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# Route map for renewable energy sources implementation for household in Bulgaria

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**Abstract.** This paper is concerned with the design of a hybrid household system, located in the city of Sofia with the possibility of grid connection. It is comprised of photovoltaic (PV) arrays, wind generator and battery energy storage devices. A multi-objective, non-derivative optimisation is considered in this residential application; the primary objective is the system cost minimisation. The commercial software, HOMER Pro, is utilised to identify the least-cost design among hundreds of options. This paper discusses suitability of renewable energy (RE) applied in one-family household according socio-economic situation in Bulgaria. Finally, a route map of RES implementation options is presented, and economic indicators such as Total net presents cost (NPC), Cost of Energy (COE) and RES fraction are assessed.

## 1. Introduction

The aim of the European Union's long-term strategy is to keep Europe at the forefront and lead in global climate action, to present a vision that can lead to zero greenhouse gas emissions by 2050 through a socially just transition in a cost-effective way, [1]. Bulgaria adopted the Renewable Energy Act in 2011, and the aim is to achieve national targets for the use of renewable energy sources (RES) in final gross energy consumption. The European Union's Framework Strategy for Energy (2015) aims to achieve an energy transition that is fully European-oriented. The strategy is based on five pillars and aims to achieve the objectives faster and more effectively of the EU in the field of energy climate: reducing territorial greenhouse gas emissions in the EU (by 20 % by 2020 and by 40 % by 2030), increasing the share of energy coming from renewable sources (by 20 % to 2020 and 27 % to 2030) and improving energy efficiency (by 20 % by 2020, by 27 % by 2030), [2].

New renewable energy targets have been set in the new policies of a number of countries where the share of fossil energy, including renewable energy, is expected to reach more 32 % in 2030. Energy consumption from renewable sources in new buildings should represent more than 10% of total energy consumption.

In 2016, household electricity prices in Bulgaria were more than twice below the EU average. When measured in purchasing power standards per unit of energy, Bulgarian retail prices look much closer to the EU average, indicating potential accessibility problems for a particular consumer group. There are no restrictions on the territory of Bulgaria for household consumers to choose their electricity suppliers, but a very large part of them remain with a non-competitive offer of the active suppliers, which are regional. As a result, the switch-over for residential customers and low voltage companies is negligible. In Bulgaria, electricity prices are regulated, and progressive deregulation of prices in the electricity sector is envisaged [3].



### *1.1. Energy system in Bulgaria*

The Bulgarian internal electricity market is highly regulated and there is only one licensed supplier in each geographical region.

The retail electricity market is highly concentrated with a low level of competition and fixed energy prices set by the State Energy and Water Regulatory Commission. Nuclear power and solid fuels are dominated in energy production mix in Bulgaria. In recent years, renewable energy sources have become increasingly important and currently represent about 20% of Bulgaria's electricity production, [4, 5, 6]. Various scenarios related to the electricity mix in Bulgaria from 2020 to 2050 are given in the literature. According to the ambitious decarbonisation objective and the corresponding RES support schemes, Bulgaria will achieve a share of 53÷54 % in electricity production from renewable sources by 2050. This part will be composed mainly of wind, some hydro and solar energy. There are forecasts that, if support for renewable energy is phased out and the carbon dioxide (CO<sub>2</sub>) target is not set, the share of RES in electricity consumption will reach around 33 % in 2050 [7].

### *1.2. Decarbonisation of economy (residential)*

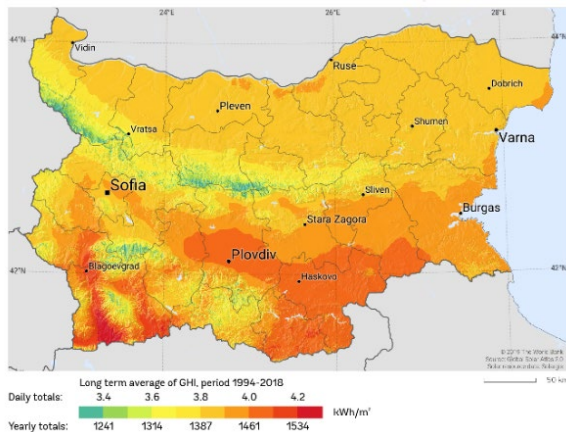
Climatic and meteorological conditions affect natural and anthropogenic processes that affect the state of the environment. In recent years, the incidence of extreme meteorological and climatic events in Bulgaria has increased, causing serious material damage to agricultural production, infrastructure, residential and public buildings, including human casualties, [8]. Bulgaria remains the most GHG (*Greenhouse Gas*) - intensive EU Member State. In 2015 in Bulgaria, the largest sectors in terms of GHG emissions were the energy sector, followed by transport (15.2 %), industry (13.9 %) and agriculture (10.5 %). In relative terms, the GHG emissions from residential and commercial sectors of Bulgaria were more than 5 times below the EU average (2.2 % vs 12.1 %) [3].

