urban cities of Greece, Athens and Thessaloniki.

Due to the economic crisis the country faces over the last two years, more and more citizens are searching for economical solutions in order to satisfying their heating energy demands in residential buildings. In this context, the substitution of diesel oil with biomass is expected to bring some advantages, as well as the need to overcome some disadvantages both in national and local level.

In particular, biomass energy has the potential to cover part of the country's heating energy demands without contributing to the CO_2 built up, since it is considered as a carbon neutral solid fuel. Moreover, given that the CO_2 produced by the sustainable exploitation of biomass is considered carbon neutral when biomass is exploited in a sustainable way, the produced CO_2 could be further consumed by plants during photosynthesis.

The particular benefit that expected to arise in a national level from lignicellulosic biomass stocks exploitation for energy production is the increase of the country's energy autonomy as biomass will substitute an imported fossil fuel (diesel oil). In this context and in comparison to diesel oil, the biomass supplementary exploitation will also contribute in achieving the current RES policy requirements according to the 20-20-20 goal, by reducing up to 20% the GHG emission relatively to the levels existing in 1990.

Additionally, the sustainable use of biomass for energy production could enhance the multi-sectorial interactions. Towards that direction the integration of the agricultural sector (biomass production), agro-industrial sector (pretreatment and production of biomass residues) with building industry will further encourage the embodiment of a low cost renewable energy source like biomass in the residential energy sector. It would also assist towards balancing the trade of local solid fuel resources that could otherwise not meet the end-users need of low cost heating.

Concerning the effect of altering from diesel oil to biomass there will be also a sectorial integration and new employment opportunities in primary, secondary and tertiary sectors of agriculture, energy and industry as well as logistics and processes, respectively.

Additionally, among others the main advantages of biomass utilization in local communities are: (a) the low or even zero cost fuel utilization (agricultural residues abandoned in fields), (b) the avoidance of energy dependence on conventional fossil fuel supplies as well as a central system of fossil fuels supply, (c) the strengthening of the bio-business sector employment in decentralized regions (islands and/or rural areas), (d) the contribution on the green energy production targets and even (e) the positive impact to environmental economics taking into consideration the positive externalities.

Moreover the creation of new job opportunities particularly in the rural areas of Greece is one of the most important social benefits arising from the exploitation of biomass in the residential heating sector. Strengthening of employment in rural areas of the country and re-developing the regional job opportunities will support the re-population of the Greek rural areas and that is another important benefit. Since the economy of Greece was traditionally based on agriculture and agro-industrial activity the exploitation of lignocellulosic residues could significantly improve the economics of the biomass production methods and as a consequence the living standard of citizens in the Greek periphery.

Following to the above advantages of biomass utilization, there are also some disadvantages bringing difficulties to local biomass exploitation in heating sector: (a) difficulties in collection and transportation from remote rural areas and islands, (b) seasonal production and variety in quality even for the same biomass sample, (c) high moisture content, and (d) low energy density. Additionally, as biomass residues have high bulk density, they cannot be store, handled and transported conveniently. Moreover the lower efficiency of the traditional biomass combustion devices compared to diesel oil ones, results to a lower energy usage of the fuel. On the contrary, liquid fossil fuels like diesel oil can be handled, stored and transported easily. Especially in countries with rough topographies like Greece with mountainous areas as well as remote islands, the lower energy density of biomass and diverse physicochemical properties are the main disadvantages for biomass exploitation in residential heating sector. Pelletization, however, increases biomass energy density, improves biomass logistics and at the same time stabilizes biomass' physicochemical properties while the utilization of local biomass stocks optimizes the cost-benefit results.

Furthermore, biomass was traditionally used in local communities of Greece e.g. woody biomass (forest residues) in mountainous areas and agricultural residues (olive kernels) in islands with minimum pretreatment (chopping and open air storage). The latest years there is an accelerating development of biomass pelletization-utilization business revealing the increasing end-users market demands. It is also a fact that biomass stocks demands (wood pellets, forest residues and longs as well as agro-residues like olive kernels) increased surprisingly under the current economic crisis indicating the renewed interest of the society in that traditional fuel as well as its future potential for the local coverage of heat energy demands. Towards that direction, the Greek Government recognized the necessity of the biomass utilization in residential heating sector, Ministerial Decision 189533/2011 [44], allowing the biomass utilization in form of logs or pellets given directions for its efficient and sustainable utilization even in the capitals of the country.

On the contrary, a disadvantage that will have to be faced is that the replacement of imported diesel oil with local biomass stocks is that it could not be considered as an immediate solution in terms of power efficiency and availability.

Nationally the internal transportation of big quantities of biomass is expected to result in increased greenhouse gas emissions in the transport sector as a result of the lower energy density of the biomass in comparison to diesel oil and thus will lead to the need of increased capacity. Taking into account the results of the energy assessment, it becomes obvious that eventually the use of biomass in residential heating will lead ultimately to an increase on the primary energy consumption. This fact not only constitutes biomass non profitable, but it also contradicts to the requirements of the European Directives 91/2002/EC and 31/2010/EC for reducing the primary energy consumption of building sector. However, it should be emphasized that the improvement of the residential heating devices and technologies of combustion is expected to result in a short-term improvement of the appliances' efficiency and will finally result in alleviating that disadvantage.

Furthermore the substitution of diesel oil with biomass would contribute on the increase of SO_2 emissions due to the higher potential of both forest and agricultural residues. Moreover, based on the CORINAIR database findings, the use of biomass on the residential building sector would also increase the emissions of NO_x, PM, CO, and NMVOC. This fact, along with the expected presence of secondary pollutants in the atmosphere of the urban areas, will have a negative effect on their microclimate. Especially in the northern regions of the country, where the biomass use will be enlarged due to the severe climate conditions during the winter, the increased emissions combined with the high relative humidity of air and the dense urban fabric are expected to raise the air pollution levels significantly, leading to the direct degradation of the quality of life.

Although some of the negative aspects affecting currently the biomass exploitation in residential heating sector will be faced with further technological advancements as well as processes optimization (e.g. logistics), the utilization of residual lignocellulosic biomass will also be proved useful in fulfilling the heat energy demands of the final end users.

6. Conclusions

The main conclusions drawn from the substitution of diesel oil with biomass for covering the heating energy demands of residential buildings in Greece could be summarized as follows:

1. The use of biomass fuels instead of diesel oil increase the primary energy consumption by3-4%, on a national level with the smaller values appearing in southern and hotter regions.
2. The CO_2 emission, resulting in the case of the three more characteristics biomass types of Greece (pine sawdust, corn stalks and olive kernel) is increased by about 40%, when compared to that of the diesel oil. Regardless of the geographical area, the pine sawdust presents the lowest and the olive kernel the highest emissions.
3. The SO_2 emission is also higher with biomass, the highest corresponding to corn stalks, followed by pine dust and olive kernel, accounting for 323%, 147% and 56% increase compared to that of the diesel oil, respectively.
4. The substitution of oil in central heating systems with pine sawdust, corn stalks or olive kernel is proved economically feasible. The turnover period of the investment ranges from 1.7 to 8.7 years, for the pine sawdust usage, from 1.3 to 5.6 years for corn stalks, while for olive kernel it oscillates between 1.1 and 3.9 years as the heating demands decrease. Respectively, the NPV of the substitution under examination is in every case positive, ranging from 903.6 € to 15,478.1 €, depending on the geographical region and the type of biomass, with the higher values corresponding to the colder areas of the country. Similar conclusions can be drawn from the cost-benefit analysis, with the corresponding index ranging between 2.94 and 1.12.
5. From a social point of view, the substitution of diesel oil with biomass will increase the energy autonomy of the country, support the local communities with the creation of new employment opportunities in several sectors and strengthen the income of the agricultural society. However the exploitation of biomass in a non-sustainable way will increase the emission of the gaseous

pollutants from the transportation and building sectors as well as it will contribute to the deterioration of the urban environment.

Results of the present study could be taken into consideration for establishing guidelines and for further support of the future legislation framework concerning the energy, environmental, climate and economic policies on the EU level. The indications could be useful not only in the short term (2020), but also in the long term planning policies for achieving the low carbon economy on 2050. From this point of view EU could: (a) establish measurements that discourage or exclude the exploitation of biomass in an inefficient way through the existing energy generation processes or technologies while support advanced technologies, (b) restrict the use of biomass for energy to such levels that not driven by the unregulated demand but will ensure biomass' sustainable supply, (c) establish an evaluation framework for the environmental concerns of the acceleration of biomass use that currently takes into account not only the CO_2 emissions but also all the pollutants e.g. SO_2, and (d) review the sense that the use of biomass for energy is always carbon neutral.

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List of Tables

Table 1: The materials and the thickness of the layers constituting the building elements of the typical building

Climatic Zone	**B**	**C**	**D**
Building element: Material		**Thickness [m]**	
Vertical reinforced concrete elements			
Plaster (cement-lime mortar)	0.02	0.02	0.02
XPS	0.06	0.06	0.07
Reinforced concrete	0.20	0.20	0.20
Plaster (cement-lime mortar)	0.02	0.02	0.02
External masonry (in contact with the ambient air and the unheated space)			
Plaster (cement-lime mortar)	0.02	0.02	0.02
Brick masonry	0.10	0.10	0.10
EPS	0.04	0.05	0.06
Brick masonry	0.10	0.10	0.10
Plaster (cement-lime mortar)	0.02	0.02	0.02
Floor above pilotis			
Plaster(cement-lime mortar)	0.02	0.02	0.02
XPS	0.06	0.07	0.08
Reinforced concrete	0.15	0.15	0.15

Lightweight concrete	0.04	0.04	0.04
Cement mortar	0.02	0.02	0.02
Marble tiles	0.02	0.02	0.02
Flat roof			
Gravels	-	-	-
XPS	0.06	0.07	0.08
Bitumen layer	0.007	0.007	0.007
Lightweight concrete	0.04	0.04	0.04
Reinforced concrete	0.15	0.15	0.15
Plaster (cement-lime mortar)	0.02	0.02	0.02
External masonry			
Plaster (cement-lime mortar)	0.02	0.02	0.02
Brick masonry	0.10	0.10	0.10
EPS	0.04	0.05	0.06
Brick masonry	0.10	0.10	0.10
Plaster (cement-lime mortar)	0.02	0.02	0.02

Table 2: The thermal transmittance of the building elements of the typical building

Climatic zone	B		C		D	
Building element	U value [W/(m²K)]	U max [W/(m²K)]	U value [W/(m²K)]	U max [W/(m²K)]	U value [W/(m²K)]	U max [W/(m²K)]
Vertical reinforced concrete elements	0.436	0.50	0.436	0.45	0.38	0.40
External masonry (in contact with the ambient air and the unheated space)	0.493	0.50	0.423	0.45	0.371	0.40
Floor above pilotis	0.416	0.45	0.366	0.40	0.326	0.35
Flat roof	0.425	0.45	0.372	0.40	0.331	0.35

Table 3: Basic climate parameters of building's area

City	**Andravida [32]**	**Kavala [32]**	**Kastoria [31]**
Latitude / Longitude	37° 92′ 12″ N / 21° 16′ 48″ E	40° 58′ 48″ N / 24° 36′ 00″ E	40° 27′ 00″ N / 21° 16′ 00″ E
Heating period		November–March	
Heating design conditions (99.6%)	0°C	-2.9°C	-7.5°C
Mean daily temperature in January	9.5°C	5.6°C	2.2°C
Cooling period		Mid of May–October	
Cooling design conditions (0.4% DB/MCWB)	33.1 DB/22.0 WB	32.2 DB/21.5 WB	33.5 DB/21.0 WB
Mean daily temperature	25.9°C (July)	24.5°C (August)	23.2°C (August)

Table 4: Basic simulation characterists of building

City	**Andravida**	**Kavala**	**Kastoria**
Latitude / Longitude	37° 92′ 12′′ N / 21° 16′ 48′′ E	40° 58′ 48′′ N / 24° 36′ 00′′ E	40° 27′ 00′′ N / 21° 16′ 00′′ E
Operation Period	24hours/day		
Heating Period	16 November – 15 May		
Desired Temperature during normal/soft operation	21°C / 18°C		
Cooling Period	16 May – 15 November		
Desired Temperature during normal/soft operation	26°C / 30°C		
Air Changes of apartments during normal/soft operation	0.45 ach / 0.2 ach		
Lighting elevation of apartments	6 W/m^2 and 3.5 W/m^2 for WC only		
People	280 W for Apartments 2 & 3, and 140 W for Apartment 1		

Devices	780 W for Apartments 2 & 3, and 660 W for Apartment 1

Table 5: Ultimate and proximate analysis of non-edible residual biomass [8,24,40]

Residue	**Forest residues [40]**	**Agricultural residues [8]**	**Olive kernel [24]**
	Ultimate analysis (%ww, dry)		
C	53.16	45.53	48.59
H	6.25	6.15	5.73
O*	40.00	41.01	40.46
N	0.30	0.78	1.57
S	0.09	0.13	0.05
	Proximate analysis (%ww, dry)		
Ash	0.20	6.40	3.60

* by difference

Table 6: Lower Heating Value (LHV) of non-edible residual biomass

Residue	Forest residues	Agricultural residues	Olive kernel
LHV [kWh/kg]	4.95	4.18	4.34

Table 7: Fuel specific emission factors for small household boilers

Fuel	**CO_2 [kg/GJ]**	**CO [42] [g/GJ]**	**PM [42] [g/GJ]**	**NO_x [42] [g/GJ]**	**NMVOC [42] [g/GJ]**	**SO_2 [g/GJ]**
Diesel oil	73.34 [29]	40	3	70	15	46.61
Forest residues	109.30	4000	475	120	400	100.94
Agricultural residues	111.02					172.90
Olive kernel	114.01					63.99

Table 8: Fiscal analysis of oil substitution with biomass residues for building heating in Greece

Parameter	Andravida			Kavala			Kastoria	
	Forest residues	**Agricultural residues**	**Olive Kernel**	**Forest residues**	**Agricultural residues**	**Olive Kernel**	**Forest residues**	**Agricultural residues**
Initial cost of oil burner-boiler [€]	1,300							
Initial cost of biomass burner-boiler [€]	3,300							
B/C ratio	1.12	1.34	1.73	1.45	1.88	2.94	1.51	1.99
NPV [€]	903.6	2,078.2	3,488.4	7,325.6	11,071.5	15,568.7	10,495.7	15,478.1
Turnover period of the investment [y]	8.6	5.6	3.9	2.2	1.6	1.1	1.7	1.3

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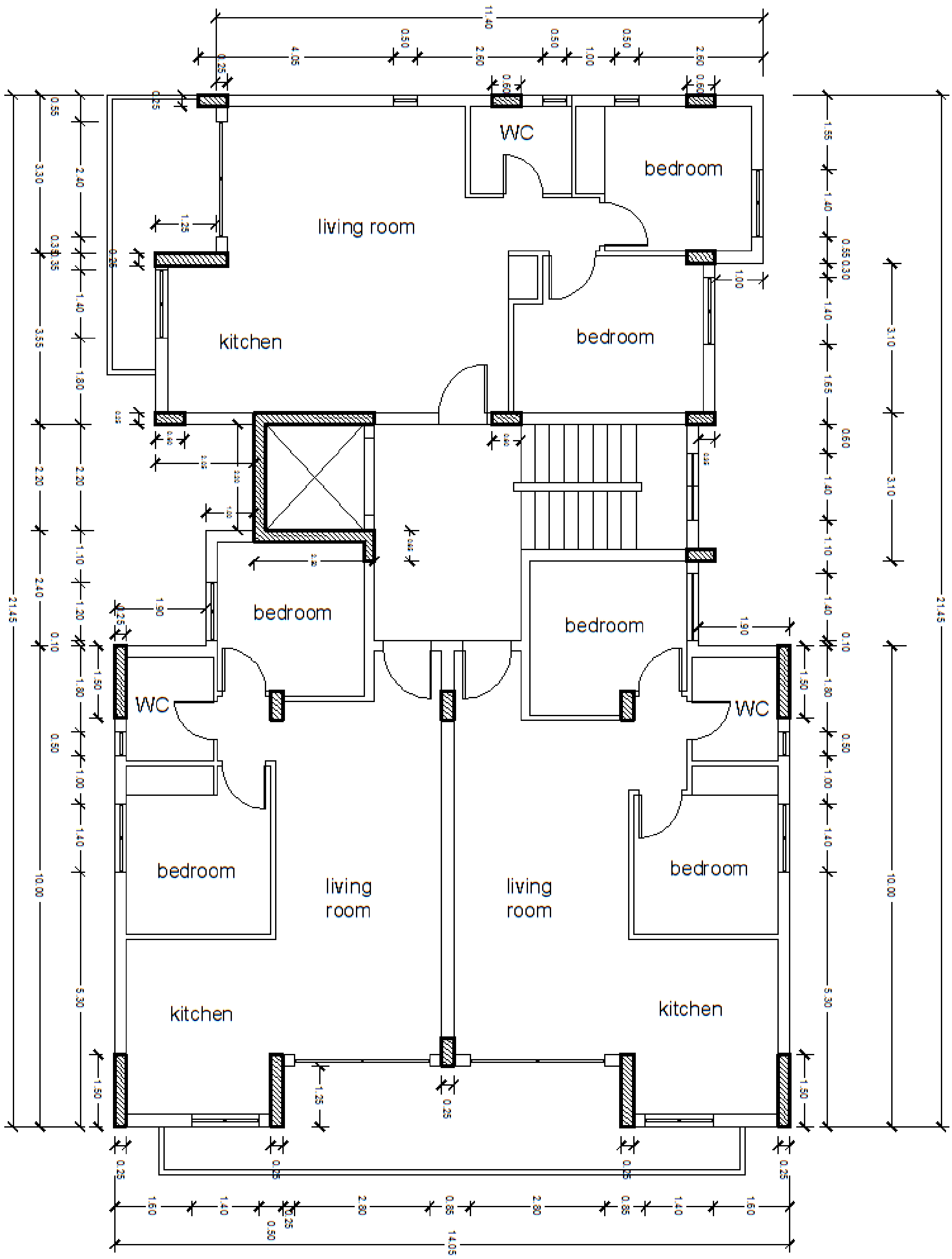


Figure 1: Floor plan of the typical multi-family building in Greece

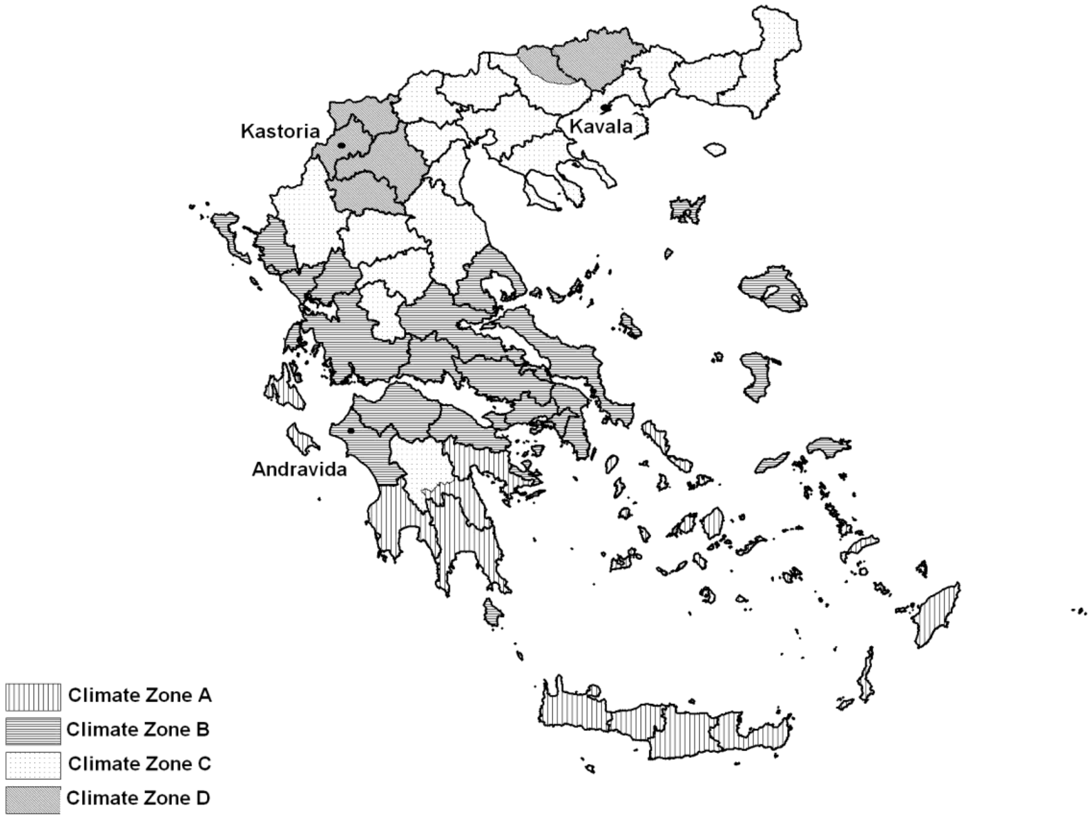
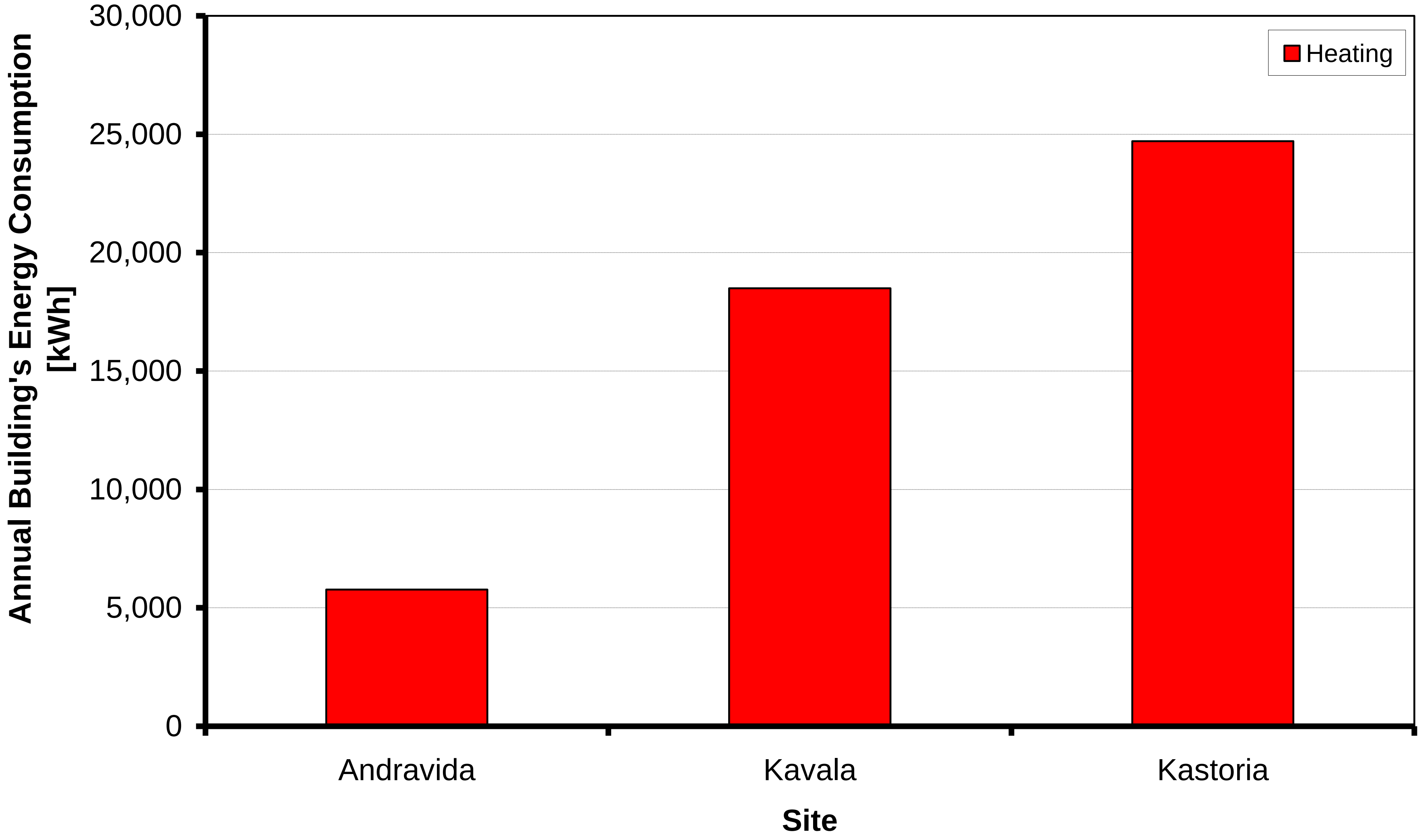


