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Renewable energy production in Artvin Çoruh University ANG Botanical Garden: Potential, application and challenges

Artvin Çoruh Üniversitesi ANG Botanik Bahçesi'nde yenilenebilir enerji üretimi: Potansiyel, uygulama ve zorluklar

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Abstract

This study evaluates the capability of renewable energy sources (wind, solar and biomass) to meet the energy needs of Artvin Coruh University Ali Nihat Gokyigit Botanical Garden.. As a result of the study, it has been determined that the wind speed in the region is insufficient for electricity generation from wind energy, as 0.0845 kW/h. In the analyses performed on the PVsol environment for the potential of a PV system, it has been concluded that 256.9 MWh of energy could be generated annually. The economic analyses resulted in the payback period of the PV system being calculated as 8.8 years.. It was also suggested that the annual average of 3500 - 5000 kg of pruning waste could be utilised by elemental analysis and incineration or used for biogas production by anaerobic digestion together with food waste (27 tonnes/year). The study aims to raise awareness for on-site energy production by using local resources and thus reducing energy costs.

Keywords: Renewable energy, wind energy, solar energy, biomass energy, Weibull distribution, PVSOL

Öz

Artvin Çoruh Üniversitesi Ali Nihat Gökyiğit (ANG) Botanik Bahçesi'nin enerji ihtiyacını karşılamak amacıyla bu çalışma, yenilenebilir enerji kaynaklarının (rüzgar, güneş ve biyokütle) değerlendirmesini sunmaktadır. Yapılan çalışmalar sonucunda rüzgar enerjisi potansiyelinin düşük olduğu (0,0845 kW/saat) tespit edilirken, PVSOL simülasyon progrmaı ile gerçekleştirilen güneş enerjisi projesi, yıllık 256,9 MWh enerji üretimi ve 8,8 yıllık geri ödeme süresiyle ekonomik olarak uygulanabilir bulunmuştur. Ayrıca, yıllık ortalama 3500 – 5000 kg olan budama atıklarının elementel analizi yapılarak yakma yoluyla değerlendirilebileceği veya yemek atıklarıyla (27 ton/yıl) birlikte anaerobik çürütme ile biyogaz üretimi için kullanılabileceği önerilmiştir. Çalışma, yerel kaynakların kullanılarak yerinde enerji üretimi yapılması ve böylece enerji giderlerinin azaltılmasına yönelik farkındalık oluşturmayı hedeflemektedir.

Anahtar Kelimeler: Yenilenebilir enerji, rüzgar enerjisi, güneş enerjisi, biyokütle enerjisi, Weibull dağılımı, PVSOL

1 Introduction

Energy is among the most basic requirements of life, and the quest for meeting energy demand is as old as the beginning of life.. Over time, the diversified and increasing use of energy has begun to take its place at the center of civilizational competition with the industrial revolution.. The increase in the world population and the acceleration of industrialization have increased energy consumption and made the environmental impacts of the widely used fossil fuels even more critical.. Energy consumption is expected to double in 2035 compared to 1998 and triple in 2055. Non-renewable fossil fuels and nuclear energy pose a serious threat to the environment and human health. Especially the transportation sector (95% oil dependency) is an important dimension of this problem and is expected to increase in the coming years [1]. As a solution to these problems, governments are implementing policies that encourage the use of renewable energy sources and taking various measures to increase energy efficiency and reduce carbon emissions.

In recent years, many studies have focused on the use of renewable energy sources in public buildings in order to meet the increasing energy demand and ensure environmental sustainability. These studies examine the evaluation and integration of different sources such as solar, wind and biomass energy [2]-[7]. A study conducted in Poland [7] has proven that energy savings of up to 80% and significant CO2 emission reductions can be achieved by reducing energy demand through thermo-modernization of school buildings and the use of renewable energy systems. A study examining data for Türkiye for the period 1990-2020 [6] showed that economic growth, urbanization and industrialization increased carbon dioxide emissions, but renewable energy use, agricultural productivity and forest areas reduced emissions. . The analysis revealed that a 1% increase in economic growth, urbanisation, industrialisation and tourism would increase emissions by 0.39%, 1.22%, 0.24% and 0.02% respectively, while an increase in renewable energy, agriculture and forestry would decrease emissions by 0.43%, 0.12% and 3.17% respectively. Various studies have been conducted on the use of renewable energy in

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public buildings in Türkiye. In [5], an economic analysis for solar and wind energy systems has been made for the Çanakkale 112 Emergency Call Center, and the feasibility of these systems has been proven by the resulting short payback periods after the analyses. [4] determined the most suitable configuration for a hybrid solar energy system at Eskişehir Technical University. [3] analysed the energy saving potential of solar energy and heat pump systems at Yalova University and showed that significant energy savings can be achieved. [2] analysed the implementation of photovoltaic systems at Harran University Osmanbey Campus. These studies support the technical and economic feasibility of renewable energy integration in public buildings in Türkiye. Studies in Croatia [8], Russia [9] and Türkiye [10] address the utilisation of waste for sustainable energy production. The Croatian study examines the use of waste as biogas production and fertiliser, the Russian study examines the heat and electricity generation potential of urban wood waste, and the Turkish study examines different methods of energy recovery from household waste. These studies emphasise the importance of utilising various waste sources for energy production.