## **2. Renewable energy sources implementation and suitability household sector in Bulgarian**

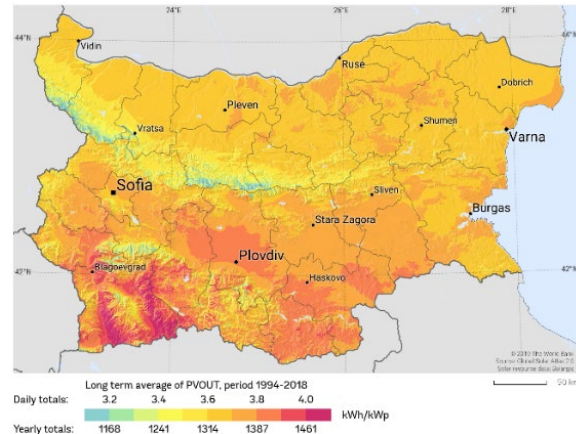
It is well known that Bulgaria has long fulfilled its commitments to increase the share of RES in final energy consumption and after the change of the state policy for preferential prices for buying energy from RES, the "boom" in the period 2007÷2012 to build these capacities are sharply reduced. Given the higher targets set in the 2030 climate/energy package for a 27 % share of RES, the Bulgarian policy may need to undergo some changes. The ten-year plan for the transmission system commented on the problems that would arise. Operating capacities with direct dependence on atmospheric intensity, and changes in operating capacities need to be offset by conventional power plants. The connection of new wind and photovoltaic capacities is limited and depends on the available resource for regulation. These considerations are likely to lead to a change in Bulgaria's energy policy and to further decentralization in energy production, especially at a low level [9]. To move to this state of affairs the Bulgarian Government endorses renewable energy sources. These energy sources may deal with restraint about fuel flexibility, efficiency, reliability, economics and emission. The energy mix should revolutionize and start further RES to diminish power generation pollution.

In 2018, renewable energy accounted for 21 % of the total energy used for heating and cooling in the European Union (EU). Increases in industry, services and households have all contributed to the growth in renewable energy used for heating and cooling. According to Eurostat the share of renewable energy in the total energy used for heating and cooling in Bulgaria is 33 % [10].

The development of the RES applied in buildings, no matter the PV, wind or the geothermal heat pump systems (GSHP) application, depend mostly on regional conditions. The dominance of photovoltaic (PV) among renewable energy technologies is owed mostly to its noiselessness, non-toxic emission, and relatively simple operation and maintenance. Taking the application of PV as an example, the commonly used indicators for evaluation of solar radiation condition are the peak sunshine duration hours.



**Figure 1.** Map of solar radiation for Bulgaria for long term period 1994-2018 [11].



**Figure 2.** Map of photovoltaic potential for Bulgaria – daily and yearly for long term period 1994-2018 [11].

Having a peak electricity load of 21 kW, being totally dependent on oil and gas provides an excellent opportunity for the generation of solar energy because of available high rate of daily sunshine, Table 1. A Solar Radiation Atlas developed by KACST in collaboration with the US National Renewable Energy Laboratory (NREL) in 2013 to monitor and map Bulgaria solar, wind, geothermal and waste-to-energy resources. Based on data, it has been found that direct normal radiation exceeds 14.4 MJ/m<sup>2</sup> in some regions yearly, Figure 1 and Figure 2.