Figure 2: The climate zones of the Greek territory [18]

Figure 3: Annual energy consumption of the building at the three different sites



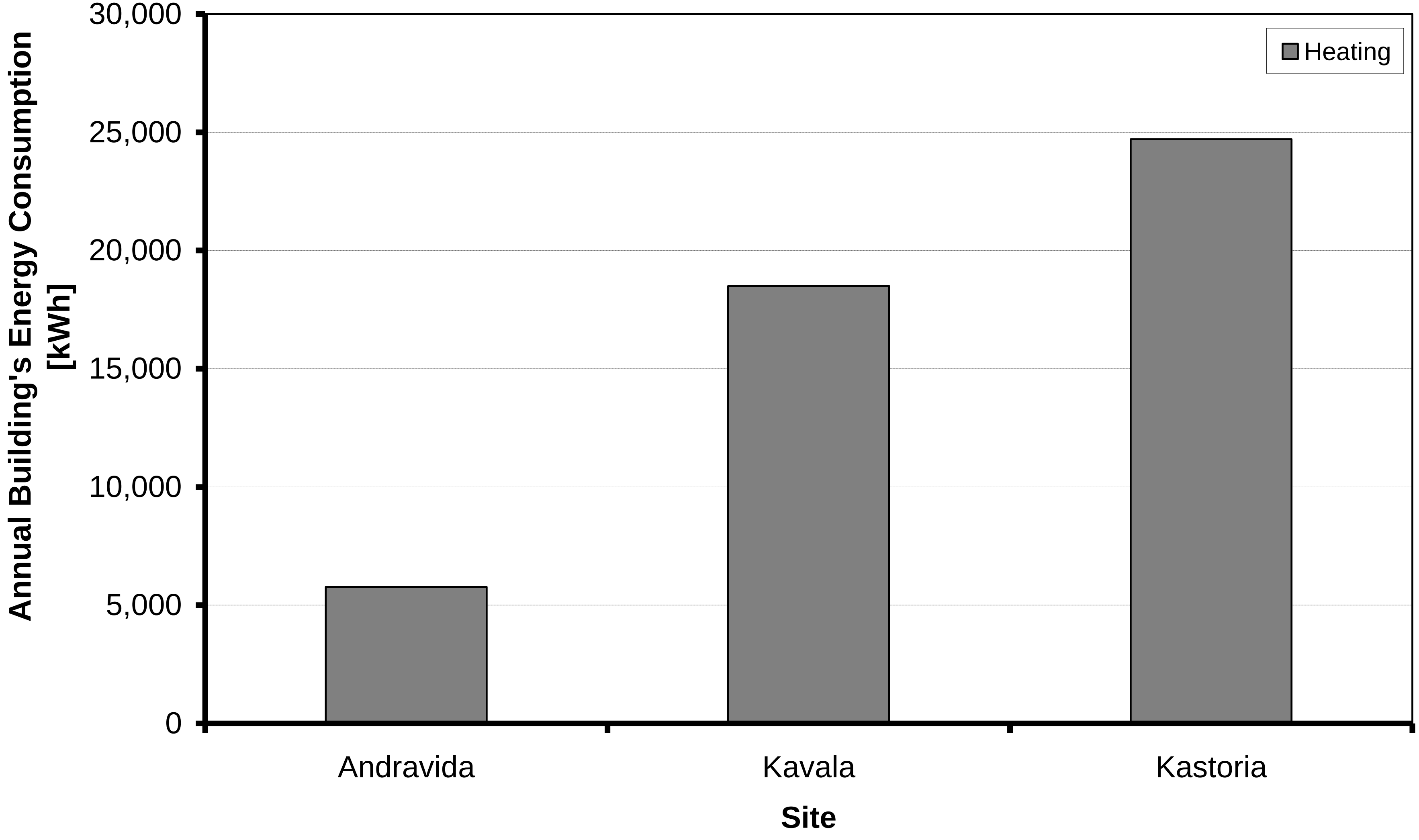


Figure 3: Annual energy consumption of the building at the three different sites

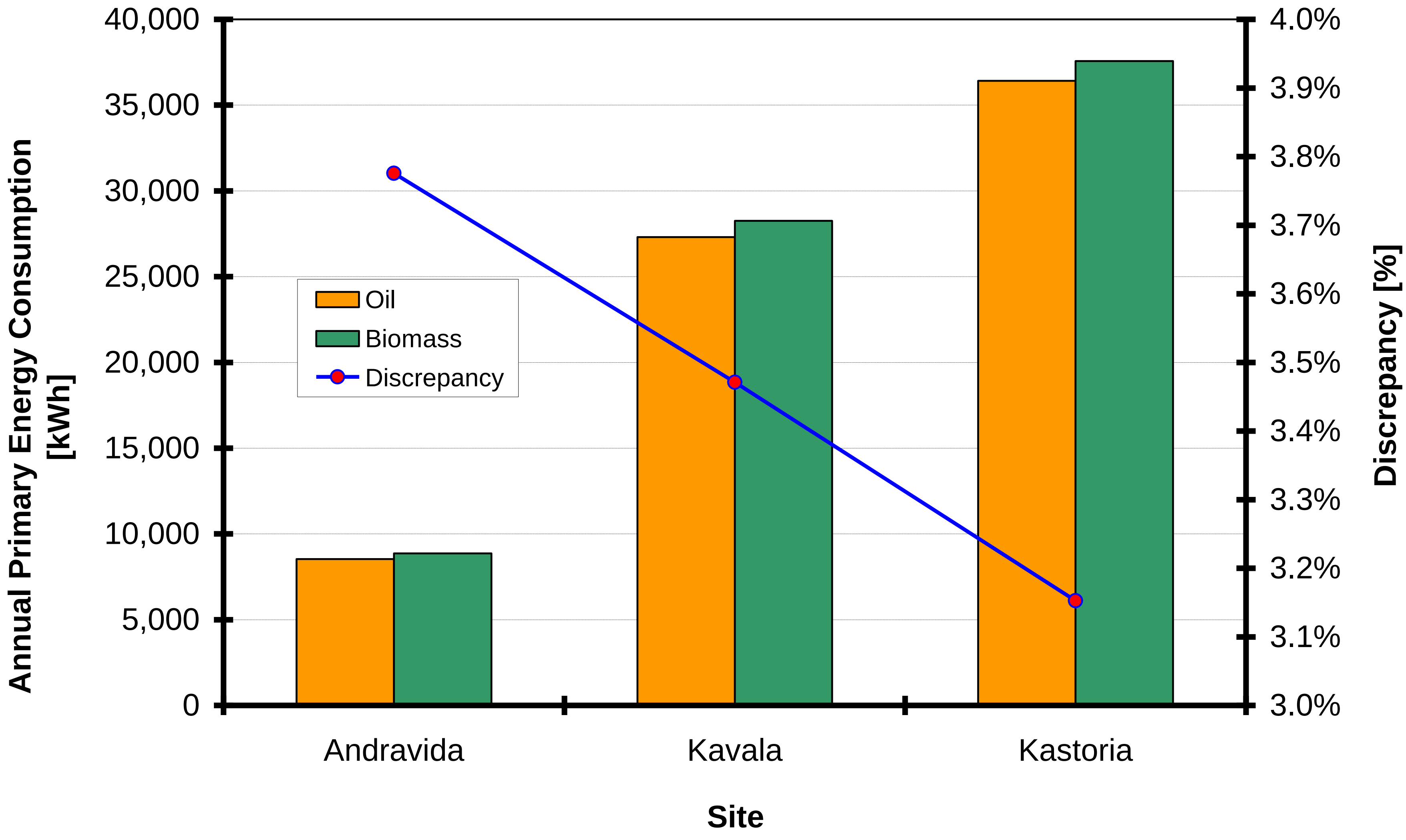


Figure 4: Primary energy consumption of the building at the three difference sites using oil and biomass fuels

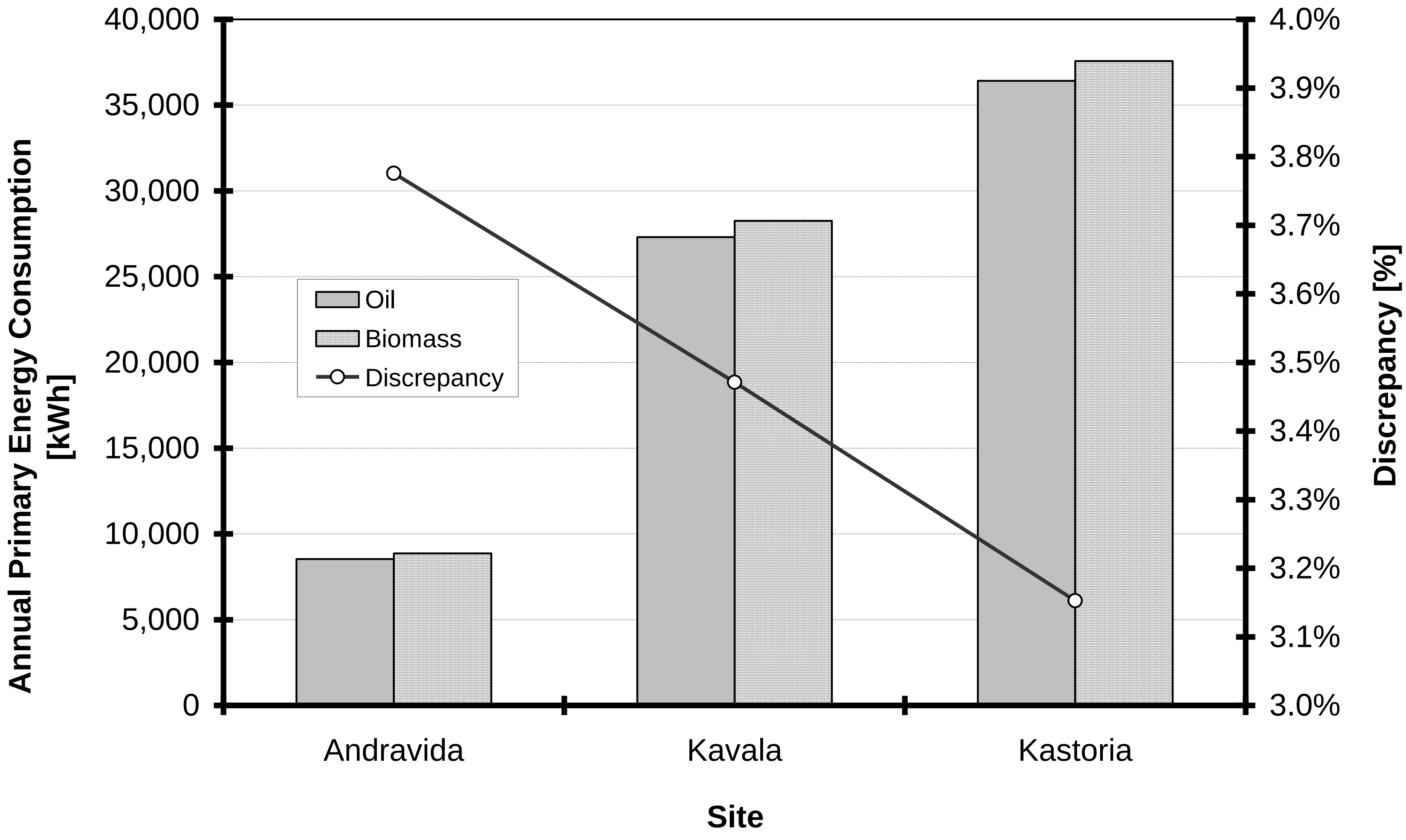


Figure 4: Primary energy consumption of the building at the three difference sites using oil and biomass fuels