A review of the literature reveals that studies have generally evaluated a single renewable energy source or a limited number of sources, and the utilisation of biomass has generally been limited to waste incineration or limited-scale biogas production. The originality of this study lies in its assessment of multiple renewable energy sources (solar, wind and biomass) with an integrated approach in the Ali Nihat Gökyiğit (ANG) Botanical Garden of Artvin Çoruh University (AÇÜ). In particular, the originality of the study lies in evaluating the potential of local biomass resources such as pruning waste and food waste for biogas production both by incineration and anaerobic digestion. In conclusion, the aim of this study is to propose an economically feasible and environmentally friendly renewable energy system design that can meet the energy needs of the ANG Botanical Garden by providing a more comprehensive approach compared to the existing literature and to set an example for other public institutions.

2 Materials and methodology

2.1 Study Area

Artvin Çoruh University was established by Law No. 5662 dated 17 May 2007 and has campuses in Artvin Centre (Seyitler Campus, Central Campus and ANG Botanical Garden) and in Arhavi, Hopa, Borçka, Şavşat and Ardanuç districts. The focus of this study is the 143 decare ANG Botanical Garden, which is located within the borders of Salkımlı village of Artvin Centre and opened in 2022 (Figure 1). The aims of the garden include the conservation and promotion of plant gene resources in Türkiye, scientific research in various fields, and the collection of plants used for different purposes in thematic gardens. The garden has indoor areas such as 1,164.32 m² Administrative and Research Building, 390.41 m² Café, 241.5 m² Conference Hall, 1064.38 m² Guest House, 452 m² R&D greenhouse and 200 m² production greenhouse. The electricity installed power of the garden is 250 kW and the contract power is 150 kW. Due to its distant location from Salkımlı village, it is far away from the existing low voltage network. Although the current 150 kW contract power is sufficient for the time being, additional grid investments may be required to meet future energy needs.

Figure 1. ANG Botanical Garden.

2.2 Material and method

2.2.1 Wind energy

The assessment of the wind potential for Artvin province has been performed with the wind rose data (Figure 2) created using Lakes Environmental software. The analysis showed that the dominant wind direction is west and west-northwest, and wind speeds are mostly between 0.50-3.60 m/s.. The average wind speed is determined as 1.87 m/s, and 12.09% of the data corresponds to calm wind conditions, which is below 0.50 m/s.. Wind speeds above 11.10 m/s are rarely observed. These results reveal that low wind potential prevails in the region.

In the analysis of wind data required for the calculation of the energy to be obtained from a wind turbine, probabilistic approaches such as Weibull, Rayleigh, Gamma and Lognormal are used to account for the variable nature of the wind. In the literature, the Weibull distribution function [11], which has the highest accuracy, is commonly preferred. This function is defined over the wind speed (v), shape parameter (k) and scale parameter (c) and is given in Equation (1).

$$f(V,k,c)=\frac{k}{c}.\left(\frac{V}{c}\right)^{k-1}.e^{-\left(\frac{V}{c}\right)^{k}} \quad (1)$$

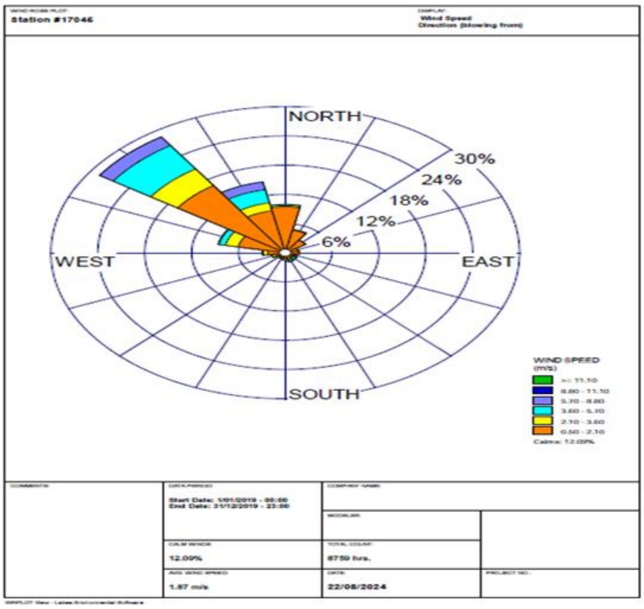

Figure 2.Wind rose belonging to Artvin city center.