**Table 1.** Daylight duration by months and city in Bulgaria, h

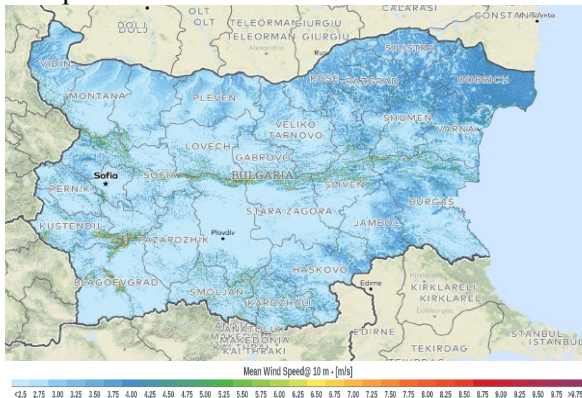
Month	Sofia	Plovdiv	Burgas	Varna	Ruse	Pleven	Lom	Sandanski
January	9.26	9.28	9.26	9.22	9.13	9.21	9.18	9.32
February	10.36	10.3	10.29	10.26	10.26	10.25	10.24	10.32
March	11.58	11.52	11.51	11.51	11.51	11.51	11.51	11.52
April	13.27	13.19	13.20	13.22	13.22	13.22	13.23	13.18
May	14.42	14.33	14.35	14.39	14.43	14.40	14.42	14.30
June	15.22	15.11	15.14	15.18	15.20	15.20	15.23	15.07
July	15.03	14.54	14.56	15.01	15.00	15.02	15.05	14.51
August	13.58	13.5	13.51	13.54	13.70	13.55	13.56	13.48
September	12.32	12.26	12.26	12.26	12.24	12.26	12.27	12.25
October	11.07	10.59	10.58	10.56	10.54	10.55	10.54	11.00
November	9.48	9.45	9.43	9.39	9.34	9.38	9.36	9.48
December	9.07	9.09	9.06	9.01	9.00	9.00	8.57	9.13

Bulgaria has good climatic conditions for RES development: great solar radiation > 4 kWh/m<sup>2</sup> per day, Figure 1, and duration of solar lighting > 11 h/day, so the technological possibilities for the utilisation of solar power cannot be neglected, Table 1. According P. Gramatikov, Bulgaria is located at the upper border of the so-called "solar belt" of the world. As a result, the total annual solar intensity in the capital - Sofia, is equivalent to the solar intensity of Madrid in Spain, Athens in Greece, and Sicily in Italy [12]. According EBRD, [13], wind power is one of the RES that has significant growth potential in Bulgaria, where strong winds blow from the coastal area.

### 3. Simulation and results

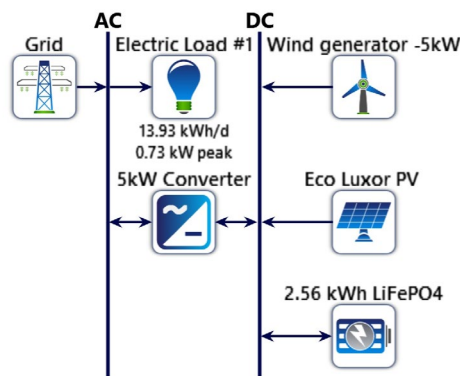
Some studies have been conducted to evaluate the RE potential of Bulgaria. Some of these are Government policies for solar investment. It is well known the solar PV and another efficiency improvement for sustainable residential buildings, RE options and economic viability of Solar PV within the residential sector. According some authors the efficient use of renewables through smart

grid can reduce oil consumption for electricity and dependency on oil, especially in Southern European countries.



**Figure 3.** Mean wind speed map of Bulgaria for 10 m high [14].

Renewable energy has become an increasingly competitive way to meet new power generation needs. According to statistics from IRENA (International Renewable energy Agency), the cost of solar modules has been steadily falling, with a decrease of approximately 8 times from 2010 to 2018, [15]. This is a valid reason in this article to propose a technical solution for the introduction of a hybrid system for receiving energy from renewable sources on the territory of Bulgaria. The design of a hybrid power system depends on some important sensitivity variables to optimize system cost and component sizes. The proposed hybrid power system for family house, is flexible and can be easily expanded by adding new photovoltaic panels, wind turbines, fuel cells and rechargeable batteries. The system has the opportunity to add an additional parallel inverter to monitor the added components, [16]. Battery storage can be located at the centralised wind and solar power production site to smooth variable generation output as it is fed into the grid. It can also store excess renewable production for later periods. For many applications, lithium-ion has proved preferable to other chemistries with respect to energy and power density, cycle and calendar life, and cost.