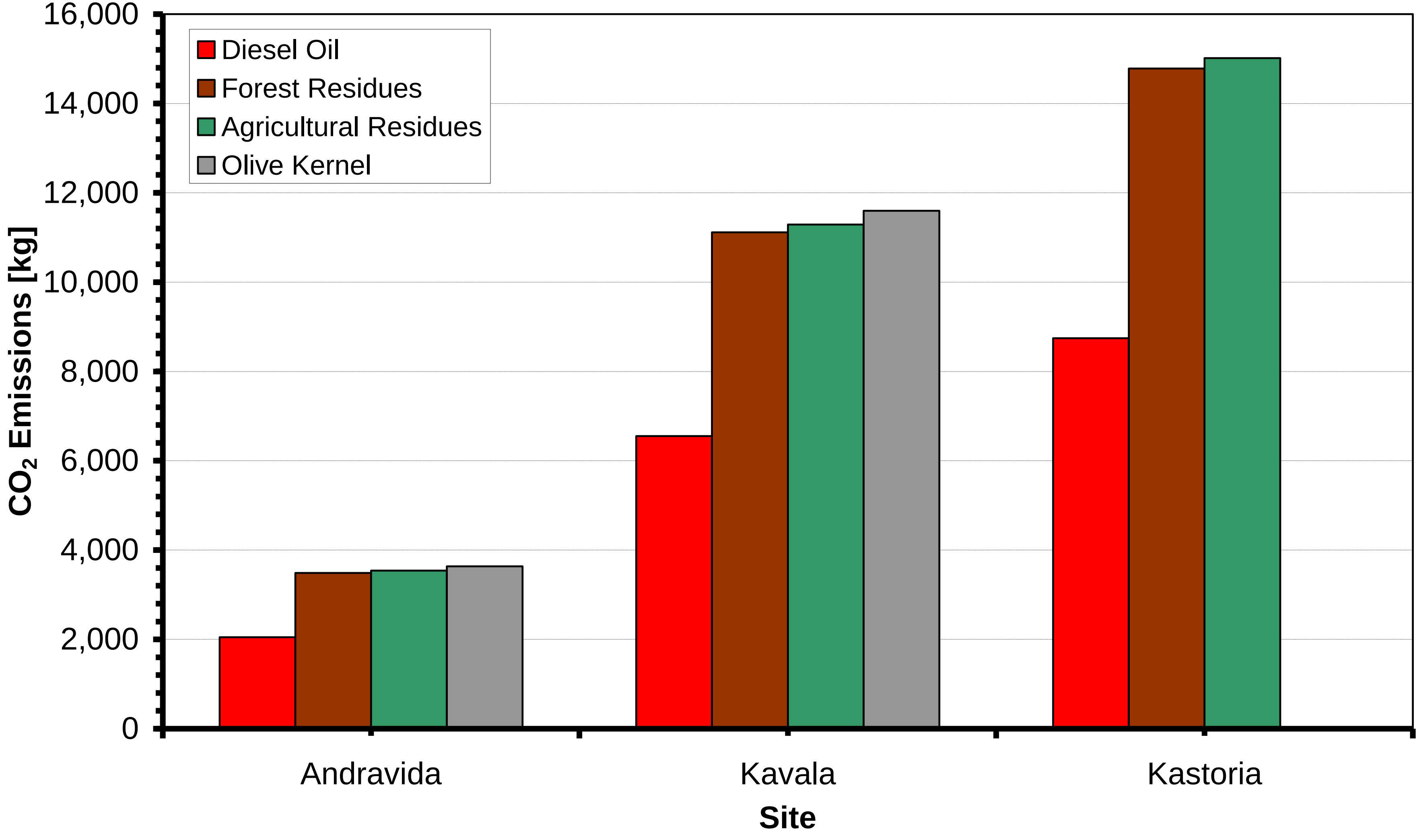


Figure 5: CO_2 emissions for diesel oil and biomass fuels

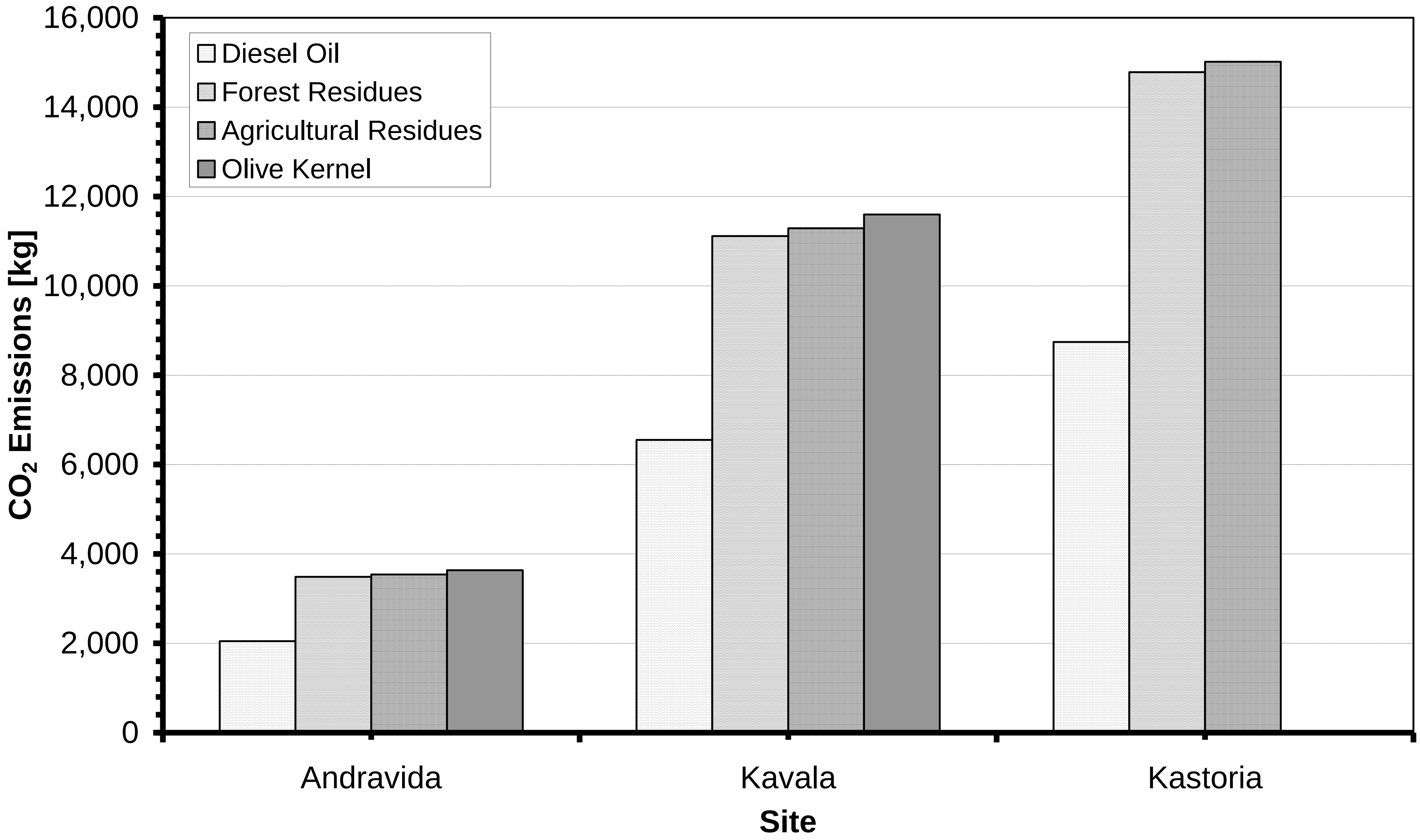


Figure 5: CO_2 emissions for diesel oil and biomass fuels

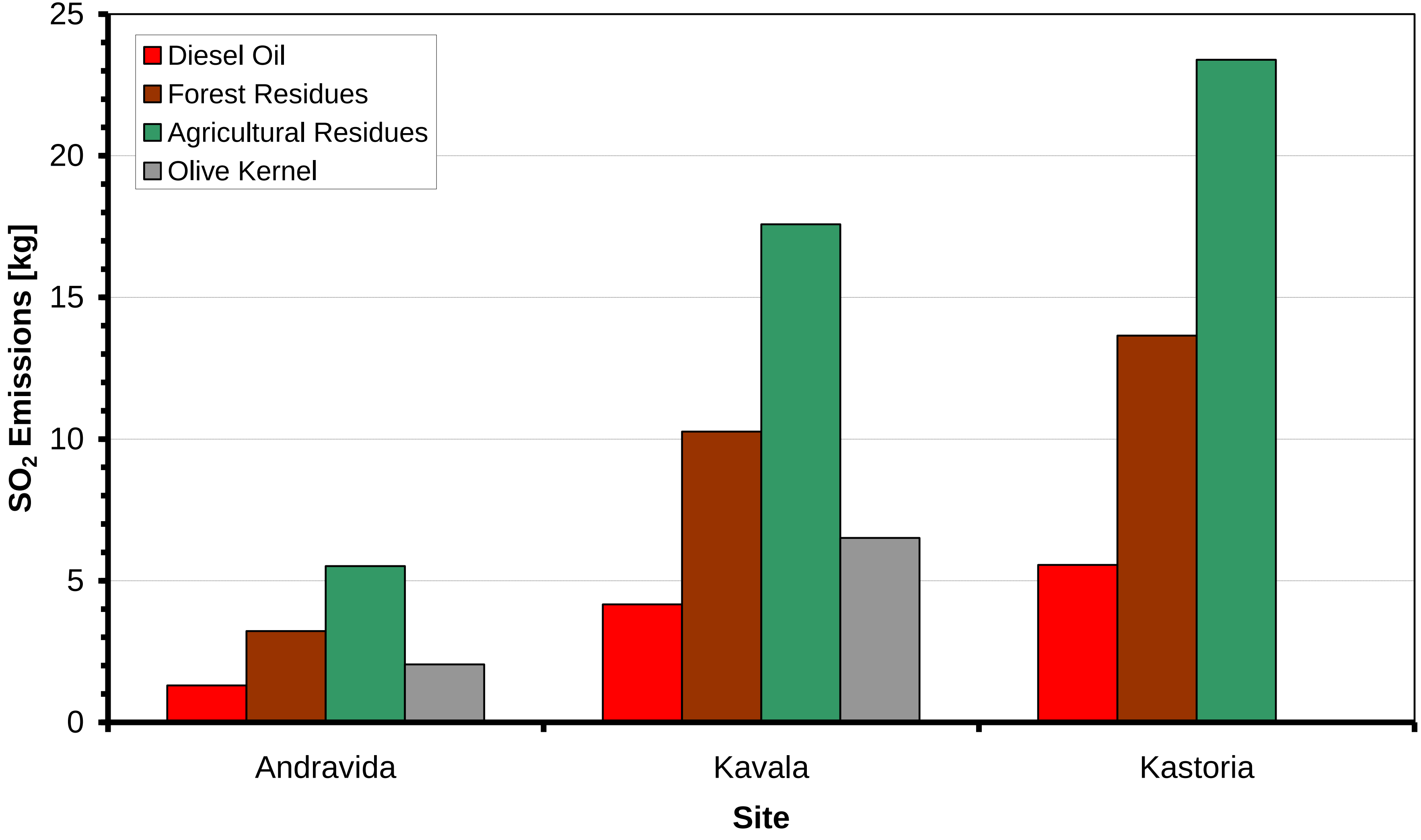


Figure 6: Comparison of SO_2 emissions for domestic heating oil and biomass fuels on the representative sites

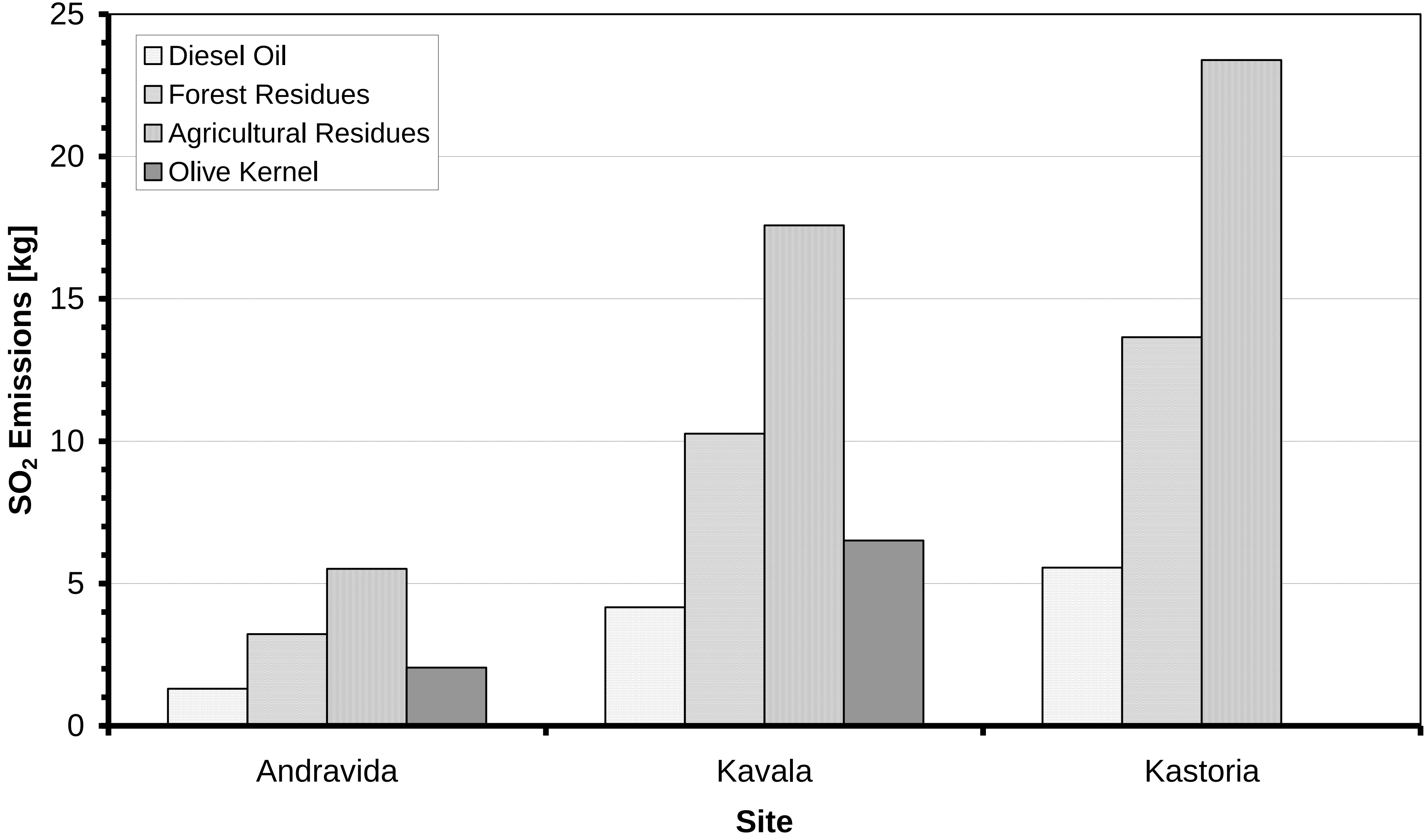


Figure 6: Comparison of SO_2 emissions for domestic heating oil and biomass fuels on the representative sites

The exploitation of biomass for building space heating in Greece: Energy, Environmental and Economic~~al~~ Considerations

A. Michopoulos[1*], V. Skoulou[2], V. Voulgari[1], A. Tsikaloudaki[3], N.A. Kyriakis[1]

[1]Process Equipment Design Laboratory, Department of Mechanical Engineering, Aristotle University of Thessaloniki, P.O.B. 487, 541 24 Thessaloniki, Greece

[2]Dr. Chemical Engineer, Kilkisiou 1, 661 00 Drama, Greece

[3]Laboratory of Building Construction and Physics, Department of Civil Engineering, Aristotle University of Thessaloniki, P.O.B. 429, 541 24 Thessaloniki, Greece

Abstract

The exploitation of forest and agricultural biomass residues for energy production may offer significant advantages to the energy ~~system~~ policy of the relevant country, but it strongly depends on a number of financial, technological and political factors. The work in hand focuses on the investigation of the energy, environmental and financial benefits, resulting from the exploitation of forest and agricultural biomass residues, fully substituting the conventional fuel (diesel oil) for building space heating in Greece. For this investigation, the energy needs of a representative building are determined using the EnergyPlus software, assuming that the building is located ~~at~~ across the various climate zones of Greece. Based on the resulting thermal energy needs, the primary energy consumption and the corresponding emissions are determined, while an

[*] Corresponding Author: Tel. +30 2 310 996220, Fax +30 2 310 996087, E-mail address: apmich@auth.gr

elementary fiscal analysis is also performed. The results show that significant financial benefits for the end-user are associated with the substitution examined, even though increased emissions and primary energy consumption ~~resulted~~have been derived.

Keywords: residual biomass; combustion; emissions; energy consumption; residential buildings;

1. Introduction

Biomass is defined as the biodegradable fraction of waste and residues emerging from agriculture activity, including the vegetal and the animal substances, residues produced by forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste according to the Directive 2003/30/EC [1].

Increasing biomass usage in the European Union (EU) can contribute to the achievement of the Union's strategic targets, concerning environmental protection and safety in energy production and supply [1-3]. Moreover, taking into account that almost the two-thirds of EU's renewable energy sources are residual biomass and waste, it is evident that increasing the share of such sources is becoming quite important for the achievement of the 20% by 2020 goal, according to Directive 2009/28/EC [4]. Furthermore, the latest EU policies promote the minimization of wastes by reusing and recycling; thus the non-edible residual biomass may be well exploited for 2nd generation biofuels and bioenergy production, as directive 2003/30/EC indicates [1].

Towards those amendments, EU established a biomass action plan dealing with the increased dependence on imported energy and the achievement of three main objectives concerning competitiveness, sustainable development and security of supply. According to the latest, three sectors are identified in which the exploitation of biomass should be prioritized: heat production, electricity production and transport (as biofuel). Based on the fact that Southern East European countries produce significant amounts of non-edible residual biomass like tree cuttings, straws, fruit and olive kernels, stalks, etc [5] it is evident that, with the aid of a well-established logistic system [6], biomass can be proved able to cover a significant share of the energy demands of the broader area. In addition, based on the fact that conventionally the energy needs of these countries are mainly covered by imports of fossil fuels, the exploitation of their indigenous, non-edible residual biomass may offer several not only environmental, but also socioeconomic advantages [5,7].

In this viewpoint, residual biomass holds an outstanding position in energy production, as its exploitation presents a number of advantages when compared to the fossil fuels, such as lower fuel cost, decentralize production and minimization of the environmental impacts [8,-9]. On the other hand, the main difficulties of biomass exploitation are caused by the need to establish an efficient logistic system, the low energy density, the seasonal production and the variation of quality. However, these difficulties are to a certain extent overcome with the in situ exploitation of residues, cyclic use and pelletization [10].

Generally speaking, biomass exploitation aiming to energy production can be achieved by thermochemical processes such as pyrolysis, gasification and combustion [11,-12]. Pyrolysis is mainly applied either for liquid biofuels production, or even carbonaceous materials of high added value e.g. activate carbons [11,-13], while gasification is mainly applied for combined heat and power production and for chemicals syntheses in the relevant industry [11,-14,-15]. On the other hand, combustion of residual biomass seems to have the potential to play a significant role in meeting the heating demands not only in rural, but also in urban areas [16,-17]. Towards that direction residual biomass could be considered as an alternative energy source for agro-industry and for the residential buildings ~~rector~~sector, in order to satisfy heating demands [18]. However, the wide variability of biomass properties may significantly influence the efficiency of the combustion systems and the environmental impacts emerging from its exploitation [18,-19].

Concerning the available biomass stocks suitable for exploitation for heating purposes in the Hellenic building sector they are mainly residues coming from the forestry and agricultural and agro-industrial activities as these residues are also characteristic for the country [8]. More specifically, forests cover almost 19% of the country's area while yield an annual production of about 800,000 m^3 of round and industrial wood, as well as 2,000,000 m^3 of fuel-wood. Among other indigenous species (beech, oak, fir, etc) pine is regarded as more characteristic and it is usually exploited for the production of wood for technical use [20]. A high added value by-product of the production of untreated technical wood in 680 sawmills in Greece [21], free of chemical substances, is pine sawdust. Today several forestry industries exploit this high added value by-product, covering at least partially their energy needs. Moreover, the newly developed pellet industry in Greece produces pellets from indigenous and imported residual biomass of mainly woody origin [10,21].

On the other hand, corn cultivation is quite extended in Greece in the frame of the food production industry, for people as well as for animals. In Greece, corn is considered a significant crop, its cultivation being widespread all over the country; the 2009 annual production reached 1.578 $*10^9$ kg, while for 2010 a $1.45*10^9$ kg was foreseen [22]. The residues remaining at fields after the harvesting period of corn crops were considered as the non-edible residues. It is worth mentioning that there is not an established management scheme of such residues; usually they are left rotten at the fields or burned in open air fires at the end of the cultivation season.

Finally, olive kernel is a widespread residue produced by the olive oil industry in Greece, with the majority of the Greek areas presenting intense olive tree cultivation activity. The olive kernel is produced seasonally and in significant amounts. As a result, olive kernel production in Greece reaches 300,000 to 400,000 ton/year [23]. The olive kernel agroresidue is traditionally exploited for covering part of the energy needs of the olive kernel oil factories, local residential heating in islands and greenhouse heating [18,24].

Within this framework, the aim of this work ~~is~~ focuses on the evaluation of the energy gain, in terms of primary conventional energy consumption, as well as of the environmental impact of substituting diesel oil with residual biomass for house heating under the Greek (i.e. South European Mediterranean) climate conditions. In parallel, the economical aspects of installing a burner system fed with biomass residuals instead of diesel oil are examined based on the Net Present Value (NPV) and the ratio of Benefit/Cost (B/C) indices are determined.

2. Description of the Building

The study focused on a typical multi-family building of Greece. In order to define the building's typology, data regarding the description of the building stock in Greece gathered from the Hellenic Statistical Authority was used [2~~0~~5]. For the majority of buildings, the bearing structure is made of reinforced concrete and the masonries (external, internal) are constructed with hollow clay bricks. In urban areas, the majority of contemporary constructions ~~have~~ comprises of 3-6 floors above the ground floor. Moreover, a significant percentage of new constructions comprises of 2 or 3 apartments per floor, each of which covers an area of circa 75 m^2 to 90 m^2 [~~21~~26-~~23~~28]. Based on the above typology, a representative building encompassing the aforementioned characteristics was designed~~,~~ (Figure 1). It encompasses 5 storeys above the ground floor, the latter housing only the building entrance; the remaining space is used as an open parking space (pilotis). Each floor covers an area of 256 m^2, divided in three almost equal apartments, Figure 1. Apartment ~~A~~ 1, (80 m^2) is located at the rear of the building plan. ~~and is separated by~~ T~~t~~he unheated staircase (28 m^2) separates Apartment 1 from the remaining two ~~(74 m^2 each),~~ A~~a~~partments ~~B~~ 2 & ~~C~~3(74 m^2 each), which have similar internal plan and are located on the main building façade, facing the street. ~~The staircase (28 m^2) is located focally on the building plan and is unheated.~~ All apartments consist of two bedrooms, a living room integrated with ~~integrated~~ the kitchen and a bathroom. Each apartment has a balcony in front of the living room, projected 2.25 m from its external wall. The storey height is equal to 3.0 m, resulting to a total volume of 3,840 m^3 (256 m x 3 m x 5 m), 3,420 m^3 of which are heated. It is assumed that the examined building is free-standing; therefore windows exist on every façade. The main façade is south-orientated and almost 30% of its area is covered with fenestration. The windows of the west and east façades are limited to 12.2% and 9.4% of the relevant façade area, while north windows account for only 4.5% of the respective façade's area.

Nowadays, due to the ~~new~~New Greek energy regulation [~~24~~29], there are strict restrictions for the thermal transmittance of the building elements, especially for the coldest climatic zones. These requirements have contributed to the current trend of positioning the thermal insulation on the exterior side of opaque vertical building elements, rather than on the core of the masonry, which was accustomed before. The insulating material (usually XPS) is attached to the masonry and the concrete elements with the help of special adhesives and hookers and then it is covered with synthetic plaster reinforced with a plastic mesh. The floor of the 1st storey, which is above the open space of the ground floor, is insulated with ~~expanded~~ extruded polystyrene below the concrete slab. The floor is paved with marble with the use of cement mortar above a 0.04 ~~c~~m layer of lightweight concrete. The building roof is flat, thermally protected with extruded polystyrene, which ~~lays~~ lies above water protection ~~(bitumen~~ layer~~)~~ and is covered with gravels. The consecutive layers of the materials constituting each building element and their thickness are presented in Table 1. The thickness of the thermal insulation used in each building element has been calculated in order to comply with the recent building energy performance regulation of Greece [~~24~~29]. The thermal conductivity values of the materials listed in the regulation [30] were taken into account ~~F~~for the calculation of the thermal transmittance of each building element (U-value, i.e. the heat flow rate though the building element divided by the area and by the temperature difference of its surrounding environments) ~~of each building element~~, which is presented in Table 2~~, the thermal conductivity values of the materials listed in the regulation [25] were taken into account~~.

The U-value~~s~~ of each window ~~have~~ has been calculated with regard to ~~their~~ its geometry and configuration, in order to comply with the requirements of the current building energy performance regulation for each climatic zone, which sets a maximum value for thermal transmittance equal to 3.0 W/(m^{2}K), 2.8 W/(m^{2}K) and 2.6 W/(m^{2}K) for climatic zones B, C, and D respectively. For all locations, it was assumed that the frame is made of aluminium with a thermal break (U_{fr} = 2.60 W/(m^{2}K)) with an average width of 0.10 m. The glazing ranged from double conventional (U_{gl} = 2.70 W/(m^{2}K)) for Zone B, double with low-e coating (U_{gl} =1.8 W/(m^{2}K)) for Zone C, to double with low-e coating filled with argon for zone D (U_{gl} =1.3 W/(m^{2}K)).

3. Definition of the Design Conditions

3.1 Description of the Greek climatic conditions

Greece extents in latitude from the 35th to the 41st parallel, with ground morphology from sea level up to 2,900 m. One of the most important topology characteristics is the total length of the coastal line, exceeding 13,600 km. As a result, the climate conditions cover a relatively wide range~~,~~ and may change drastically in relatively close distances. Legislatively, the country is divided in 4 climate zones, according to the most recent regulations [~~26~~31], shown in Figure 2.

Zone A includes the southern parts of the country and the climate is characterized as hot with high humidity. The heating requirements of the buildings in this zone are limited, the absence of central heating being not rare. Obviously, the cooling needs are the highest of the country.

Zone B includes the parts of the southern Greece excluded from Zone A, parts of western Greece and the central Ionian and Aegean seas islands. The weather conditions of the zone are mild, and the residential buildings present roughly equal heating and cooling demands.

Zone C includes the majority of central and north mainland areas, characterized by relatively cold winters and mild summers. Consequently, the energy needs for heating are clearly higher than for cooling.

Finally, Zone D includes some areas of Western and Eastern Macedonia, presenting the most severe winters in the country and the milder summers. As a result, the energy needs for heating are the highest while cooling is practically not needed.

3.2 Selection of the representative Cities

For the investigation of the energy, environmental and financial benefits resulting from substituting diesel oil with biomass in central heating installation, three cities were chosen, as representative of climate zones B, C and D; zone A was excluded from the evaluation due to the limited heating needs. The selected cities selected, (i.e. Andravida located in Zone B, Kavala in Zone B and Kastoria located in Zone D – see (Figure 2), feature climate characteristics as close as possible to the respective climate zone, (mainly in terms of the heating and cooling degree days, (HDD and CDD) respectively) as close as possible to the respective climate zone.

3.3 Design conditions and design heating loads of the building

The basic climatic design parameters are listed in Table 3, taken were retrieved from the ASHRAE database [2732] for the cases of (Andravida and Kavala, since it was) - considered as more representative reliable because due to the of the longer recording period. The ASHRAE database does not include they are based on- or from the respective Greek Regulation (Kastoria), therefore for the specific city the required climate data were retrieved from the Greek Regulation.because the ASHRAE database

~~does not include the specific city.~~ The design heating and cooling loads were calculated, using the Elite Chvac® software.

According to the calculation results, the total heating load of the building in Andravida (Zone B) is 35.5 kW, with 49.2% of it being ventilation losses, 40.1 kW in Kavala (Zone C), with 49.3% ventilation losses and 45.6 kW in Kastoria (Zone D), with 47.5% of it being ventilation losses. The total cooling load was calculated at 31.2 kW in Andravida, appearing at the time slot 17:00–20:00 in July, at 28.9 kW in Kavala, appearing at the time slot 17:00–20:00 in August and 23.3 kW in Kastoria, appearing at the time slot 17:00–20:00 in July.

4. Definition of the Energy Analysis Parameters

The energy requirements of the building in the three cities were determined with the aid of the EnergyPlus software. The building was divided in 11 independent thermal zones per floor. Accounting the common-use part of the building (staircase and entrance lobby) as an additional zone, a total of 56 zones resulted~~s~~. For each thermal zone, the ambient conditions (diurnal distribution of winter and summer temperature requirement, ventilation rate, lighting power, person presence, appliance usage etc.) of the Greek Regulation [~~28~~33] were ~~assumed~~taken into account, supplemented by the ASHRAE recommendations [~~27~~32].

Since it is of residential use, the building was assumed to be in use 24 hour per day all year around. On a daily basis, the 24:00–06:00 period was assumed to be of ~~soft~~ lower operation, the rest of the day being of normal operation. Table 4 lists the indoor simulation parameters.

Regarding the climate details, the typical meteorological year (TMY-2) given by the meteorological database METEONORM ver. 5.102 for each of the cities was used.