Weibull distribution parameters (shape and scale) were calculated with MATLAB program using hourly wind speed data for 2017-2018 obtained from Artvin Meteorology Directorate. In the analysis, 12-month data covering January-December have been used, and instead of a total of 8760 hours of data (365 days x 24 hours), 8256 data were used due to measurement deficiencies (Table 1). Hours where measurements could not be made and wind speeds with a value of "0" were excluded from the analysis.

Table 1. Number of monthly wind speed data used for Weibull distribution analysis (Artvin Meteorology Directorate).

Months	**Number of hourly data**
January	688
February	649
March	728
April	696
May	730
June	695
July	744
August	726
September	602
October	704
November	646
December	648
Total	**8256**

Wind turbine power curves are obtained by manufacturers as a result of tests conducted at different wind speeds and are presented in catalogs [12]. Considering the low average wind speeds obtained for Artvin province, a small turbine with a power of 5 kW (Soyut Wind 5 kW model) was selected. The power curve and other technical specifications of this turbine were taken from the manufacturer's catalog and are presented in the Appendix A (Figure A1 and Table A1).

Wind source and wind turbine are required for electrical energy production using wind energy. The power of the wind turbine is the function (P(v)) that varies with the wind speed (v). Using the Weibull distribution function (f(v)), the wind turbine power is calculated by the integral in Equation (2) [13].

$$P=\int_{0}^{\infty} P\,(v)f(v)dv \quad (2)$$

Wind turbines start operating above a certain cut-in speed (V_{Cin}) and the power generation increases until the nominal speed (Vn). At the nominal speed (V_n), the nominal power (P_n) is generated. At higher speeds, the power generation remains constant. At wind speeds above the cut-off speed (V_{Cout}), the turbine cuts the generation off [13]. Due to the variability of wind speed, the average power production (P_{mean}) is calculated using the Weibull distribution as shown in Equation (3).

$$P_{mean}\rightarrow\begin{cases} v<V_{Cin}\rightarrow\ P_{mean}=0\\ V_{Cin}\le v<V_n\ \rightarrow P_{mean}=P(v)\\ V_n\le v<V_{Cout}\ \rightarrow P_{mean}=P_n\\ V_{Cout}\le v\rightarrow P_{mean}=0\end{cases} \quad (3)$$

The ratio of the energy produced during a certain period to the energy that can be obtained by continuous nominal power generation gives the capacity factor. The capacity factor is calculated by Equation (4)-(7) [11].

$$CF=\frac{P_{mean}}{P_n} \quad (4)$$

$$CF=\frac{1}{P_n}\int_{0}^{\infty} P\,(v)f(v)dv \quad (5)$$

$$P_{mean}=\int_{V_{cin}}^{V_n} P\,(v)f(v)dv+P_n\int_{V_n}^{V_{cout}} f\,(v)dv \quad (6)$$

$$CF=\frac{1}{P_n}\int_{V_{cin}}^{V_n} P\,(v)f(v)dv+\int_{V_n}^{V_{cout}} f\,(v).dv \quad (7)$$

To model the speed-power curve of the "SoyutWind 5 kW" wind turbine, a 6th degree polynomial equation has been obtained with 99% accuracy using the curve fitting method in MATLAB (Equation (8)).

$$P(v)=2.041*10^{-5}*v^6-0.0006953*v^5+0.006779*v^4-0.007173*v^3-0.1083*v^2+0.4223*v-0.337 \quad (8)$$

In MATLAB, the shape (k) and scale (c) parameters for the Weibull distribution function (f(v)) have been calculated using the available wind speed data. Using these parameters, the f(v) function, which depends only on the wind speed (v) variable, expressed as in Equation (9).

$$f(v) = 0.6481 * \left(\frac{v}{2.0067}\right)^{0.3006} * e^{-\left(\frac{v}{2.0067}\right)^{1,3006}} \quad (9)$$

As a result, the average power generation (P_{mean}) of the wind turbine is expressed as in Equation (10).