Component	Name	Size	Unit
PV	Generic flat plate PV	5.50	kW
Wind turbine	Aeolos-V5kW	1	ea.
System converter	System Converter		
	EasySolar	5.00	kW
Grid	Grid	999 999	kW
Dispatch strategy	HOMER Load Following		

**Figure 4.** System architecture and component table of the proposed hybrid power system made by HOMER software.

The capacity of proposed hybrid system estimates include small solar PV (5.5 kW) and wind turbine (1 kW) installations coupled with battery storage at the household level. The data expressed in [17] shows that the li-ion battery with the highest system price actually provides the lowest cost per cycle. Battery storage at a household allows greater self-consumption of electricity produced by solar PV. It can also help relieve local grid capacity constraints. Our results from hybrid system modelling shows that the cost energy produced from battery remains too high: 6.75 BGN/kWh.

The proposed hybrid system may be implemented differently depending on the geographical location and socio-economic situation of the population living there. In some areas of the country, where climatic conditions are not particularly suitable for wind turbines, a hybrid system may be used. There are areas in Bulgaria with wind speed values significantly higher than other areas - the north-eastern

part of the country near the Black Sea, Figure 3. It is here that the collaboration of solar panels with wind turbines can be successfully used.

The possibility of introducing RES into single-family homes in Bulgaria has been assessed by conducting a feasibility study based on the adopted hybrid system. The analysis was performed using the HOMER Pro software product.

The parameters shown in Table 2 have been loaded into HOMER Pro for optimizing the sizing of the various components. A discount rate of 6 % has been considered for the calculations. The results are valid for a hybrid system located on the territory of the Technical University - Sofia. The total system cost is 22 853 BGN and initial capital of 18 700 BGN. The system lifetime is pre-set at 25 years.

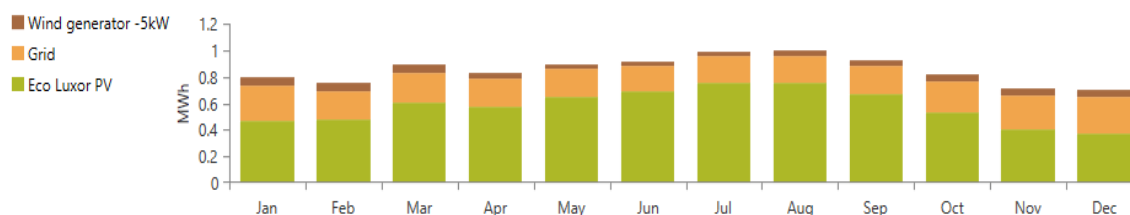
**Table 2.** Net presents costs of the hybrid system.

Name	Capital, BGN	Operating, BGN	Replacement, BGN	Salvage, BGN	Total, BGN
Aeolos-V5kW	1 600	1 572.00	637.61	- 349.75	3 460.00
Generic flat plate PV	6 100	129.28	0.00	0.00	6 229.00
Grid	0	- 590.83	0.00	0.00	- 590.83
HOMER Load Following System	3 000	0.00	0.00	0.00	3 000.00
Converter					
EasySolar 48/5000/70-100	8 000	0.00	3 394.00	- 638.82	10 755.00
System	18 700	1 110.00	4 032.00	- 988.58	22 853.00

The hybrid power system has been simulated by HOMER Pro in order to assess its operational and economic characteristics. HOMER Pro is being able to perform thousands of simulations in a few seconds. In this case, 342 feasible solutions were assessed taking into account various system designs to calculate the option with the least net presents cost (NPC). HOMER Pro eliminates all infeasible solutions according to total NPC. Similar models have been made for main cities in Bulgaria, Table 4. In all modelling cases dispatch strategy is Load Following and there is no Unmet Electric Load. Initial capital is 18 700 BGN and the Salvage in the end of system lifetime is constant again – 4 126 BGN.