5. Results and Discussion

5.1 Energy Analysis

Figure 3 presents the heating energy demands, as they resulted from the simulation of the building in the three cities. The annual energy demand in Andravida (Zone B) is 5,775 kWh, increasing to 18,500 kWh in Kavala (Zone C), reaching 24,700 kWh in Kastoria (Zone D).

These demands were reduced to total energy demand, assuming the minimum efficiency required by the Greek Regulations [~~24~~29,~~ 26~~31] for the heat emission and heat distribution systems, 89.0% and 96.0% respectively. From the total energy requirement, the final energy need was calculated, using diesel oil and locally produced residual biomass, assuming the minimum, power dependent, boiler efficiencies according to EN-303.2 [~~29~~34] and EN 303.5 [~~30~~35]. The primary energy need in each case was determined from the final, using the legislated reduction factors (1.1 for diesel oil, 1.0 for biomass [~~26~~31]). The results are shown in Figure 4.

As it can be clearly seen in Figure 4, the primary energy consumption with residual biomass is in all cases higher than with diesel oil, the difference starting from 3.8% in Zone B, reducing to 3.2% in Zone D. These differences are attributed to the efficiency of the biomass boiler, which, according to the relevant standards [~~29~~34,~~30~~35], is about 10% lower than that of the equivalent diesel boiler. This deviation is also confirmed by recent experimental work on biomass boilers [~~31~~36].

5.2 Environmental Impact

Forest residues, ~~(~~pine sawdust in the form of pellets~~)~~, agricultural residues (corn stalks) and olive kernels were assumed as feeding materials for a central heating system for covering the energy consumption needs at the Andravida and Kavala sites. Respectively, the residual biomass selected for Kastoria is assumed to consist of forest residues, (pine sawdust pellets,) and agricultural residues (corn stalks), since there are no olive trees in the area, because of the cold climate [3237]. It is reminded that, in the framework of this study, the exploitation of the non edible residual biomass is examined only locally.

The residual biomass is assumed to be exploited with an inherent moisture content lower of 20% w/w after short term storage in open air spaces and under the Mediterranean climatic conditions. The ultimate and the proximate analysis analyses of the selected residues are presented in Table 5. The selection was based on the availability of such residues, suitability of their physicochemical characteristics, (particle diameters and rheological characteristics in order to be suitable for automatic feeders, sufficient bulk density, low moisture, C/N ratio over than 30 and attractive heating value) [8], for enabling their combustion [3338].

Moreover, as the availability of such residual biomass seems to be an issue of great importance for implementing any energy production scenario in a country, the selection of residues that are produced locally [3439] and in a proper form, (sawdust as raw material for pellets production, crushed kernels and chopped cereals stalks) has been considered and compared with oil in terms of a cost – benefit analysis.

~~Concerning the forestry activity in Greece, forests cover almost 19% of the country's area while yield an annual production of about 800,000 m^3 of round and industrial wood, as well as 2,000,000 m^3 of fuel-wood. Among other indigenous species (beech, oak, fir, etc) pine is a characteristic forest specie and it is usually exploited for the production of wood for technical use [37]. A high added value by-product of the production of untreated technical wood in 680 sawmills in Greece [38], free of chemical substances, is pine sawdust. Today several forestry industries exploit this high added value by-product, covering at least partially their energy needs. Moreover, the newly developed pellet industry in Greece produces pellets from indigenous and imported residual biomass of mainly woody origin [10, 38].~~

On the other hand, corn cultivation is quite extended in Greece, in the frame of the food production industry, for people as well as for animals. In Greece, corn is considered a significant crop, its cultivation being widespread all over the country; the 2009 annual production reached 1.578 $*10^9$ kg, while for 2010 a $1.45*10^9$ kg was foreseen [39]. The residues remaining at fields after the harvesting period of corn crops were considered as the non edible residues. It is worth mentioning that there is not an established management scheme of such residues; usually they are left rotten at the fields or burned in open air fires at the end of the cultivation season.

Finally, olive kernel is a widespread residue produced by the olive oil industry in Greece, with the majority of the Greek areas presenting intense olive tree cultivation activity. The olive kernel is produced seasonally and in significant amounts. As a result, olive kernel production in Greece reaches 300,000 to 400,000 ton/year [40]. The olive kernel agroresidue is traditionally exploited for covering part of the energy needs of the olive kernel oil factories, local residential heating in islands and greenhouse heating [18,36].

For the estimation of the environmental impact from the exploitation of the three characteristic biomass types in Greece for heating of buildings, the CO_2 and SO_2 emission factors were determined. Based on the chemical analysis of the three residual biomass types, presented in Table 5, the lower heating value (LHV) of each type was determined (Table 6) and then, based on the carbon and sulfur content, the CO_2 and SO_2 emission factors were calculated, presented in Table 7. The SO_2 emission factor for the diesel oil was determined similarly (0.1% w/w, [41]), while for CO_2 the value suggested by the Greek legislation was adopted [294].

Regarding the remaining of the pollutants (CO, PM, NO_x and NMVOC), to our knowledge dedicated Greek emission factors have not been published yet. The CORINAIR database includes emission factors for small household boilers (of less than

50 kW power) burning wood, wood waste (residual biomass) and liquid fuels (diesel oil) [42]. Table 7 summarizes the emission factors available for this study.

In order to calculate the CO_2 emissions for the alternative fuels examined in this study, the energy consumption of the typical building for each climate zone has been converted to final energy consumption, as it is presented above, and then using the lower heating value for each fuel the annual required quantity of the fuels has been calculated. Then by multiplying the CO_2 emission factor of Table 7 with the quantity of each fuel, the annual CO_2 emissions were calculated. These results are shown in Figure 5.

Based on the CO_2 emission factor of Table 7 and the energy consumption of the typical building for each of the examined climate zones, the annual CO_2 emissions are shown in Figure 5. Clearly, in all climate zones, the diesel oil CO_2 emission is lower by roughly 40%, compared to that of any biomass fuel. It should be noted, however, at this point that the CO_2 emission resulting from biomass residues exploitation is considered as neutral, in case of sustainable grown of biomass, as they constitute part of the closed CO_2 cycle.

Respectively to CO_2, Figure 6 presents the SO_2 annual emission, which is significantly higher for biomass fuel, ranging from 56% to 322% - depending on the residual biomass specie, compared to that of the diesel oil. These increased emissions may be attributed (a) to the increased sulfur content of the biomass fuels, since they are used as received, i.e. assuming no de-sulfurization, and (b) to the lower energy content of residual biomass in terms of energy density, which increases the fuel consumption per unit of energy produced in order to cover the same energy demands as with oil.

Regarding the other pollutants (CO, NO_x, NMVOC and PM), the significant differences between the emission factors of diesel oil and biomass fuels, listed in Table 7, suggest even larger differences of emissions, taking into account the increased fuel consumption in the residual biomass case. It has to be noted however that (a) the reliability of the emission factors of Corinair is limited and (b) there are technological solutions of advanced biomass combustion systems (e.g. systems based on catalytic combustion) that can produce significantly lower emissions [43], and these systems are not included in Corinair database. Therefore, no attempt will be made to compare results for CO, NO_x, NMVOC and PM.

5.3 Economic~~al~~ Analysis

The fiscal analysis of using residual biomass for heating of buildings is based on the differences of installation cost (boiler / burner cost), service life of the system, fuel cost and discount cash flow rate.

Based on today's real values of the Greek market, and for systems of the power range of this work, the installation cost difference is estimated to be 2,000 €, regardless of the location of installation.

The service life of the systems is usually expected in the 15 – 20 years, mainly depending on the maintenance level and on the fuel quality. For the purposes of this study it was assumed at 15 years (worst case scenario).

The market price of diesel oil and biomass fuels is depended on a number of parameters of local (e.g. biomass availability), national, ~~(~~e.g. taxation policy, which may differentiate between oil and biomass,~~)~~ and international, ~~(~~e.g. oil availability, local wars etc.,~~)~~ origin. Additionally, there are obvious interrelations, e.g. the biomass producer's price increases with the increase of oil price, not necessarily representing the costs' increase.

For the purposes of this study, the consumer prices for diesel oil and biomass residues were considered equal to the free market prices prevailing today, i.e. 1 €/L for diesel oil, 0.25 €/kg, 0.15 €/kg, and 0.08 €/kg for forest residues (pine sawdust pellets), agricultural residues, (corn stalks) and olive kernel, respectively. Moreover the discounted cash flow rate is set to 7%, according to the Hellenic economic practice. The net present value (NPV), the cost-benefit analysis (B/C ratio) indices and the turnover period of the investment were determined and results are presented in Table 8. It can be clearly seen that the length of the turnover period reduces with the increase of the energy consumption (up to 8.6 years for Andravida in zone B, 2.2 years for Kavala in zone C and 1.7 for Kastoria in zone D). However, in the same climatic zone it ~~reduces~~ decreases with the increase of LHV/price ratio, ~~(~~becoming longer ~~for~~ in the case of forest residues, ~~being~~ reduced for olive kernel and minimum for agricultural residues~~)~~. Similar behavior is observed for the NPV and the B/C indices. More specifically, from the cost-to-benefit analysis it results that for all areas and for all biomass types the substitution of diesel oil with biomass is financially beneficial (B/C>1) and that the profitability of the investment increases with (a) the increase of the energy consumption, for the same type of biomass, (b) with the increase of the LHV/price, for different biomass types. Finally, ~~from~~ the NPV index ~~it results again~~verifies that the substitution is financially beneficial, especially for the northern part of the country, where the energy needs for heating are more significant.

5.4 Social Impact

The energy, environmental and economic effects resulting from the substitution of diesel oil with three different types of biomass, aiming at covering the heating energy demands of the Greek buildings, were studied, analyzed and evaluated in the previous sections. More specifically, and at a national level, the use of biomass as a solid fuel in the domestic sector is expected to grow rapidly during the upcoming years. The recently established Ministerial Decision [44] revised the already existing legislative framework concerning heating in domestic buildings and from now on the biomass utilization is permitted even in the major urban cities of Greece, Athens and Thessaloniki.

Due to the economic crisis the country faces over the last two years, more and more citizens are searching for economical solutions in order to satisfying their heating energy demands in residential buildings. In this context, the substitution of diesel oil with biomass is expected to bring some advantages, as well as the need to overcome some disadvantages both in national and local level.

In particular, biomass energy has the potential to cover part of the country's heating energy demands without contributing to the CO_2 built up, since it is considered as a carbon neutral solid fuel. Moreover, given that the CO_2 produced by the sustainable exploitation of biomass is considered carbon neutral when biomass is exploited in a sustainable way, the produced CO_2 could be further consumed by plants during photosynthesis.

The particular benefit that expected to arise in a national level from lignicellulosic biomass stocks exploitation for energy production is the increase of the country's energy autonomy as biomass will substitute an imported fossil fuel (diesel oil). In this context and in comparison to diesel oil, the biomass supplementary exploitation will also contribute in achieving the current RES policy requirements according to the 20-20-20 goal, by reducing up to 20% the GHG emission relatively to the levels existing in 1990.

Additionally, the sustainable use of biomass for energy production could enhance the multi-sectorial interactions. Towards that direction the integration of the agricultural sector (biomass production), agro-industrial sector (pretreatment and production of biomass residues) with building industry will further encourage the embodiment of a low cost renewable energy source like biomass in the residential energy sector. It would also assist towards balancing the trade of local solid fuel resources that could otherwise not meet the end-users need of low cost heating.

Concerning the effect of altering from diesel oil to biomass there will be also a sectorial integration and new employment opportunities in primary, secondary and tertiary sectors of agriculture, energy and industry as well as logistics and processes, respectively.

Additionally, among others the main advantages of biomass utilization in local communities are: (a) the low or even zero cost fuel utilization (agricultural residues abandoned in fields), (b) the avoidance of energy dependence on conventional fossil fuel supplies as well as a central system of fossil fuels supply, (c) the strengthening of the bio-business sector employment in decentralized regions (islands and/or rural areas), (d) the contribution on the green energy production targets and even (e) the positive impact to environmental economics taking into consideration the positive externalities.

Moreover the creation of new job opportunities particularly in the rural areas of Greece is one of the most important social benefits arising from the exploitation of biomass in the residential heating sector. Strengthening of employment in rural areas of the country and re-developing the regional job opportunities will support the re-population of the Greek rural areas and that is another important benefit. Since the economy of Greece was traditionally based on agriculture and agro-industrial activity the exploitation of lignocellulosic residues could significantly improve the economics of the biomass production methods and as a consequence the living standard of citizens in the Greek periphery.

Following to the above advantages of biomass utilization, there are also some disadvantages bringing difficulties to local biomass exploitation in heating sector: (a) difficulties in collection and transportation from remote rural areas and islands, (b) seasonal production and variety in quality even for the same biomass sample, (c) high moisture content, and (d) low energy density. Additionally, as biomass residues have high bulk density, they cannot be store, handled and transported conveniently.

Moreover the lower efficiency of the traditional biomass combustion devices compared to diesel oil ones, results to a lower energy usage of the fuel. On the contrary, liquid fossil fuels like diesel oil can be handled, stored and transported easily. Especially in countries with rough topographies like Greece with mountainous areas as well as remote islands, the lower energy density of biomass and diverse physicochemical properties are the main disadvantages for biomass exploitation in residential heating sector. Pelletization, however, increases biomass energy density, improves biomass logistics and at the same time stabilizes biomass' physicochemical properties while the utilization of local biomass stocks optimizes the cost-benefit results.

Furthermore, biomass was traditionally used in local communities of Greece e.g. woody biomass (forest residues) in mountainous areas and agricultural residues (olive kernels) in islands with minimum pretreatment (chopping and open air storage). The latest years there is an accelerating development of biomass pelletization-utilization business revealing the increasing end-users market demands. It is also a fact that biomass stocks demands (wood pellets, forest residues and longs as well as agro-residues like olive kernels) increased surprisingly under the current economic crisis indicating the renewed interest of the society in that traditional fuel as well as its future potential for the local coverage of heat energy demands. Towards that direction, the Greek Government recognized the necessity of the biomass utilization in residential heating sector, Ministerial Decision 189533/2011 [44], allowing the biomass utilization in form of logs or pellets given directions for its efficient and sustainable utilization even in the capitals of the country.

On the contrary, a disadvantage that will have to be faced is that the replacement of imported diesel oil with local biomass stocks is that it could not be considered as an immediate solution in terms of power efficiency and availability.

Nationally the internal transportation of big quantities of biomass is expected to result in increased greenhouse gas emissions in the transport sector as a result of the lower energy density of the biomass in comparison to diesel oil and thus will lead to the need of increased capacity. Taking into account the results of the energy assessment, it becomes obvious that eventually the use of biomass in residential heating will lead ultimately to an increase on the primary energy consumption. This fact not only constitutes biomass non profitable, but it also contradicts to the requirements of the European Directives 91/2002/EC and 31/2010/EC for reducing the primary energy consumption of building sector. However, it should be emphasized that the improvement of the residential heating devices and technologies of combustion is expected to result in a short-term improvement of the appliances' efficiency and will finally result in alleviating that disadvantage.

Furthermore the substitution of diesel oil with biomass would contribute on the increase of SO_2 emissions due to the higher potential of both forest and agricultural residues. Moreover, based on the CORINAIR database findings, the use of biomass on the residential building sector would also increase the emissions of NO_x, PM, CO, and NMVOC. This fact, along with the expected presence of secondary pollutants in the atmosphere of the urban areas, will have a negative effect on their microclimate. Especially in the northern regions of the country, where the biomass use will be enlarged due to the severe climate conditions during the winter, the increased emissions combined with the high relative humidity of air and the dense urban fabric are expected to raise the air pollution levels significantly, leading to the direct degradation of the quality of life.

Although some of the negative aspects affecting currently the biomass exploitation in residential heating sector will be faced with further technological advancements as well as processes optimization (e.g. logistics), the utilization of residual lignocellulosic biomass will also be proved useful in fulfilling the heat energy demands of the final end users.

6. Conclusions

The main conclusions drawn from the substitution of diesel oil with biomass for covering the heating energy demands of residential buildings in Greece could be summarized as follows:

1. The use of biomass fuels instead of diesel oil ~~results in increased~~increase the primary energy consumption by~~, the difference on country level being in the order of~~ 3-4%, on a national level with the smaller values appearing ~~for~~ in southern ~~the~~ and hotter regions.
2. The CO_2 emission, resulting ~~with~~ in the case of the three more characteristics biomass types of Greece (pine sawdust, corn stalks and olive kernel) is increased by about 40%, ~~as~~ when compared to that of the diesel oil. Regardless of the geographical area, the pine sawdust presents the lowest and the olive kernel the highest emissions.
3. The SO_2 emission is also higher with biomass, the highest corresponding to corn stalks, followed by pine dust and olive kernel, accounting for ~~(~~323%, 147% and 56% increase compared to that of the diesel oil, respectively~~)~~.
4. The substitution of oil in central heating systems with pine sawdust, corn stalks or olive kernel ~~it~~ is proved economically feasible. The turnover period of the investment ranges from 1.7 to 8.7 years, ~~in case of~~for the pine sawdust usage, ~~raises from 1.7 to 8.7 years,~~ from 1.3 to 5.6 years for corn stalks, while for olive kernel it oscillates between 1.1 and 3.9 years as the heating demands decrease~~d~~. Respectively, the NPV of the substitution under examination is in ~~any~~ every case positive, ranging from 903.6 € to 15,478.1 €, depending on the geographical region and the type of biomass, with the higher values corresponding to the colder areas of the country. Similar conclusions can be

Formatted: Numbered + Level: 1 + Numbering Style: 1, 2, 3, … + Start at: 1 + Alignment: Left + Aligned at: 0.63 cm + Indent at: 1.27 cm drawn from the cost-benefit analysis, with the corresponding index ranging between 2.94 and 1.12.

5. From a social point of view, the substitution of diesel oil with biomass will increase the energy autonomy of the country, support the local communities with the creation of new employment opportunities in several sectors and strengthen the income of the agricultural society. However the exploitation of biomass in a non-sustainable way will increase the emission of the gaseous pollutants from the transportation and building sectors as well as it will contribute to the deterioration of the urban environment.

Results of the present study could be taken into consideration for establishing guidelines and for further support of the future legislation framework concerning the energy, environmental, climate and economic policies on the EU level. The indications could be useful not only in the short term (2020), but also in the long term planning policies for achieving the low carbon economy on 2050. From this point of view EU could: (a) establish measurements that discourage or exclude the exploitation of biomass in an inefficient way through the existing energy generation processes or technologies while support advanced technologies, (b) restrict the use of biomass for energy to such levels that not driven by the unregulated demand but will ensure biomass' sustainable supply, (c) establish an evaluation framework for the environmental concerns of the acceleration of biomass use that currently takes into account not only the CO_2 emissions but also all the pollutants e.g. SO_2, and (d) review the sense that the use of biomass for energy is always carbon neutral.