$$P_{mean} = \int_{3}^{10} (2.041 * 10^{-5} * v^6 - 0.0006953 * v^5 + 0.006779 * v^4 - 0.007173 * v^3 - 0.1083 * v^2 + 0.4223 * v - 0.337)\left(0.6481 * \left(\frac{v}{2.0067}\right)^{0.3006} * e^{-\left(\frac{v}{2.0067}\right)^{1,3006}}\right) dv + 5 \int_{10}^{24} \left(0.6481 \left(\frac{v}{2.0067}\right)^{0.3006} * e^{-\left(\frac{v}{2.0067}\right)^{1.3006}}\right) dv \quad (10)$$

2.2.2 Solar energy

Türkiye has significant solar energy potential due to its geographical location. According to the Ministry of Energy and Natural Resources, Solar Energy Potential Atlas [14], the annual average sunshine duration is 2741 hours, and the annual total radiation is 1527.46 kWh/m^2. The sunshine durations of Artvin province are below the Turkish average (Appendix B-Figure B1). Considering the southern location of the garden, two potential solar panel installation areas (Appendix B – Figure B2-3) were simulated using PVSOL Premium 2021 (R8)(demo version) software. Using Google Maps integration and 1991-2010 climate data (Appendix B – Figure B4), a system with a total installed power of 210.8 kW was designed. These designs were arranged in 3D on the simulation programme with the help of previously loaded climate data and Google Maps integration.

Solar energy system equipment such as PV panels and inverters are included in the relevant section of the simulation programme with current companies and brands. In the relevant section of the simulation programme, CW Energy's CWT400-72PM (400W) model solar panels and inverters belonging to Huawei Technologies were installed in two polygon areas (Polygon 01 and Polygon 02). The areas specified for installation are flat surface areas without slope. The placement of the panels is designed to be south facing (180°) with a 15° tilt angle for minimum shading. A total of 527 PV modules (210.8 kWp) are planned to be installed, 322 PV modules (128.8 kWp) in Polygon 01 and 205 PV modules (82 kWp) in Polygon 02.

The solar power plant project has an investment period of 25 years and an average annual return on capital of 33%. Polygon 01 area has an automatic/programmed connection with a single inverter and 10 MPPT devices and Polygon 02 area has an automatic/programmed connection with two inverters and 4 MPPT devices to each inverter. The unit price of electrical energy was determined as 2.1983 TL/kWh according to EMRA (EPDK) tariffs as of 03.07.2023 and covers the period 02.11.2022-01.11.2047 [15]. Solar energy installation cost is calculated as 700 USD/kW (18.221 TL/kW - 03.07.2023 1 USD = 26,03 TL). The inflation rate is determined as 19.63% based on TUIK PPI data (electricity, transmission and distribution services) for 2013-2023 [16]. This rate was calculated taking into account the fluctuations in the markets due to the COVID-19 pandemic, the Russia-Ukraine war and the Kahramanmaraş earthquake.

2.2.3 Biomass energy

Samples were taken to evaluate the energy potential of biomass wastes from plant cultivation and landscape maintenance in the ANG Botanical Garden. It was calculated that approximately 3500-5000 kg of biomass is generated by the annual pruning of various trees in the garden. Prior to autumn 2023 pruning, a sample of a mixture of shoots of fig, apple, pomegranate, peach, walnut, blackthorn, rose, willow, acacia, thuja and firethorn was collected, cut into 10 cm pieces (chopping) and dried naturally (Appendix C – Figure C1).

Woody and herbaceous plant pruning wastes generated as a result of plant cultivation and maintenance in the Botanical Garden are a potential source of biomass for energy production through incineration. In addition, an analysis was conducted to evaluate the daily food waste generated from the dining halls in all campuses of Artvin Çoruh University for energy production. According to the data of the Department of Health, Culture and Sports of AÇÜ, 143378 lunches were served in 2023 and approximately 27088 kg (54016 litres) of organic waste was generated. These food wastes were analysed together with biomass wastes to increase the total energy potential.

Prior to elemental analysis, the samples were dried in a JSR JSOF-400T oven at 70°C for 48 hours and ground to a size of 1 mm in the laboratory of the Faculty of Forestry, AÇÜ. A separate drying process was carried out for moisture content determination. A sample of 55.47 g of twigs and 7.8 g of leaves, weighed on a RADWAG PS4500.R2 precision balance, was dried at 105°C for approximately 24 hours. Moisture content (%M) was calculated using Equation (11) [17].

$$M(\%) = \frac{m_{first} - m_{last}}{m_{last}} * 100 \quad (11)$$

After drying for 48 hours, the samples were ground with a LAVION HC-1500Y grinder, sieved through a 1 mm mesh sieve and prepared for elemental analysis in the laboratory of the Faculty of Forestry, AÇÜ. Elemental analysis was carried out at Van Yüzüncü Yıl University Science Application and Research Centre using a Thermo Scientific Flash 2000 CHNS/O analyser. Samples of approximately 2.250 mg were used. All analyses were performed in 3 repetitions and the average values were used in the calculation.