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List of Tables

Table 1: The materials and the thickness of the layers constituting the building elements of the typical building

Climatic Zone	**B**	**C**	**D**
Building element: Material		**Thickness [m]**	
Vertical reinforced concrete elements			
Plaster (cement-lime mortar)	0.02	0.02	0.02
XPS	0.06	0.06	0.07
Reinforced concrete	0.20	0.20	0.20
Plaster (cement-lime mortar)	0.02	0.02	0.02
External masonry (in contact with the ambient air and the unheated space)			
Plaster (cement-lime mortar)	0.02	0.02	0.02
Brick masonry	0.10	0.10	0.10
EPS	0.04	0.05	0.06
Brick masonry	0.10	0.10	0.10
Plaster (cement-lime mortar)	0.02	0.02	0.02
Floor above pilotis			
Plaster(cement-lime mortar)	0.02	0.02	0.02
XPS	0.06	0.07	0.08
Reinforced concrete	0.15	0.15	0.15

Lightweight concrete	0.04	0.04	0.04
Cement mortar	0.02	0.02	0.02
Marble tiles	0.02	0.02	0.02
Flat roof			
Gravels	-	-	-
XPS	0.06	0.07	0.08
Bitumen layer	0.007	0.007	0.007
Lightweight concrete	0.04	0.04	0.04
Reinforced concrete	0.15	0.15	0.15
Plaster (cement-lime mortar)	0.02	0.02	0.02
External masonry			
Plaster (cement-lime mortar)	0.02	0.02	0.02
Brick masonry	0.10	0.10	0.10
EPS	0.04	0.05	0.06
Brick masonry	0.10	0.10	0.10
Plaster (cement-lime mortar)	0.02	0.02	0.02

Table 2: The thermal transmittance of the building elements of the typical building

Climatic zone	B		C		D	
Building element	**U value [W/(m²K)]**	**U max [W/(m²K)]**	**U value [W/(m²K)]**	**U max [W/(m²K)]**	**U value [W/(m²K)]**	**U max [W/(m²K)]**
Vertical reinforced concrete elements	0.436	0.50	0.436	0.45	0.38	0.40
External masonry (in contact with the ambient air and the unheated space)	0.493	0.50	0.423	0.45	0.371	0.40
Floor above pilotis	0.416	0.45	0.366	0.40	0.326	0.35
Flat roof	0.425	0.45	0.372	0.40	0.331	0.35

Table 3: Basic climate parameters of building's area

City	**Andravida [2732]**	**Kavala [2732]**	**Kastoria [2631]**
Latitude / Longitude	37° 92′ 12″ N / 21° 16′ 48″ E	40° 58′ 48″ N / 24° 36′ 00″ E	40° 27′ 00″ N / 21° 16′ 00″ E
Heating period		November–March	
Heating design conditions (99.6%)	0°C	-2.9°C	-7.5°C
Mean daily temperature in January	9.5°C	5.6°C	2.2°C
Cooling period		Mid of May–October	
Cooling design conditions (0.4% DB/MCWB)	33.1 DB/22.0 WB	32.2 DB/21.5 WB	33.5 DB/21.0 WB
Mean daily temperature	25.9°C (July)	24.5°C (August)	23.2°C (August)

Table 4: Basic simulation characterists of building

City	Andravida	Kavala	Kastoria
Latitude / Longitude	37° 92′ 12′′ N / 21° 16′ 48′′ E	40° 58′ 48′′ N / 24° 36′ 00′′ E	40° 27′ 00′′ N / 21° 16′ 00′′ E
Operation Period	24hours/day		
Heating Period	16 November – 15 May		
Desired Temperature during normal/soft operation	21°C / 18°C		
Cooling Period	16 May – 15 November		
Desired Temperature during normal/soft operation	26°C / 30°C		
Air Changes of apartments during normal/soft operation	0.45 ach / 0.2 ach		
Lighting elevation of apartments	6 W/m^2 and 3.5 W/m^2 for WC only		
People	280 W for Aapartments B 2 & C3, and 140 W for Aapartment A1		

Devices	780 W for ~~apartments~~ Apartments ~~B~~ 2 & ~~C~~3, and 660 W for ~~apartment~~ Apartment ~~A~~1

Table 5: Ultimate and proximate analysis of non-edible residual biomass [8,24,3540,36]

Residue	Forest residues [3540]	Agricultural residues [8]	Olive kernel [3624]
	Ultimate analysis (%ww, dry)		
C	53.16	45.53	48.59
H	6.25	6.15	5.73
O*	40.00	41.01	40.46
N	0.30	0.78	1.57
S	0.09	0.13	0.05
	Proximate analysis (%ww, dry)		
Ash	0.20	6.40	3.60

* by difference

Table 6: Lower Heating Value (LHV) of non-edible residual biomass

Residue	Forest residues	Agricultural residues	Olive kernel
LHV [kWh/kg]	4.95	4.18	4.34

Table 7: Fuel specific emission factors for small household boilers

Fuel	CO_2 [kg/GJ]	CO [42] [g/GJ]	PM [42] [g/GJ]	NO_x [42] [g/GJ]	NMVOC [42] [g/GJ]	SO_2 [g/GJ]
Diesel oil	73.34 [2429]	40	3	70	15	46.61
Forest residues	109.30	4000	475	120	400	100.94
Agricultural residues	111.02					172.90
Olive kernel	114.01					63.99

Table 8: Fiscal analysis of oil substitution with biomass residues for building heating in Greece

Parameter	Andravida			Kavala			Kastoria	
	Forest residues	Agricultural residues	Olive Kernel	Forest residues	Agricultural residues	Olive Kernel	Forest residues	Agricultural residues
Initial cost of oil burner-boiler [€]	1,300							
Initial cost of biomass burner-boiler [€]	3,300							
B/C ratio	1.12	1.34	1.73	1.45	1.88	2.94	1.51	1.99
NPV [€]	903.6	2,078.2	3,488.4	7,325.6	11,071.5	15,568.7	10,495.7	15,478.1
Turnover period of the investment [y]	8.6	5.6	3.9	2.2	1.6	1.1	1.7	1.3

List of Figures

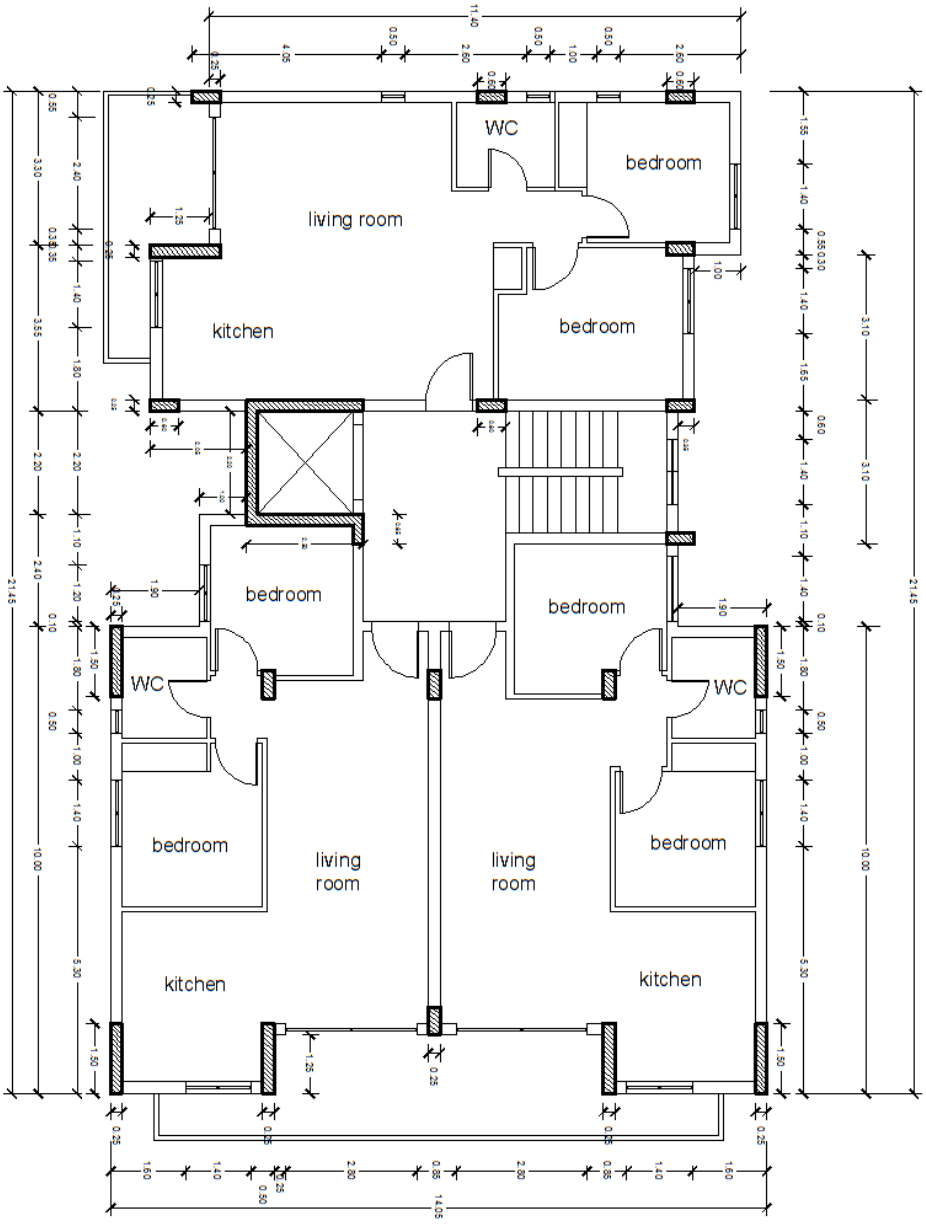


Figure 1: Floor plan of the typical multi-family building in Greece

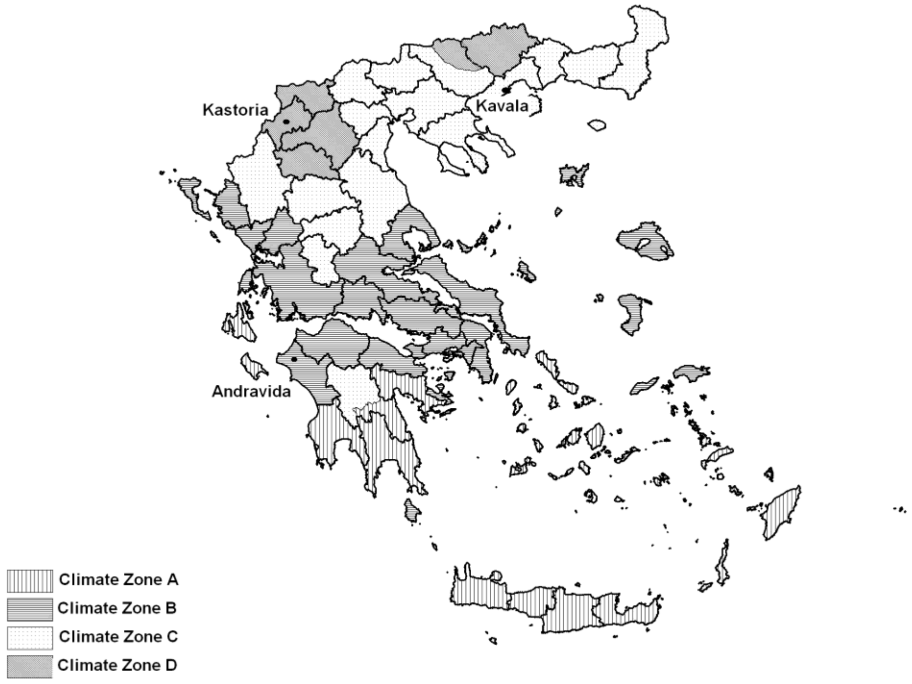


Figure 2: The climate zones of the Greek territory [18]

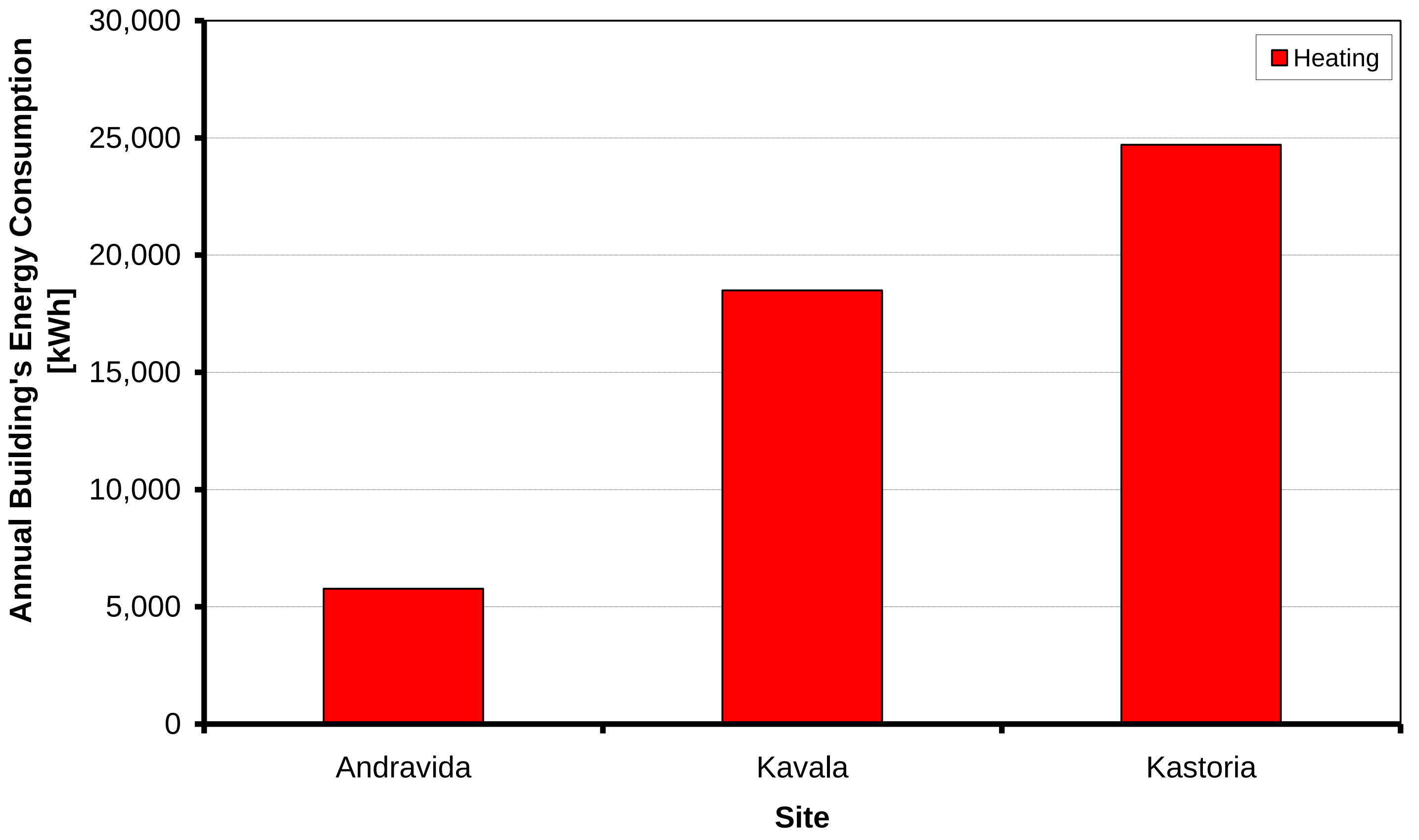
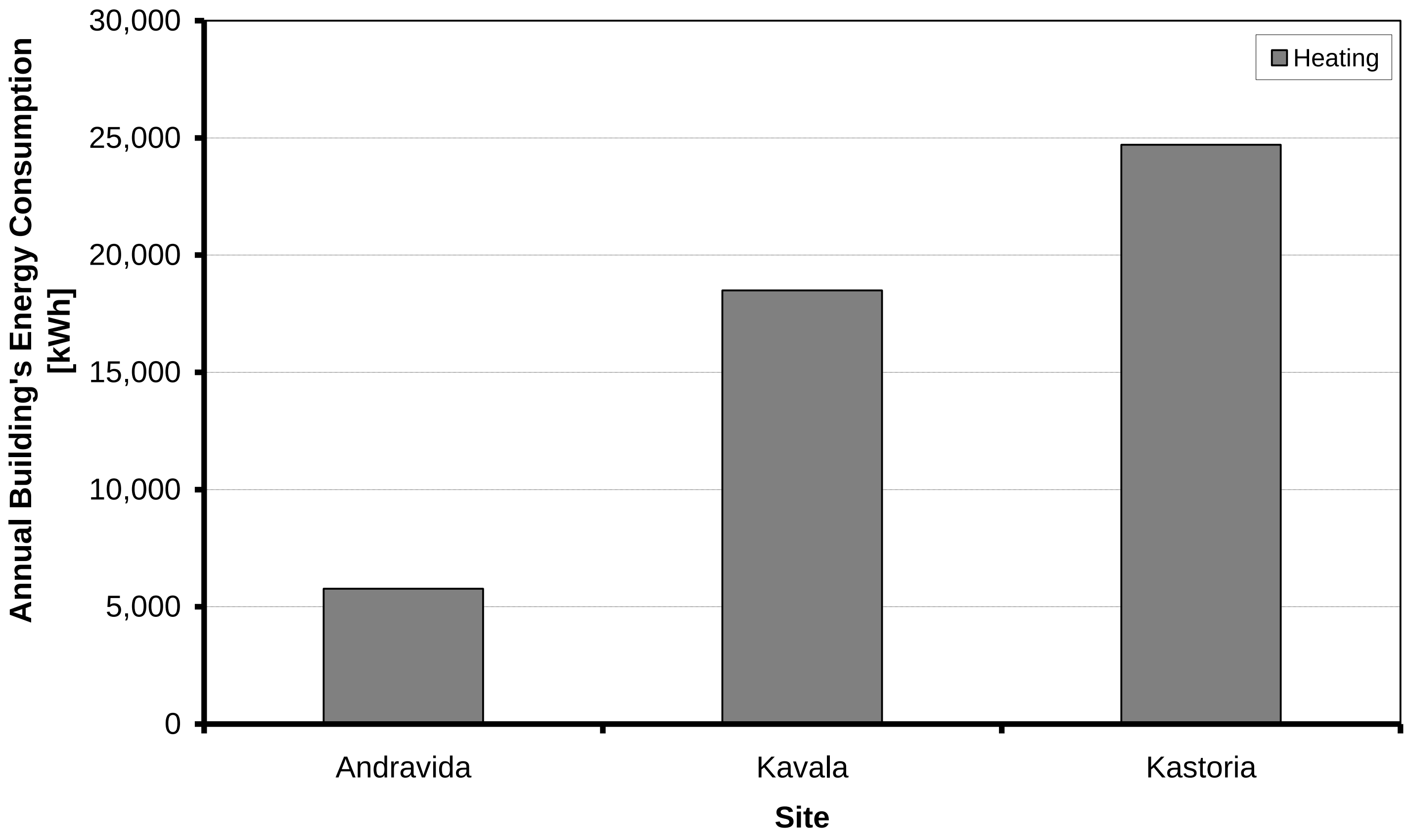


Figure 3: Annual energy consumption of the building at the three different sites



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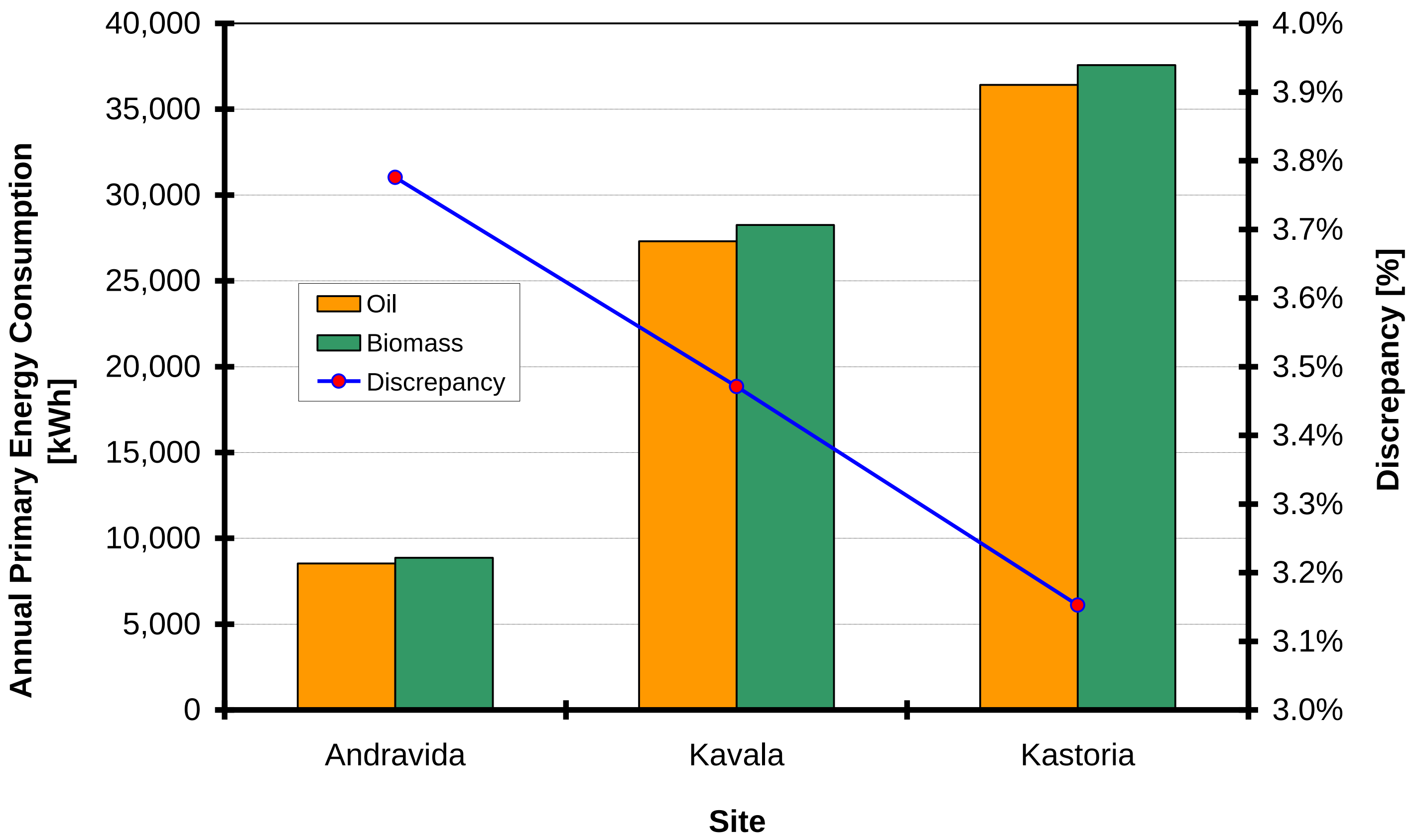

Figure 4: Primary energy consumption of the building at the three difference sites using oil and biomass fuels

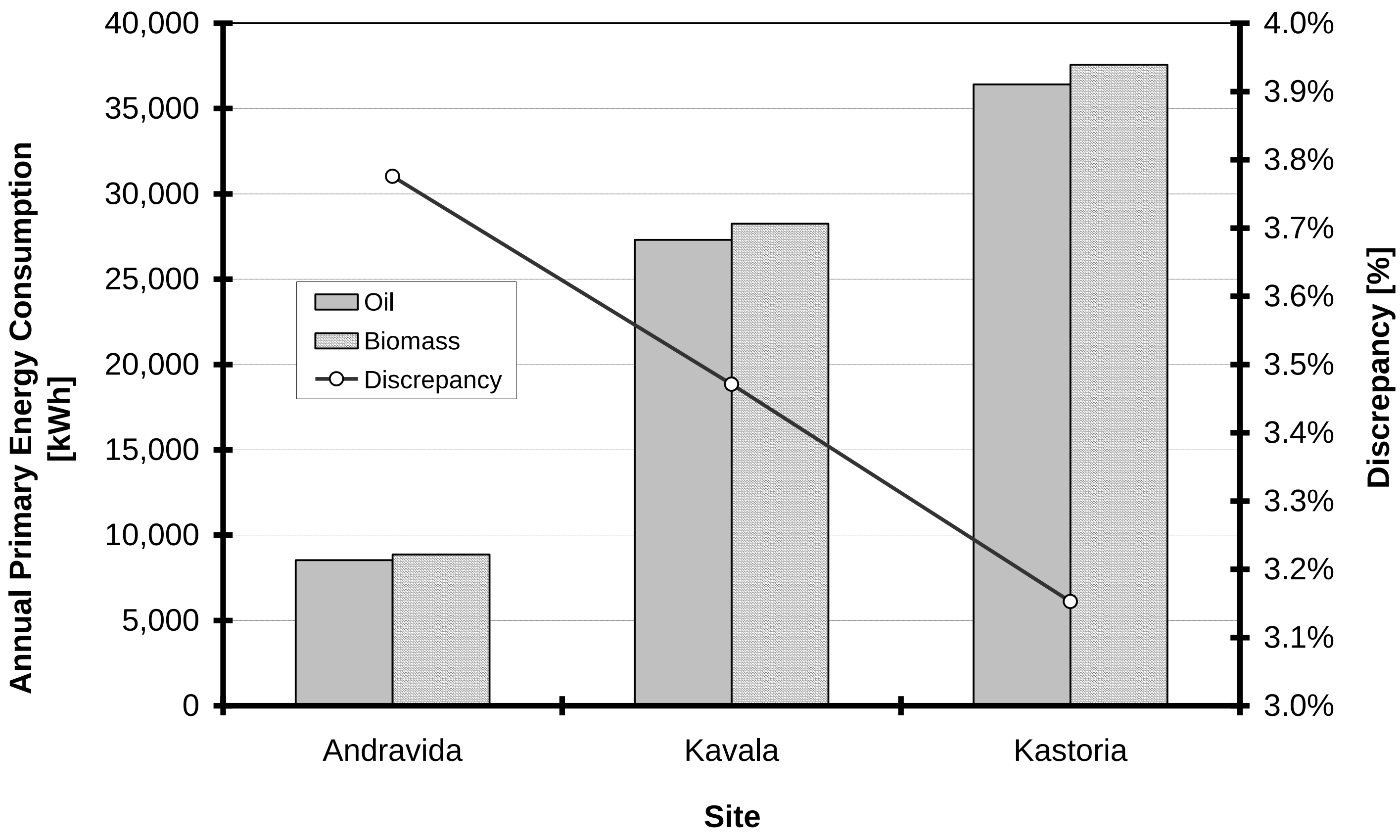

Figure 4: Primary energy consumption of the building at the three difference sites using oil and biomass fuels

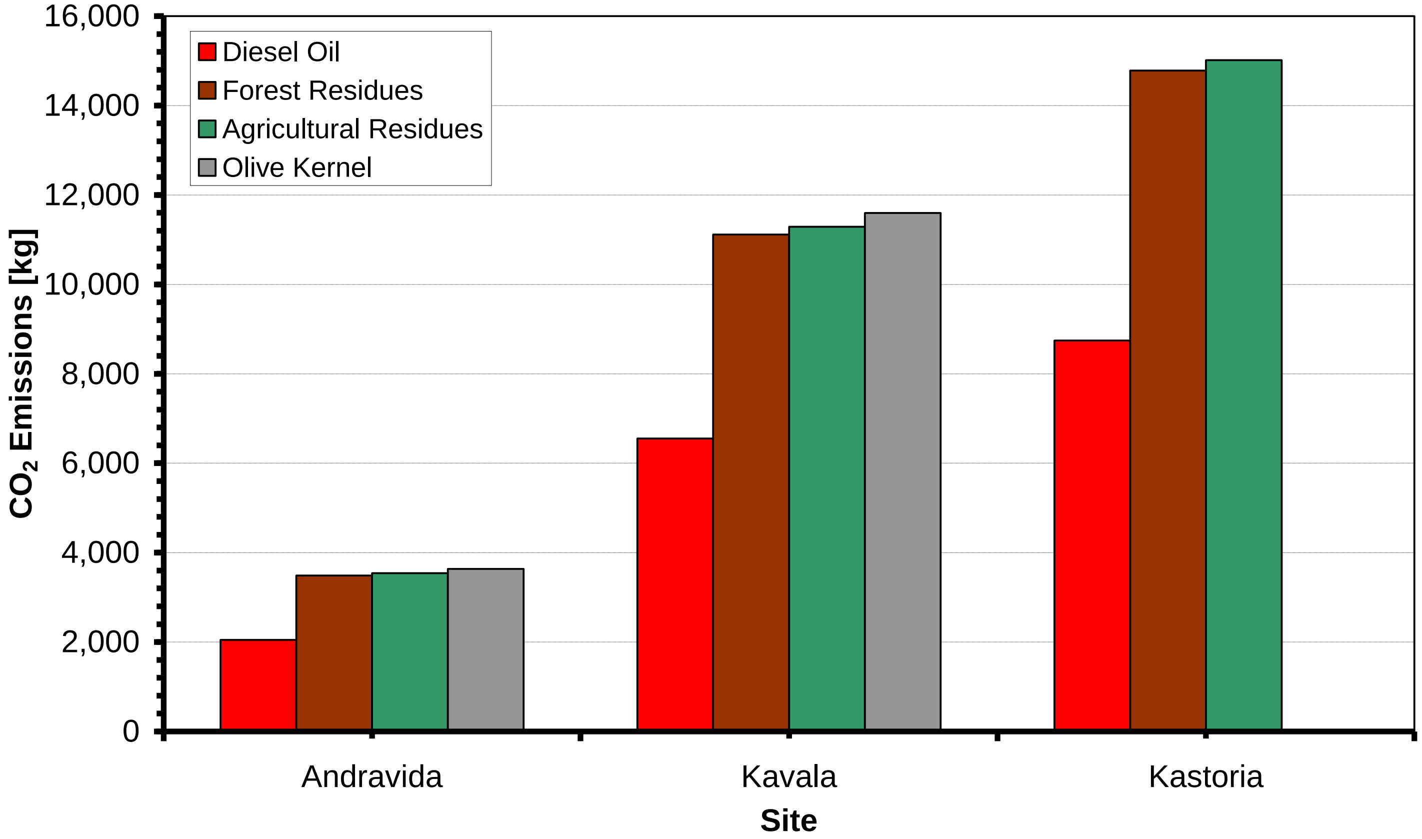

Figure 5: CO_2 emissions for diesel oil and biomass fuels

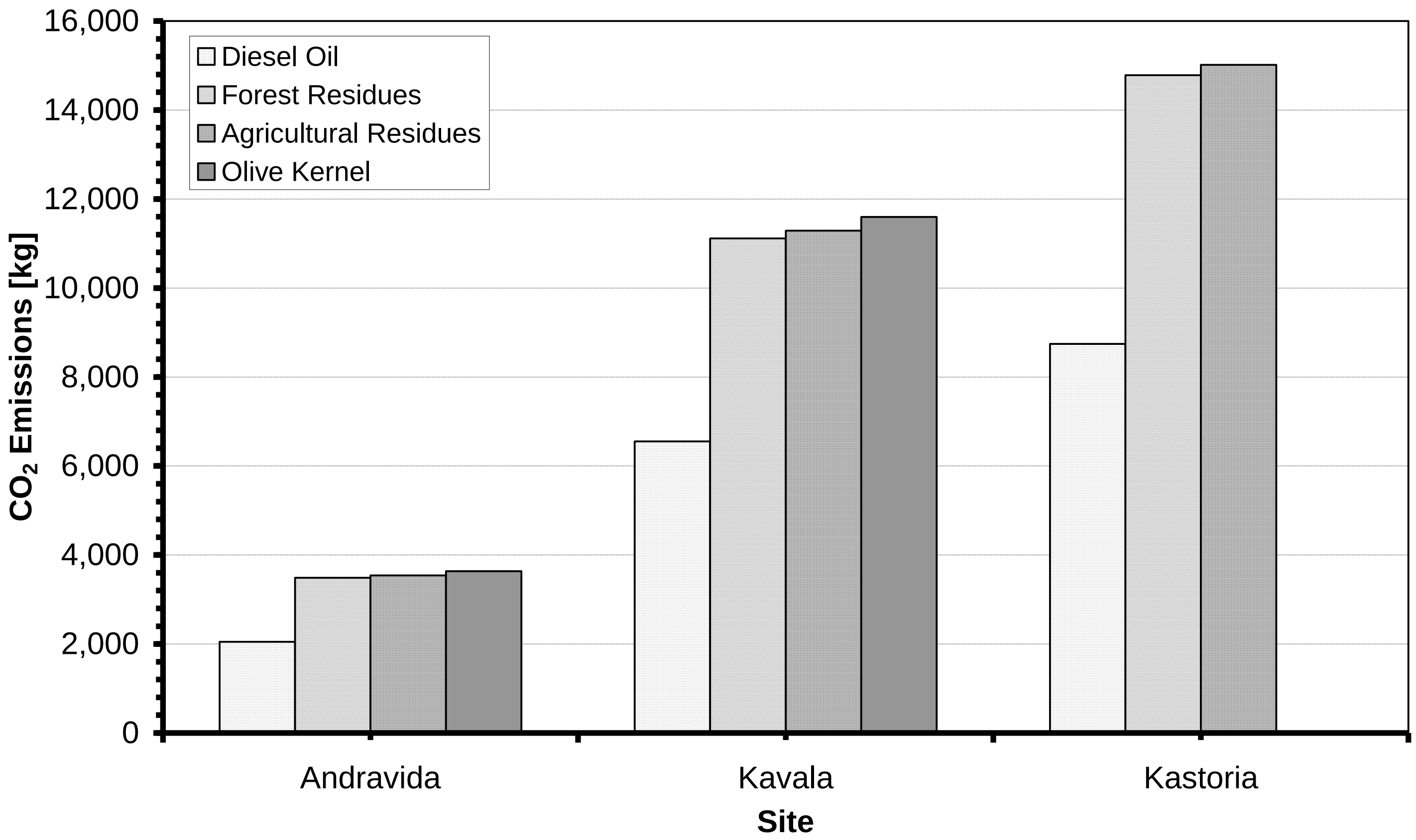

Figure 5: CO_2 emissions for diesel oil and biomass fuels

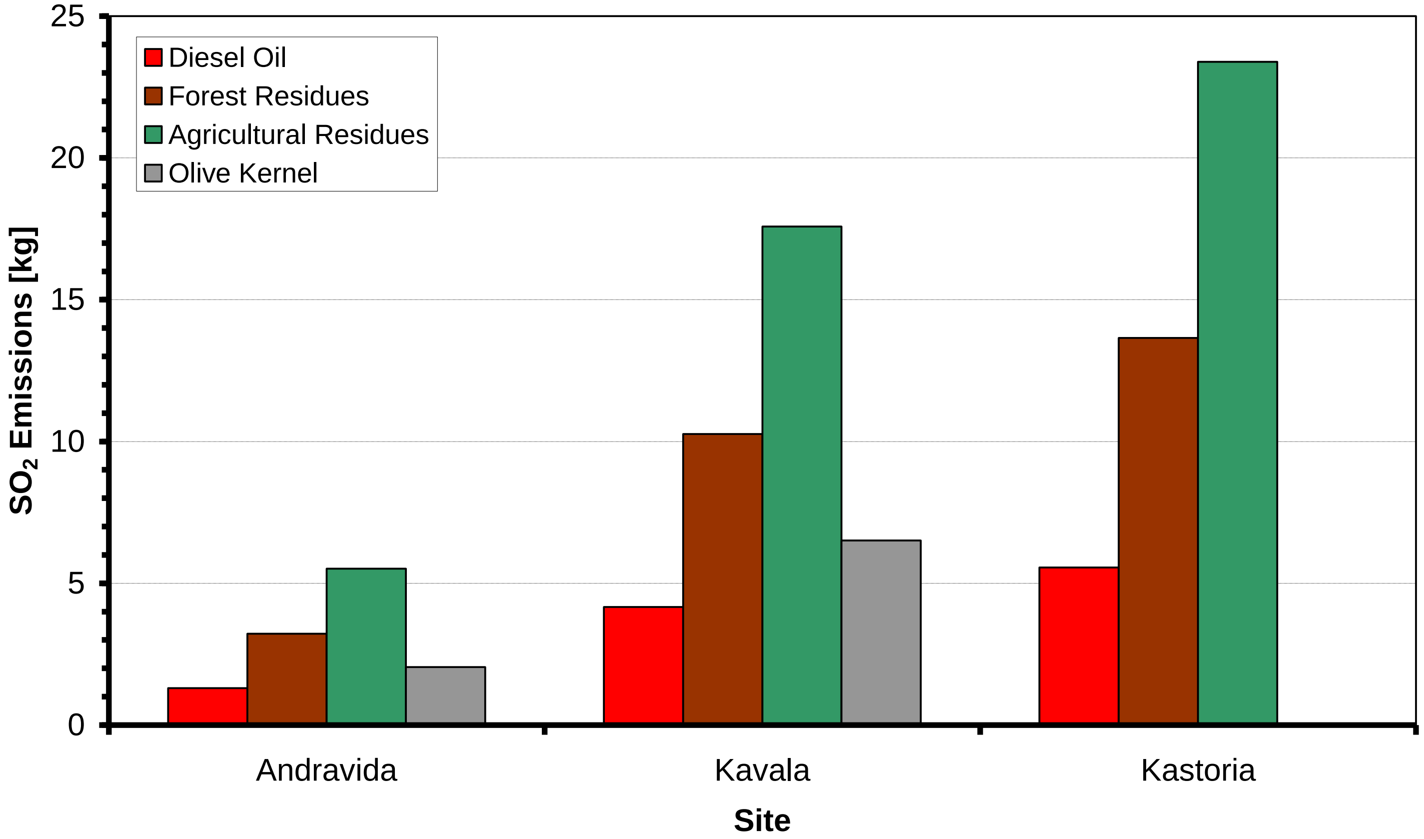

Figure 6: Comparison of SO_2 emissions for domestic heating oil and biomass fuels on the representative sites

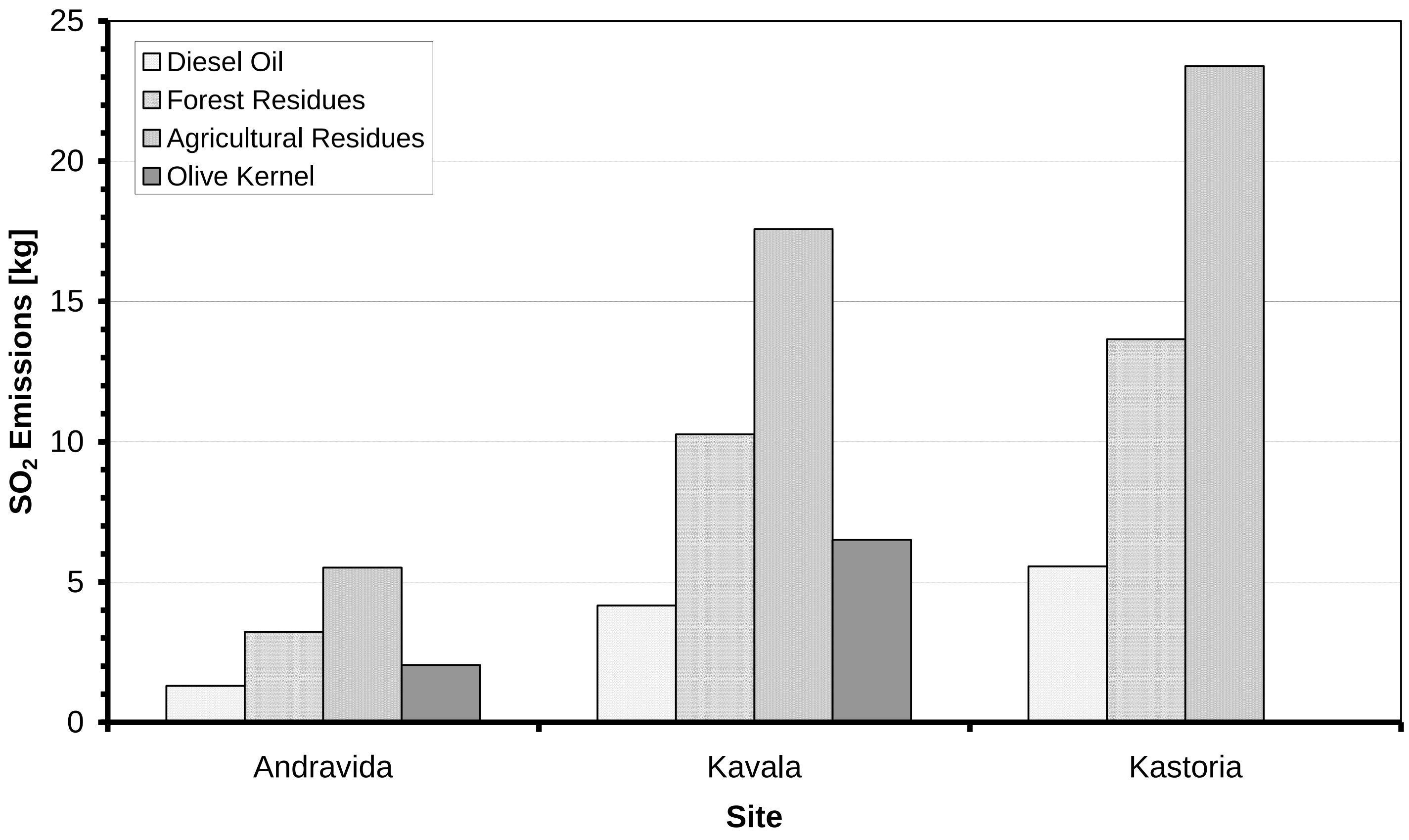

Figure 6: Comparison of SO_2 emissions for domestic heating oil and biomass fuels on the representative sites

Figure 01
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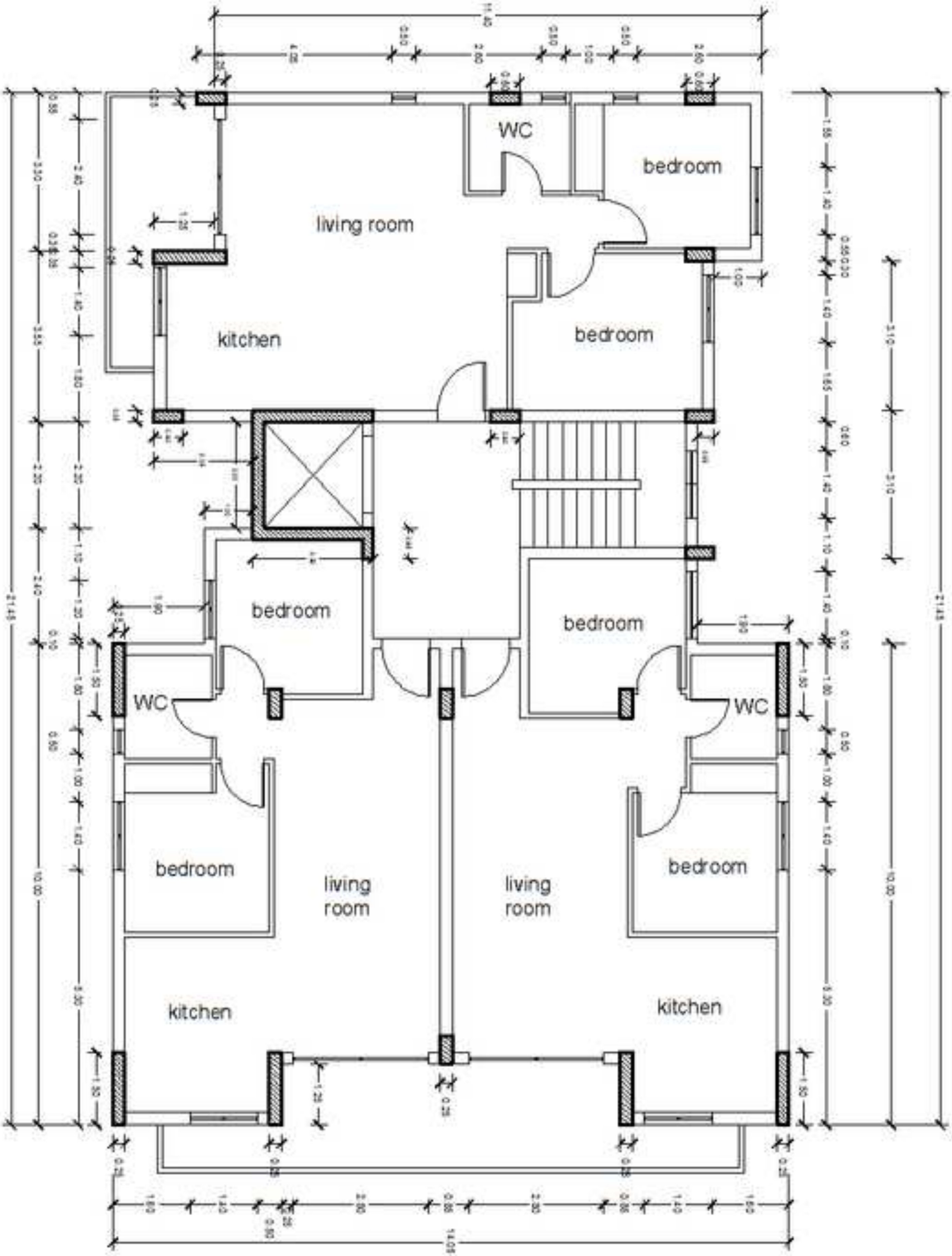