The higher heating value (HHV) of biomass was calculated by seven mathematical models given in Table 2 using the elemental analysis results [18]-[21].

Table 2. Higher heating value estimates based on elemental analysis results [18]-[21].

Model No	Equality (MJ/kg)
1	HHV = 0.3259C + 3.4597
2	HHV = -3.147 + 0.468C
3	HHV = 5.736 + 0.006C^2
4	HHV = -2.907 + 0.491C - 0.261H
5	HHV = -5.290+0.493C + 5.052H^{-1}
6	HHV = -3.440 + 0.517(C +N)-0.433(H +N)

7	HHV = -3.393 + 0.507C - 0.341H + 0.067N

3 Results and discussions

The ANG Botanical Garden's current electricity installed capacity is sufficient to meet the instantaneous demand. However, the isolated location of the campus may make grid infrastructure investments difficult in case of an increase in future energy demand. Therefore, within the scope of the study, the integration of wind, solar and biomass energy sources was evaluated and various project proposals were developed. The energy consumption data for 2021-2023 (Table 3) is taken as a basis for this evaluation and interpretation of the results.

Table 3. ANG Botanical Garden electricity consumptionvalues in the period of the years 2021-2022-2023 (kWh).

Months	2021	2022	2023
January	6276	6494	6624
February	6257	5957	6166
March	7908	6514	7343
April	3804	4293	6378
May	5397	4278	6756
June	2906	3734	6568
July	2634	3510	6944
August	2731	5566	6324
September	3056	6071	5294
October	4379	5937	5622
November	6702	5618	8103
December	8810	6127	8787
Total	60860	64099	80909

3.1 Wind Energy

Using hourly wind speeds for a 12-month period, the average power value of the wind turbine was found to be 0.0845 kW according to the result of the integral expression of the product of the Weibull distribution function and the turbine power curve equation (Equation (12)). The reasons for this low value are that the turbine used should generate power at a minimum wind speed of 3 m/s and the hourly wind speeds in the region are generally less than 3 m/s.

$$P_{mean} = 8.2992 * 10^{-2} + 1.5546 * 10^{-3} = 0.0845\ kW \qquad (12)$$

The nominal power of the wind turbine used in the study is 5 kW. The result obtained is 0.0845 kW. Accordingly, the capacity factor is found to be 1.69% (Equation (13)). This value is a very small value even below 10%.

$$CF = \frac{P_{mean}}{P_n} = \frac{0.0845}{5} = 0.0169 \Rightarrow \%\text{CF} = 1.69\% \qquad (13)$$

The capacity factor value calculated for wind energy using the sample wind turbine is very small. In this case, generating electricity from wind energy in the region will not be an appropriate method considering the investment costs.

In 2019, in a similar study [22] conducted for AÇÜ Seyitler campus, it was concluded that Artvin province is not at a sufficient level in terms of wind energy potential. In this study, wind speed data were taken from the meteorological directorate. The real and net energy equivalent of wind energy will only be possible if wind speed measurements are measured hourly for at least one year in the planned area and calculations are made accordingly.

In studies on wind energy, due to the central locations of public spaces, suggestions such as producing energy in different places and either directly transporting the energy to the planned areas or making a protocol with a grid connection [3]-[5] have been presented. Since the ANG botanical garden is far from the settlement, there is no environmental factor in wind turbine installation. On the contrary, with the necessary measurements made, several wind turbines to be installed in various parts of the campus will add a different visual beauty in the campus landscape.

Wind energy use and applications have been on an increasing trend since 2000s. Many small-scale sample applications are carried out in public buildings and private buildings. However, even the installation cost of a small turbine with a power of 10 kW together with other equipment can exceed 15000 dollars (calculated average value). For this reason, it would be more appropriate to plan and project wind energy as a hybrid system.

3.2 Solar Energy

The system design project was obtained by adjusting the conditions of the place where the photovoltaic (PV) system will be installed in the most realistic conditions possible in PVSOL programme. With the installation of the selected PV panels in the determined areas, a total of 1052.9 m^2 surface area PV panels were installed. The installed power was found to be 210.8 kW. 527 PV panels were used and 3 inverters were connected to the grid (Table 4).

Table 4. 3D grid connected PV system technical information.

Climate Data	Salkımlı, TUR (1991 - 2010)
PV Generator Output	210.8 kWp
PV Generator Surface	1052.9 m^2
Number of PV Modules	527
Number of Inverters	3

The annual energy production of the PV system under the specified and adjusted conditions is 256900 kWh and the system performance is 81.5%. The annual efficiency reduction due to shading is 6.6% and the annual CO2 emission value reduced and prevented is 123.5 tonnes (Table 5).