Figure 02

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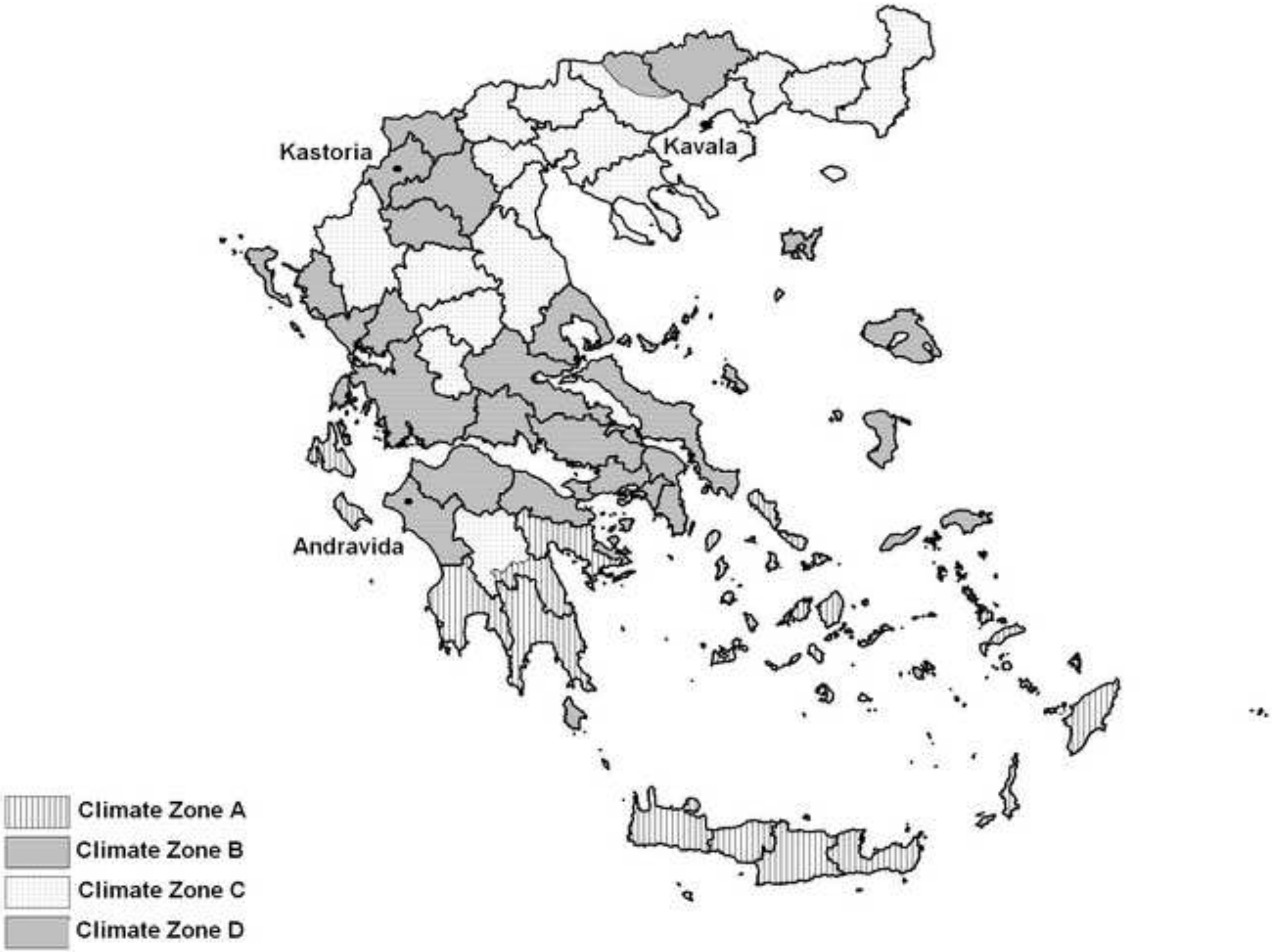

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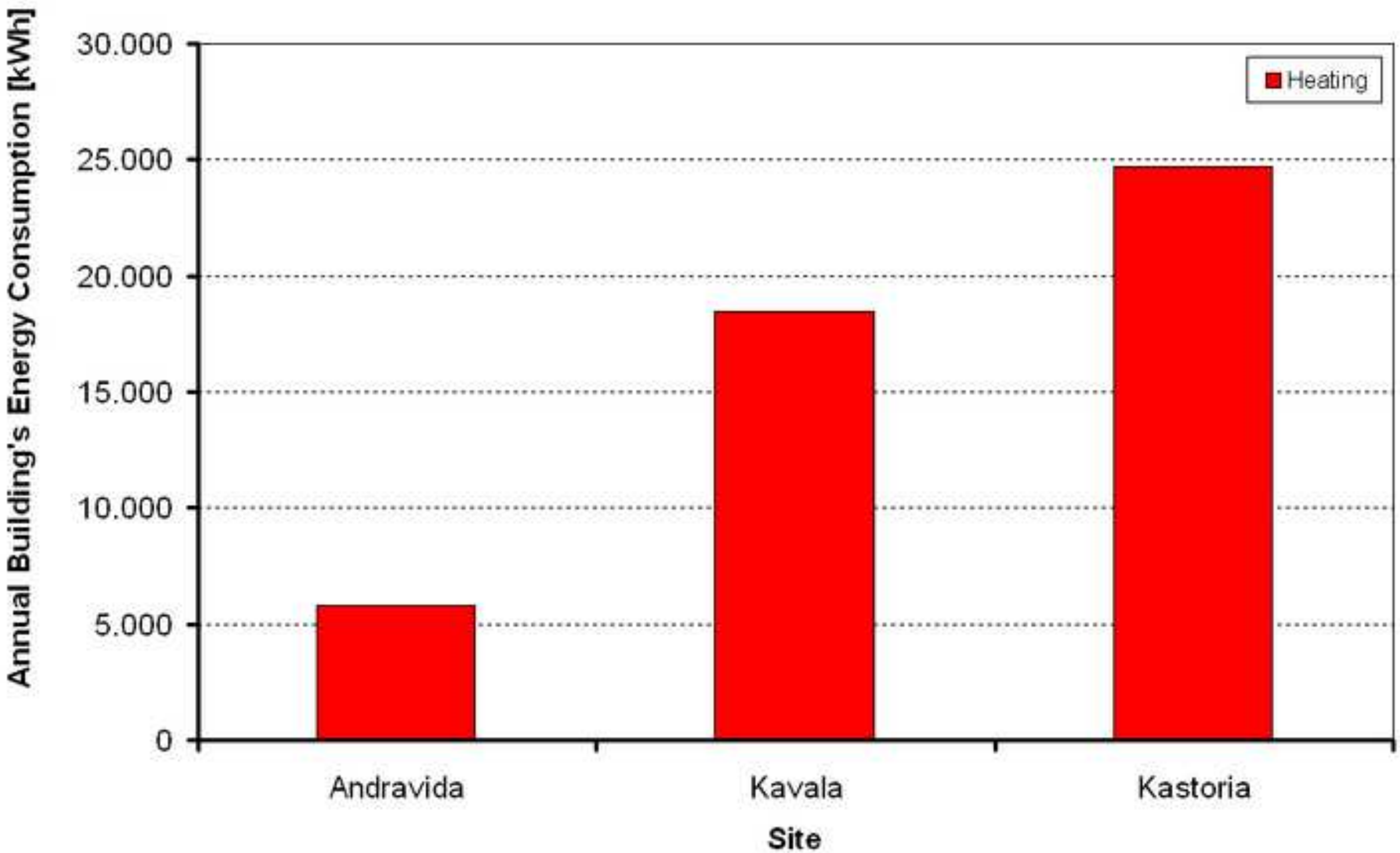

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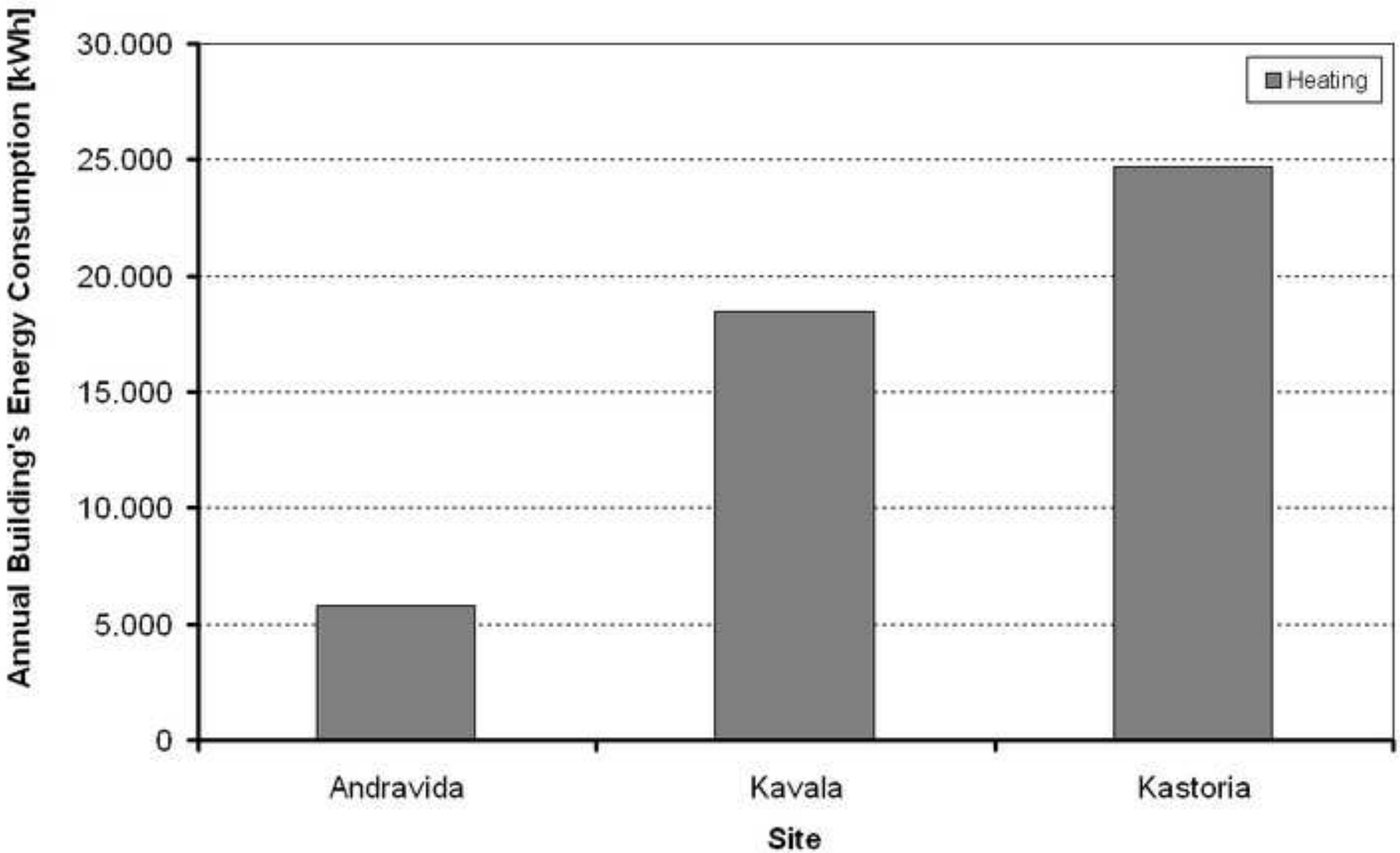

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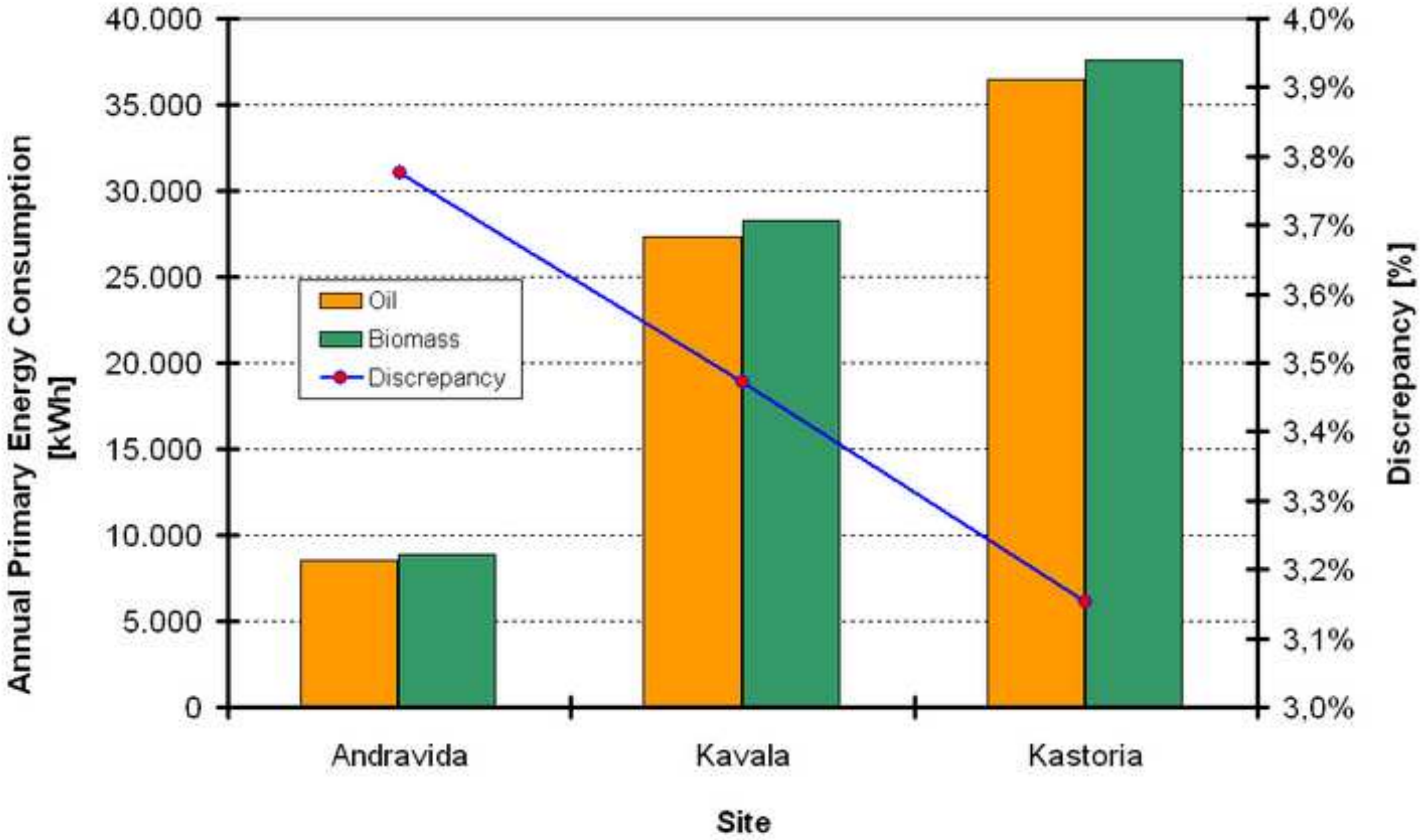

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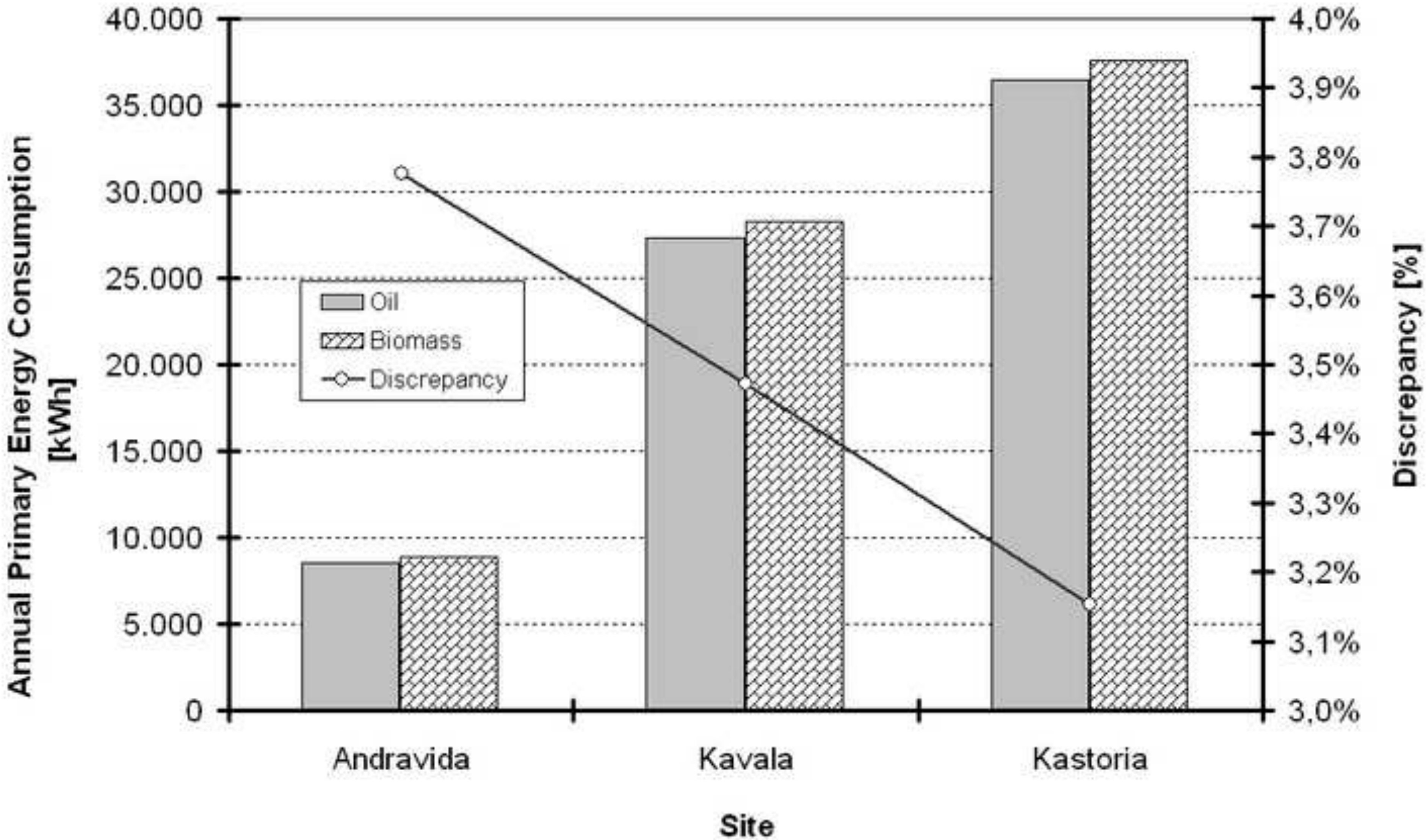

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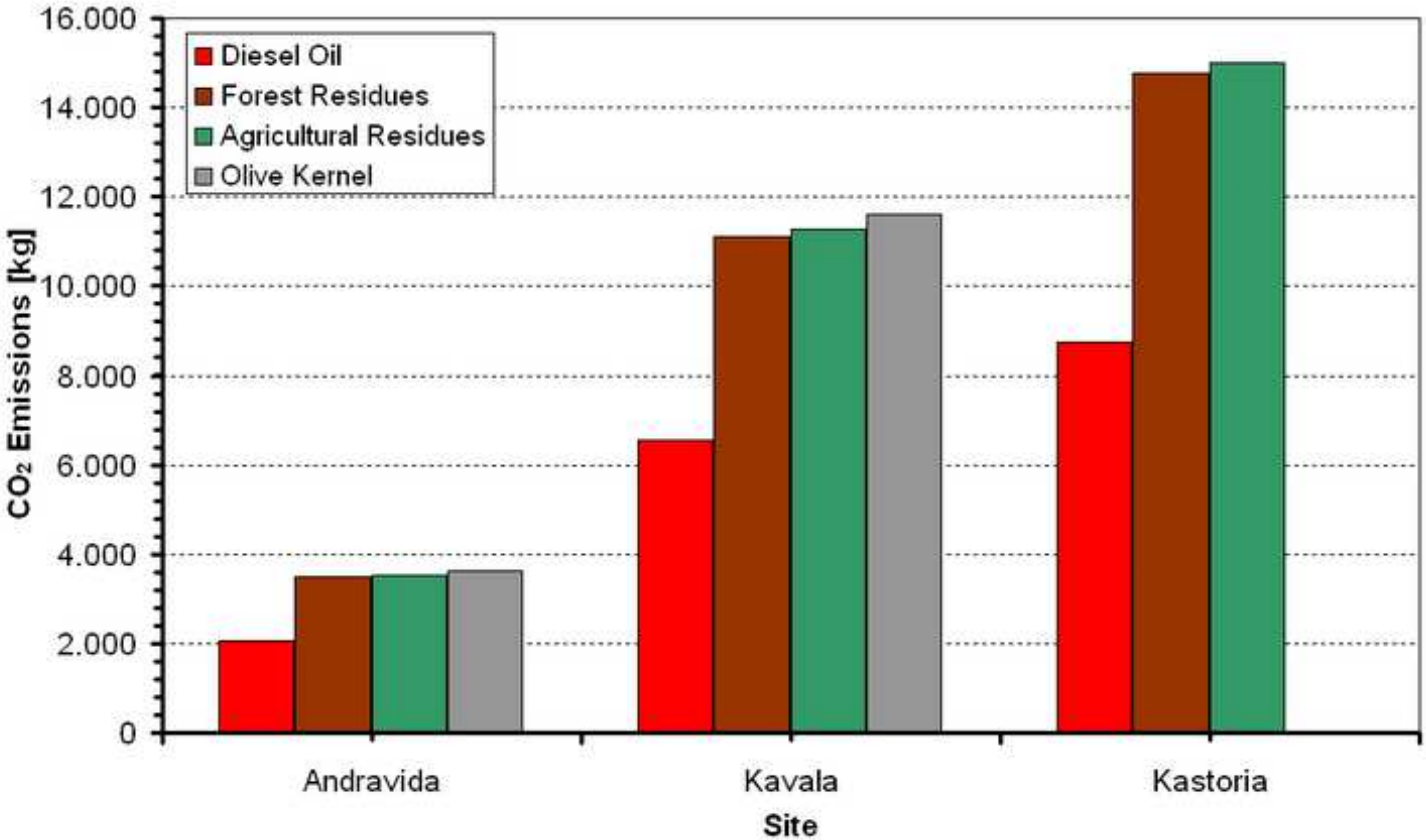