Table 5. 3D grid connected PV system's yield table.

PV Generator Energy (AC grid)	256900 kWh
Grid Feed-in	256900 kWh
Down-regulation at Feed-in Point	0 kWh
Own Power Consumption	0 %
Solar Fraction	0 %
Spec. Annual Yield	1218.34 kWh/kWp
Performance Ratio (PR)	81.5 %

Yield Reduction due to Shading	6.6 %/Year
CO_2 Emissions avoided	123534 kg/year

The total cost of the project was calculated by the programme according to the unit prices entered and found as 3,840,986.80 TL (700USD/kW). The asset return rate of the system is 41.8% and the amortisation period is 8.8 years. 1 kWh energy production cost is 5.24 TL (Table 6).

Table 6. 3D grid connected PV system gain status and financial analysys

Total investment costs	3840986.80 ₺
Return on Assets	4180 %
Amortization Period	8.8 Years
Electricity Production Costs	5.24
Energy Balance/Feed-in Concept	Full Feed-in

In the PVSOL simulation programme, the profitability of the system according to the annual production in the time period entered for financial analysis was calculated by the programme and the results in Table 7 were obtained. The cash flow graph in Figure 3 shows the graphical curve of these results. Starting from the 8th year, the system amortises the investment cost and enters the profitability period. As of the 25th year, only operating expenses are deducted and the production cost continues in a constant direction.

Table 7. Cash flow values of PV System according to the years.

Years	Cash Flow (TL)	Years	Cash Flow (TL)
1	-3348633,23	14	1172797,04
2	-2761578,05	15	1341724,98
3	-2232019,05	16	1495857,28
4	-1753360,23	17	1636518,21
5	-1319967,96	18	1764906,77
6	-926993,14	19	1882110,05
7	-570231,65	20	1989114,96
8	-246014,04	21	2086818,32
9	48881,98	22	2176035,81
10	317301,56	23	2257509,91
11	561769,08	24	2331916,77
12	784533,99	25	2399872,55
13	987608,2	26	2429522,07

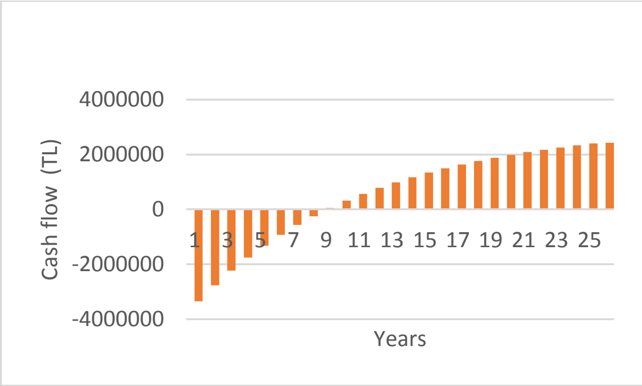

Figure 3. Cash flow curve graphic of the system.

The ANG Botanical Garden consumed 60680 kWh of electrical energy in 2021, 64099 kWh in 2022 and 80909 kWh in 2023 (Table 3). It is seen that there is an increasing energy demand. The designed solar energy system is capable of meeting this need with an annual production capacity of 256900 kWh.

Solar energy has been widely used in applications other than electrical energy generation until the 2010s. Today, there are examples of all uses of solar energy worldwide. Researches and studies in the literature [3],[4],[5],[23] emphasise the importance of the use of solar energy. There are many studies and applications on solar energy and renewable energy in the relevant departments of universities in Türkiye. In public buildings, systems that will pay for themselves between 5-10 years on average are designed with campus-based or building-based projects. With the widespread use of solar energy, solar energy systems are also becoming widespread and system unit costs are becoming accessible and applicable.

3.3 Biomass Energy

The results of the elemental analyses of the biomass sample with three repetitions are given in Table 8. C (carbon), H (hydrogen), N (nitrogen), O (oxygen) and S (sulphur) ratios of each sample were obtained as a result of the analysis. The amount of oxygen was found by subtracting the sum of other elements from 100.

Table 8. Results of elemental analysis of ANG botanical garden pruning waste.