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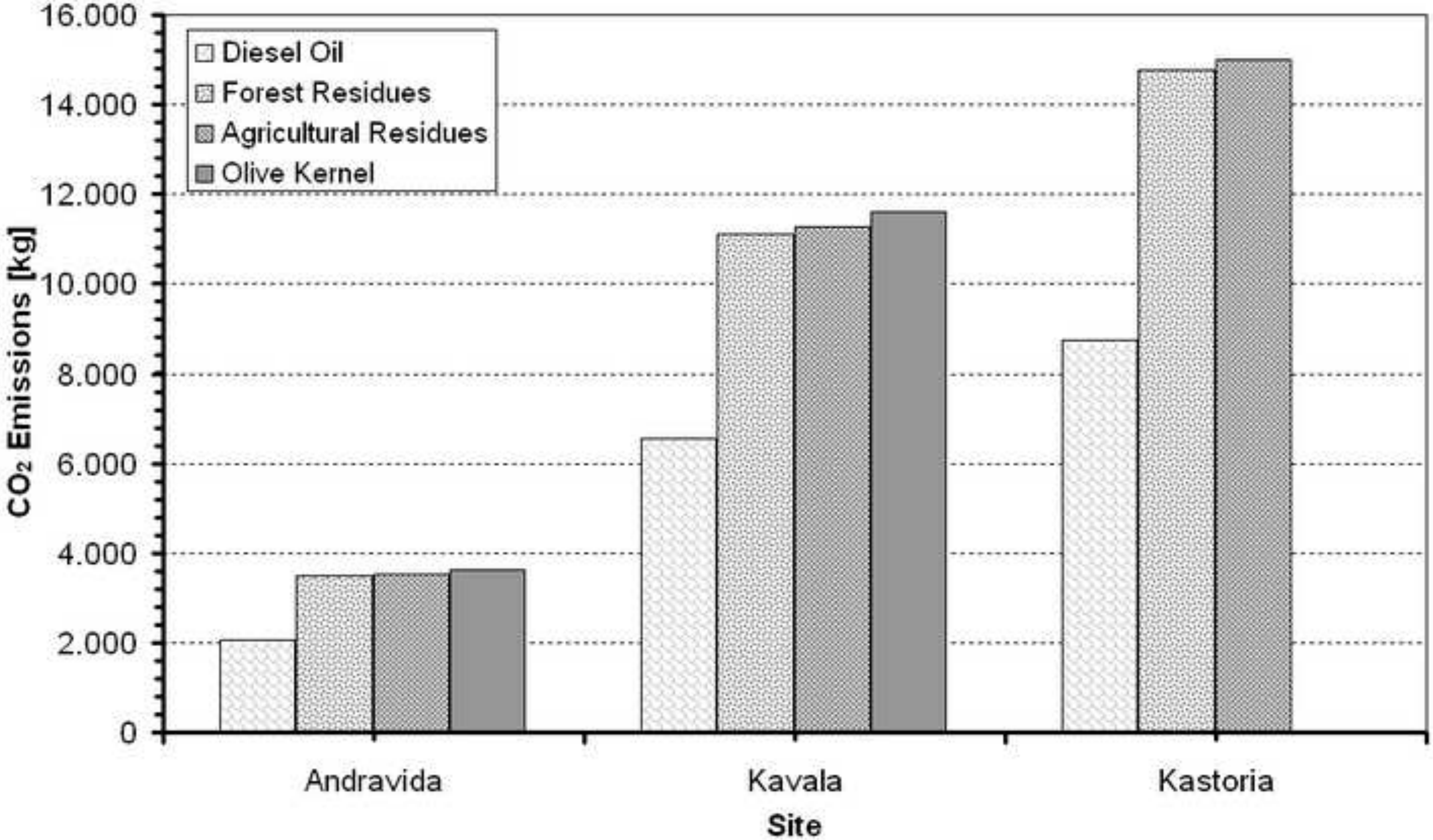

Figure 06 in colour

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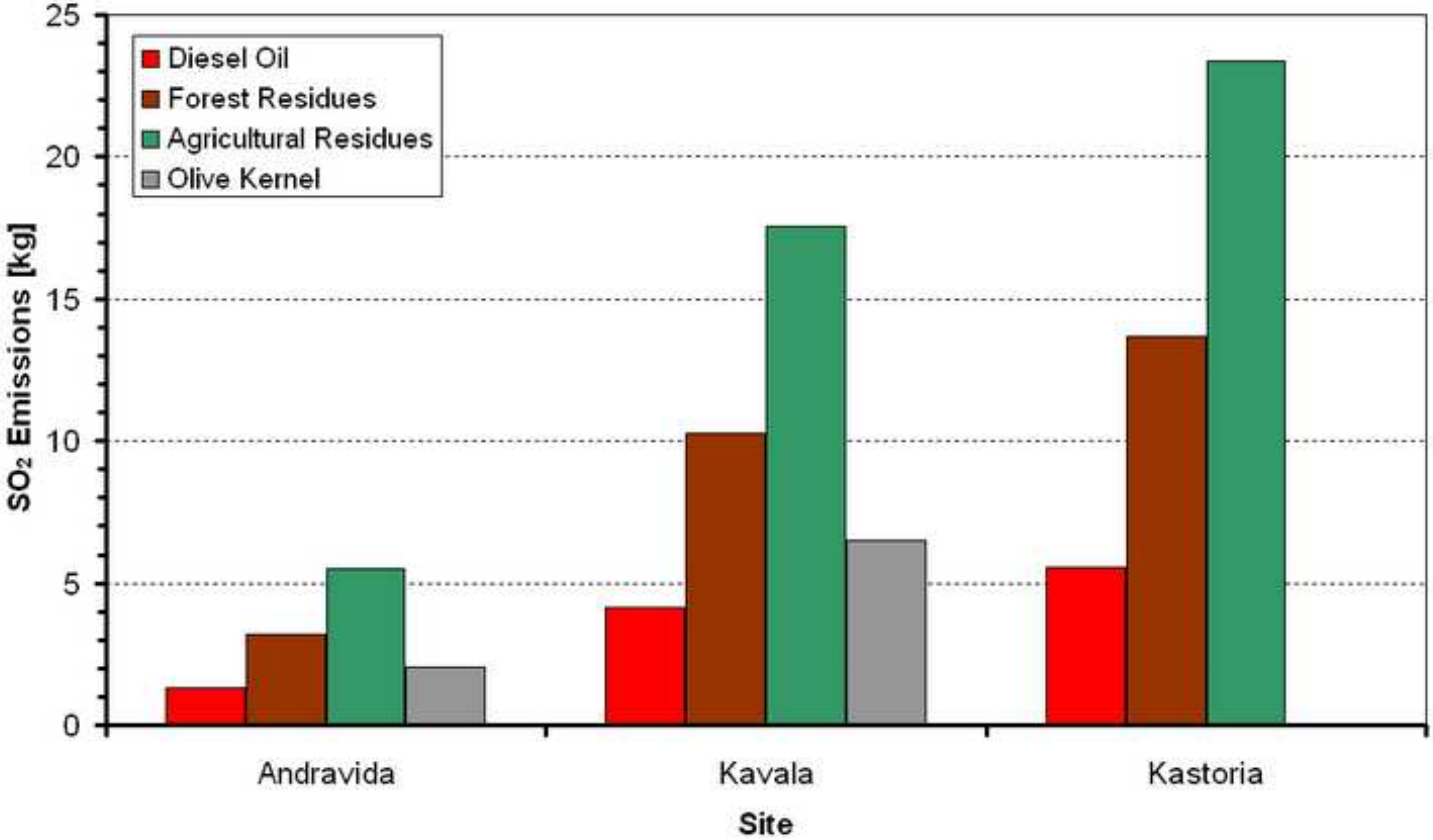

Figure 06 black and white
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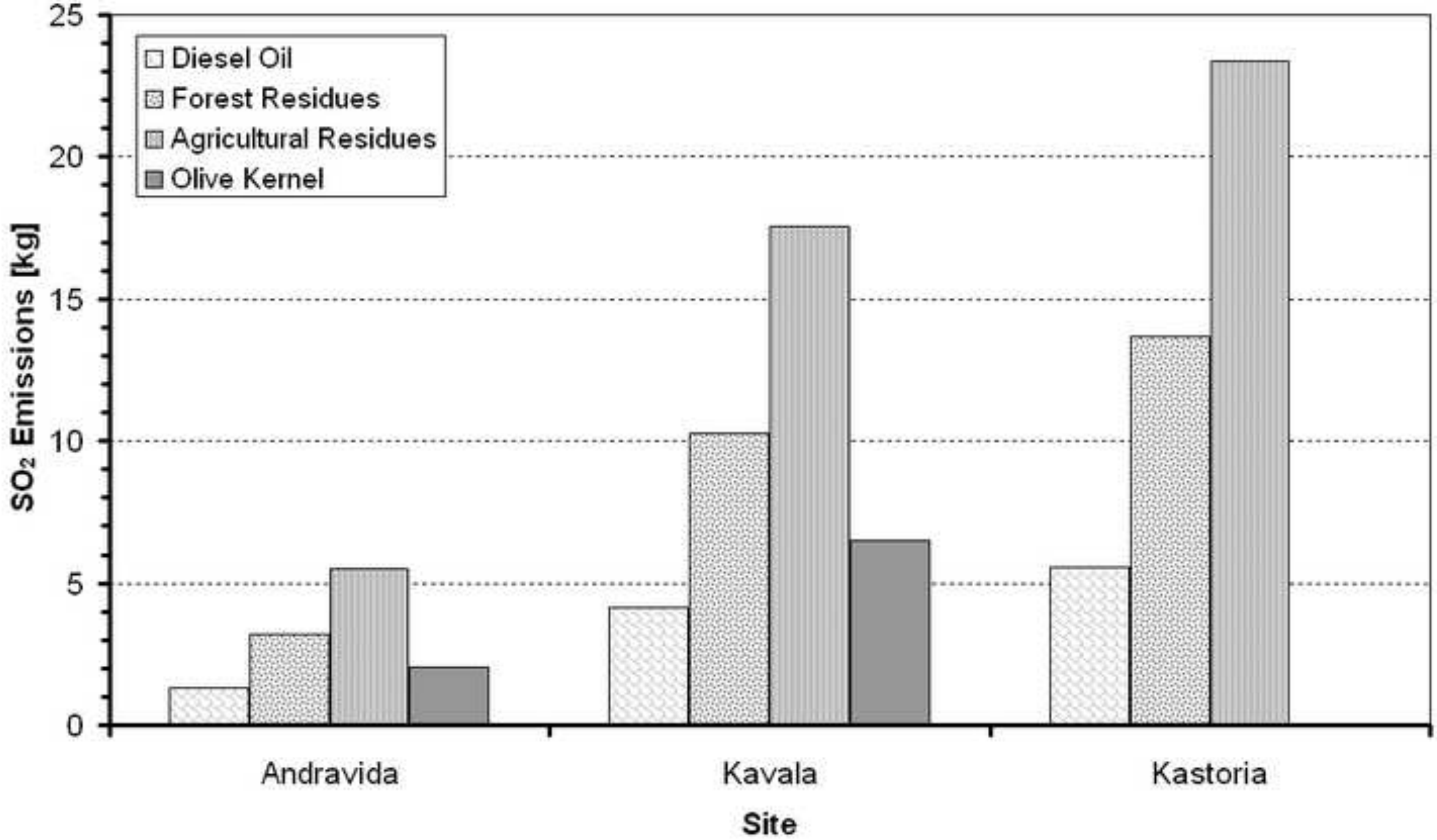

ECM-D-12-00141 General comments :

Comment 1: Thank you for sending the manuscript, "The exploitation of biomass for building space heating in Greece: Energy, Environmental and Economical Considerations" to Energy Conversion and Management for publication. I apologize for the lengthy period of review. The review is now complete, and unfortunately, it is not completely favorable. Therefore, the paper cannot be published in Energy Conversion and Management as it is presented. I have consolidated the review comments below in the hope that they will be helpful to you in modifying the paper.

Action taken: The manuscript has been revised according to the reviewers' comments, as well as the editor's advice.

ECM-D-12-00141 Editing comments:

Comment 1: I have consolidated the review comments below in the hope that they will be helpful to you in modifying the paper.

Action taken: A list of the modifications-changes has been made and submitted in this manuscript, based on the reviewers' comments.

Comment 2: In the revision process we would like to request you return three files:
(1) Please submit a list or table of changes (or your rebuttal) against each point raised when you upload your revised article and upload this as your 'Response to Reviewers' file/doc - note our system will not allow you to complete the resubmission process without this file.
(2) Also please highlight any revised text using coloured highlighting in a separate word document. This will enable the Editor /Reviewers to identify the amendments and subsequently make faster decisions on the revisions.

(3) In addition we request one final file, a 'clean' word document of the revised manuscript without any annotations, highlighting or comments, in font 10 or 12 pt with double line spacing.

Action taken: The above mention requested files returned according to the editor's advice under the file names:
(1) Michopoulos et al_response_to_the_reviewers.doc
(2) Michopoulos et al_revised_highlighted.doc
(3) Michopoulos et al_revised.doc

ECM-D-12-00141 1st Reviewers' comments:

Major Comments

Comment 1: Forest residues emissions (CO_2: 109.30, CO: 4000, NO_x:120), CO emissions are 100 time than diesel combustion and NO_x emissions are almost two times.

- CO combines with the hemoglobin in the blood and consequently increases stress on those suffering from cardiovascular and pulmonary diseases.
- NOx causes acid rains, bio-depleted oxygen.

In this manuscript, bioresidual fuels are using in residential buildings. This will causes health problems. How this present system is feasible for residential buildings ?????

Answer: CO and NO_x emission factors was taken from the CORINAIR database, Ref. 42, and as it is stated on page 12, lines 14-15, their validity for the Greek energy system is still unknown. Moreover on page 13 authors state: "*It has to be noted however that (a) the reliability of the emission factors of Corinair is limited and (b) there are technological solutions of advanced biomass combustion systems (e.g. systems based on catalytic combustion) that can produce significantly lower emissions [43], and (c) these systems are not* *included in Corinair database.*" The Greek legislation (Ministerial Decision 189533/2011), however, allows the exploitation of bio-residual fuels even though on the urban areas as it came up as an obligation for the European Directives, e.g. 2009/28/EC, 2010/31/EC, etc.

Comment 2: Complete emissions analysis data for Agricultural residues and Olive kernel are not provided in the manuscript (Table 7). Since CO_2 emissions for Agricultural residues and Olive kernel are higher than forest residuals, hence reviewer or reader can assume emissions from these two residuals are higher than forest residual.

Answer: On page 12 lines 8-11, authors state: "*Based on the chemical analysis of the three residual biomass types, presented in Table 5, the lower heating value (LHV) of each type was determined (Table 6) and then, based on the carbon and sulfur content, the CO_2 and SO_2 emission factors were calculated, presented in Table 7*". Unfortunately, the existing literature does not include emission factors of the CO, NO_x, PM and NMVOC for Agricultural residues and Olive kernel. In general the emissions for solid fuels are based on the chemical composition and granulometry of the fuel, as well as on the technology of combustion system. Hence it is not correct to assume that Agricultural residues and Olive kernel have higher emissions than Forrest residues.

Comment 3: 1 €/L for diesel oil, 0.25 €/kg, 0.15 €/kg, and 0.08 €/kg for forest residues (pine sawdust pellets), agricultural residues, (corn stalks) and olive kernel, respectively. Given in manuscript.

However, the diesel fuel energy density (energy/kg fuel) is high hence transportation is easy and less cost. For the case of bioresidues huge transportation is required and it is more cost effective. Also the process (making powder or pallets) cost also increases. By considering these all parameters, cost comparison of diesel fuel and bioresidual fuels to provided in the revised manuscript.

Answer: The present work took place under the scenario that the biomass is utilized as feeding material in residential heating systems in the form of pellets, which are produced and consumed locally, as it is stated on page 10 lines 17-19: "*It is reminded that, in the framework of this study, the exploitation of the non edible residual biomass is examined only locally.*" Moreover the price of the suggested alternative fuels (agricultural and forest residues) examined in the present work has been taken from the local markets during the winter of 2011-2012; thus represents the actual cost that housekeepers are forced to pay during the aforementioned period.

Comment 4: Figure captions are missing from Fig 3. In list of figures the total number of figures are given 6 only. But total 10 figures are provided in the revised manuscript.

Answer: Figure captions are provided on page 32. There are 6 figures in total of which figures 3-6 has been submitted in color and black and white form as it is required by the journal's guidelines by the time of its initial submission (February 2012).

Comment 5: Conclusion section is not up to the detailed.

Action taken: Conclusions' section was updated and presented in the revised manuscript.

Minor Comments

Comment 1: This work is most practical way of application of combustion system in a human useful way with biofuels. Good written and aim of the present work is so appreciable.

Answer: Thank you very much.

Comment 2: Page No 4 of 42, line number 20 the word "rector" should be "sector"

Action taken: The word has been revised according to the reviewer's comments.

Comment 3: Dimensions in the Fig. 1 is not readable, font size has to be increased

Action taken: The figure has been revised according to the reviewer's comments. Authors apologize for the inconvenience.

Comment 4: In page no 6, "The floor is paved with marble with the use of cement mortar above a 0.04 cm layer of lightweight concrete. "It might be 0.04 m, instead of 0.04 cm". verify it once.

Action taken: Reviewer's comment taken into consideration and the unit has been corrected according to advice.

Comment 5: Definition of "Thermal transmittance" is not given in the manuscript.

Answer: Following the reviewer's wish, the definition of thermal transmittance has been added to the manuscript, on page 7.

Comment 6: In section 2 Description of the Building, apartments A, B and C are defined, in the same section zone B, C and D also defined without any predefinition. In the next section 3.1 Description of the Greek climatic conditions, Climate zone of A, B, C and are defined. This is confusion the reader, hence authors should take care in the proper definition of apartments, zones and climate zones.

Action taken: Apartments name's has been changed to 1, 2, and 3 instead of A, B, and C.

Comment 7: Section 3.3: "Andravida (Zone B) is 35.5 kW, with 49.2% of it being ventilation losses, 40.1 kW in Kavala (Zone C), with 49.3% ventilation losses and 45.6 kW in Kastoria (Zone D), with 47.5% of it being ventilation losses. The total cooling load was calculated at 31.2

kW in Andravida, appearing at the time slot 17:00-20:00 in July, at 28.9 kW in Kavala, appearing at the time slot 17:00-20:00 in August and 23.3 kW in Kastoria, appearing at the time slot 17:00-20:00 in July" is written.

In Table 3, it is mentioned that November-March is heating period and Mid of May-October is cooling period. But in section 3.3, heating load given for time period of July and August. Why this condition is considered. Usually, maximum heat load requirement condition should be considered. Authors have to give clarification why this condition is considered in this section.

Answer: For the scope of clarification, a part of Section 3.3 is reproduced here: "*According to the calculation results, the total heating load of the building in Andravida (Zone B) is 35.5 kW, with 49.2% of it being ventilation losses, 40.1 kW in Kavala (Zone C), with 49.3% ventilation losses and 45.6 kW in Kastoria (Zone D), with 47.5% of it being ventilation losses. The total cooling load was calculated at 31.2 kW in Andravida, appearing at the time slot 17:00–20:00 in July, at 28.9 kW in Kavala, appearing at the time slot 17:00–20:00 in August and 23.3 kW in Kastoria, appearing at the time slot 17:00–20:00 in July*."

In this section authors describe the calculation procedure of heating and cooling load of the reference building on the three examined regions. At the beginning of the second paragraph, which is also presented above, authors refer to the design heating load, while in the last sentence the design cooling load is discussed. It is clearly stated that the cooling loads appear on the summer months, July or August, which are in line with the statement on Table 3. Additionally the heating loads presented in the first sentence are referred to the winter period operation which is from November to March, (Table 3).

Comment 8: Reviewer suggests avoiding putting huge mater in parenthesis.

Action taken: Manuscript has been revised according to reviewer's comment.

Comment 9: <IOTA>n Greece, corn is considered a significant crop, its cultivation being widespread all over the country; the 2009 annual production reached 1.578 *109 kg, while for 2010 a 1.45*109 kg was foreseen. The numbers are showing decrease in corn crop production, however in the manuscript authors are written "widespread".

Answer: The annual production of a crop depends not only on the area of land fields in which it is cultivated, but also on the meteorological conditions of each period. The cultivation of the corn is widespread as it is cultivated all over the Greek tertiary.

Comment 10: Text in the section of Environmental impact is looks more about introduction about crops in Greece. Better to move some text in the introduction section.

Action taken: Section has been relocated/revised according to reviewer’s comment.

ECM-D-12-00141 2nd Reviewers’ comments:

General: This paper describes the exploritation of biomass for building space heating in Greecc and analyze the energy, environment and economy. It is meaningful to energy policy of Greece, and it is worthy of publishing in the journal of <<Energy conversion and management>>.

Minor revisions

Comment 1: Some calculatin process such as the amoumt of CO_2 emission and SO_2 emission should be given clearly.

Action taken: The appropriate revision has been made and the explanation concerning the calculations of CO_2 and SO_2 has been inserted in the manuscript. Please, see page 12, last paragraph.

Comment 2: What is the disadvantage on the sustitution of diesel oil with biomass in Greece? it should be described explicitly.

Action taken: The disadvantages of the substitution of diesel oil with biomass have been discussed in a new session, session 5.4 that has been added in the revised manuscript.

ECM-D-12-00141 3nd Reviewers' comments:

General: The exploitation of biomass for building space heating in Greece: Energy, Environmental and Economical Considerations " by Michopoulos et al is based on a very important concept of use of biomass for the building space heating and holds merit as it significantly reduce the pressure on the use of fossil fuels.

The manuscript seems interesting even to a non-expert and fits very well into the scope of the journal. The text structure is OK and the overall illustrations and presentation of the manuscript is excellent.

I have only few minor concerns with regard to the Manuscript as follows:

Comment 1: The authors need to address the cost effectivity in terms of using Biomass over the conventional processes in Greece. It would be appropriate to draw conclusions regarding Pros and cons of the above process over each other and simultaneously mitigating the green house gas emissions, reduction in CO2 emission etc making the manuscript moré reader friendly and easy to understand even to a non-expert in the field.

Action taken: A new session, namely Social Impact, has been added in the revised manuscript that includes an extensive discussion based on the reviewer's suggestion.

Comment 2: The manuscripts should also mention in a paragraph or two about other social and environmental concerns regarding the preferred use of Biomass over the conventional oils.

Action taken: A new session, with the title Social Impact, has been added in the revised manuscript. It includes the discussion on the social and the environmental concerns of substituting diesel-oil fuel with biomass.

Comment 3: Authors need to clarify regarding the EU Directive in Greece legislation 2002/91/EC whether it is active and also the positive global effects of using biomass over conventional fuels.

Action taken: A new session, namely Social Impact, has been added in the revised manuscript in which a short discussion based on the European building's directives and the biomass usage is now included according to the reviewer's suggestion.

Comment 4: Authors require to make conclusions more precise with a future directive on exploring the exploitation of Biomass.

Action taken: Conclusions has been revised according to the reviewer comment.

Comment 5: Authors also need to strictly adhere to the Journal guidelines for the Reference style as it is not strictly followed at places.

Action taken: The references' style checked, updated and corrected according to the printing journal's style.