	Analysis 1	Analysis 2	Analysis 3	Average
Sample weight (g)	2.34	2.23	2.18	2.25
C (%)	45.85	45.46	45.59	45.63
H (%)	5.88	5.83	5.79	5.83
N (%)	2.25	2.14	2.01	2.13
S (%)	0.00	0.00	0.00	0.00
O (%)	46.01	46.58	46.61	46.40
C/N	20.35	21.28	22.64	21.42

C, H and O are the biomass elements that make up the components of the organic part of the fuel. Carbon makes the most important contribution to combustion. In general, among the wastes that make up biomass wastes, woody biomass has a carbon content of 47% and mixed biomass has a carbon content of 46-47%. Agricultural biomass has a lower carbon content of 45% [24]. As can be seen from Table 8, the carbon content of the mixture of various woody pruning wastes used in this study is close to 46%. Accordingly, it can be said that it would be more convenient to use the mixture in incineration.

In determining the moisture content of the biomass, branches and leaves were evaluated separately. 55.47 g of branch samples and 7.8 g of leaf samples were taken and the moisture content of the branches was 31.25% and the moisture content of the leaves was 14.7%. The high moisture content of the tree branches is due to the fact that the trees are alive and old branches are cut for rejuvenation. The ideal moisture content of the waste in incineration should be between 15-25%. This range provides a favourable balance for the incineration process and increases the yield. This moisture content will decrease after longer natural drying.

Using the elemental analysis results of the biomass sample, the HHV values in Table 9 were found according to the HHV calculation models given in Table 2. According to this, we can say that the HHV value is 18 MJ/kg. Considering that 5000 kg of waste is generated annually, the energy equivalent of the incineration of this waste is 90000 MJ. The electrical energy (1 kWh = 3.6 MJ) equivalent of the calculated energy value corresponds to 25000 kWh. This value is a value that can meet one year's energy in a section that requires heat energy in the botanical garden. Another alternative is to burn this waste to obtain electrical energy with a small thermal steam turbine generator. Electrical efficiency in thermal power plants is around 40%. According to this, 10000 kWh electrical energy can be obtained from 25000 kWh energy per year. Waste heat energy can also be utilised as heat energy in the field.

Table 9. Higher heating values of the samples.

Samples	**HHV Mathematics Models (MJ/kg)**						
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**
Analysis 1	18.4024	18.3111	18.3497	18.0702	18.1732	17.9074	17.9986
Analysis 2	18.2744	18.1272	18.1344	17.8909	17.9883	17.7182	17.8106
Analysis 3	18.3175	18.1891	18.2067	17.9669	18.0584	17.7918	17.8814
Average	18.3314	18.2092	18.2301	17.976	18.0721	17.8052	17.8961

The value of landfill gas potential generated in waste collection areas for the population within the municipal boundaries in Türkiye is 0.97 billion m^3/year. The lower heating value of this gas is 19-23 MJ/m^3 (5.27-6.38 kWh/m^3). Based on the calculation made by taking into account that it contains 50% methane gas, 17.20 MJ/m^3 (4.77 kWh/m^3) is taken as the energy equivalent of approximately 5 kWh/m^3 [25],[26]. Based on the data obtained and calculations made, it was determined that 54016.47 litres of food waste with a volume of 54016.47 litres and 27008.235 kg of food waste is generated annually in all dining halls of AÇÜ. When food waste is stored and utilised without mixing with other municipal wastes, the energy equivalent will be higher due to its high organic matter content. Accordingly, the energy equivalent of food waste can be accepted as 5-10 kWh/m^3. Since 1 m^3 = 1000 litres, approximately 55 m^3 of food waste is generated from the dining halls of AÇÜ in a year. In this case, the annual energy equivalent of cafeteria waste will be in the range of 275-550 kWh.

The installed capacity of biomass energy in Türkiye has approached 2500 MW today. This corresponds to a value of 2.5 per cent. Waste management is the practices carried out to reduce the impact of waste materials on the environment and to increase the recovery of materials and energy [27]. The majority of the registered biomass power plants are established with the waste management practices of metropolitan municipalities. Others are located in provinces with agricultural and industrial production. Biomass is found wherever there is life and consumption. However, the processing and conversion of biomass into energy has not yet reached an accessible and applicable level in the world and in Türkiye. Countries with good economies in the world, similarly in Türkiye, there are energy production applications from biomass in metropolitan municipalities and provinces with large industries.

4 Conclusion and suggestions

This study presents the evaluation of local renewable resources (wind, solar and biomass) to meet the energy needs of Artvin Çoruh University ANG Botanical Garden. The wind energy potential was found to be low (average power 0.0845 kW, capacity factor 1.69%), therefore it was concluded to be uneconomical. The overall wind potential for Artvin province also appears to be insufficient. However, the geographical location of the garden requires a more detailed investigation for future wind energy production.

The designed 210.8 kW photovoltaic system has the potential to generate 256900 kWh of energy per year (approximately 1000000 kWh after deducting losses). The current energy consumption of the garden corresponds to about 10% of this value. However, due to the time mismatch between energy production and consumption (day-night, summer-winter), a grid-connected system is proposed.

Analyses of approximately 5000 kg of pruning waste per year showed that the upper heating value of the biomass was 18 MJ/kg (about 25000 kWh of heat energy). Since it is not economical to convert this heat energy into electrical energy in a thermal power plant, it is recommended to use it directly for heating purposes. The utilisation of food waste for energy production does not seem to be economically viable due to its low energy potential and operating costs. However, in the future, it is proposed to utilise catering wastes and lawn mowing wastes together for biogas production by anaerobic digestion. The biogas to be obtained can be used in the production of electricity and heat energy with a cogeneration system.

In conclusion, the most appropriate and economical solution for the energy needs of the garden is the installation of a grid-connected photovoltaic system, while wind energy will be evaluated in the future after more detailed analyses and biomass will be used for heating purposes.

5 Acknowledgement

This study is derived from the master's thesis titled 'Analysis of Artvin Çoruh University Ang Botanical Garden Energy Needs to be Met From Renewable Energy Sources' conducted and accepted at Artvin Çoruh University, Graduate Education Institute, Department of Natural Resource Management.

6 Author contribution statements

This article is derived from the master's thesis as stated in the acknowledgement section. Author 3 has made the necessary examinations and arrangements in wind and solar energy sections. Author 2 conveyed her knowledge and experience on biomass energy, and waste to energy. Author 1 has finalised the thesis and article with the advisory of Author 2 and Author 3.

7 Ethics committee approval and conflict of interest statement

"There is no need to obtain an ethics committee approval for the article prepared".

"There is no conflict of interest with any person / institution in the article prepared".

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Appendix A

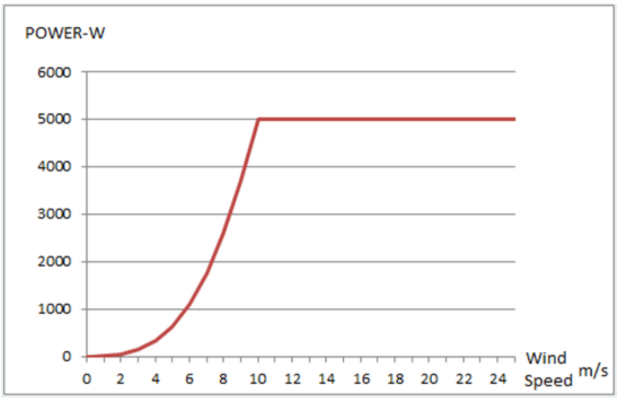

Figure A 1. Power curve of the SoyutWind 5 kW model wind turbine.

Table A 1. Other technical specifications of the SoyutWind 5 kW model wind türbine.

Rated Wind Speed	10 m/s
Cut-in Wind speed	3 m/s
Cut-out Wind speed	25 m/s
Rotor Diameter	6.5 m
Swept Area	33.18 m²
Tower Height	6,5 m
Operating Temperature	-30°C - +50°C
Blade Type	Fiberglass Composite
Tower Type	Steel Lattice
Yaw System (Facing – Avoiding)	Furling
Gear Box	No
Control System	PLC
Brake	Electromagnetic
Alternator	3 Phase Permanent Magnet (PMG)
Voltage	220/400 VAC – 50/60 Hz
Wind Speed Sensor	Yes
Temperature Sensor	Yes
Remote Control and Monitoring	Yes
Ligtning Protection	Yes
Battery Voltage	12V – 24V – 48V

Appendix B

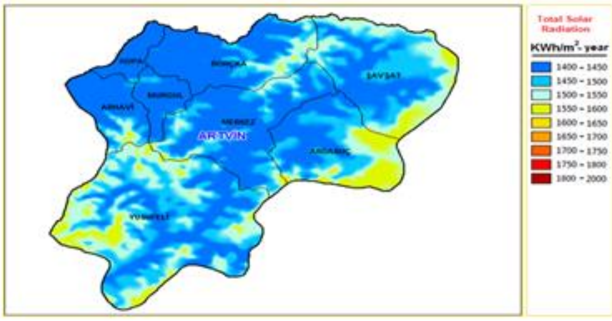

Figure B 1. Artvin Potential Solar Energy Map (ETKB).

Figure B 2. The region where solar energy installation is planned within the scope of the project.

Figure B 3. The second area, which is called a parking lot in the project and where solar energy panels can be installed.

Figure B 4. Polygon areas where the pv panels are installed.

Appendix C

Figure C 1. (a): The pruning wastes in ANG botanical garden (b): Samples taken from pruning waste (c): 10 cm chopped volume of the samples.