**Table 3.** Production summary of the system located on the Territory of Technical University in Sofia.

Component	Production, kWh/year	Percent
Generic flat plate PV LUXOR Eco Line 275 W	6 935	67.9
Aeolos-V5kW	563	5.5
Grid Purchases	2 711	26.6
Total	10 210	100.0



**Figure 5.** Monthly electric production of the hybrid system located on the Territory of Technical University in Sofia calculated by HOMER Pro.

#### 4. Socio-economic situation in Bulgaria and possibility of RES implementation into the household

Households are the third largest sector in terms of final energy consumption after transport and industry and ahead of services and agriculture. The distribution of electricity consumption of Bulgarian households depends mainly on the heating source they are using – electricity, natural gas, coal, wood or other fuels. In 2015 the electricity consumption of Bulgarian households was distributed as follows: 46 % was used for water heating; 20 % for lightning and small appliances; 16 % for cooling (refrigerator use); 8 % for cooking; and 10 % was used for other purposes. In Bulgaria 20 % of

the poorest households spent more than 14 % of their budget on domestic energy [18]. Around 67 % of the most socially deprived households were still unable to keep their homes warm. This represents a decrease but it remains significantly above the EU average of 23 % and makes Bulgaria the worst performer in the EU on that metric [3].

**Table 4.** Compare indicators connected with the financial balance and renewable energy fraction.

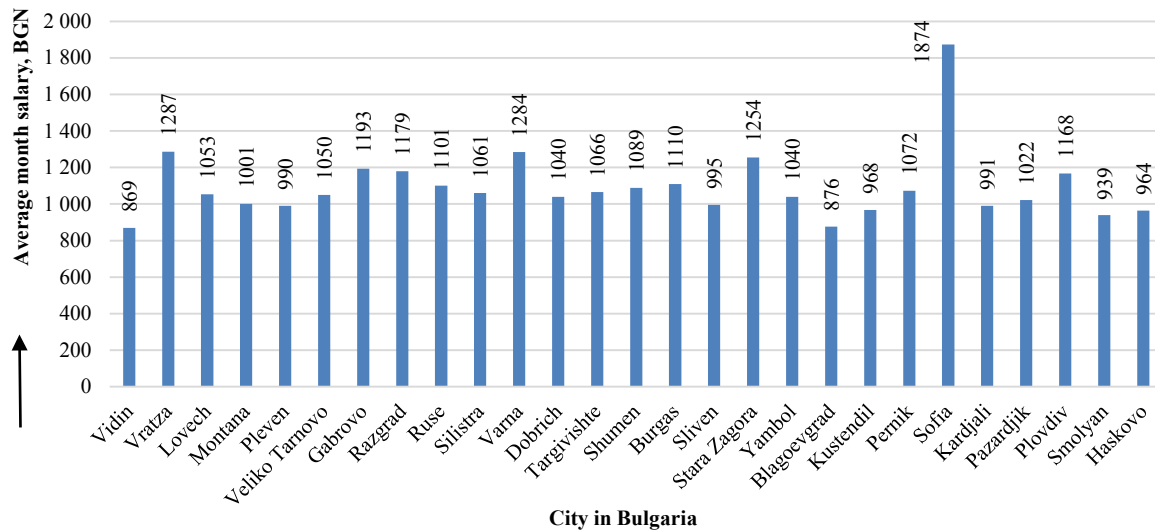
City in Bulgaria	Preferred RE source implementation in the hybrid system Solar/Wind	Total net presents cost of the system (NPC), BGN	Cost of Energy (COE), BGN	RES fraction, %
Vidin	Solar	24 051	0.192	72.7
Vratza	Solar	23 923	0.188	73.2
Lovech	Solar	23 758	0.184	73.8
Montana	Solar	23 538	0.181	74.8
Pleven	Solar	23 766	0.185	73.8
Veliko Tarnovo	Solar	23 736	0.184	73.9
Gabrovo	Solar	23 905	0.188	73.3
Razlog	Solar	23 937	0.189	73.2
Ruse	Solar	23 609	0.169	75.6
Silistra	Solar	23 468	0.180	75.0
Varna	Solar and Wind	22 568	0.166	78.9
Dobrich	Solar and Wind	22 711	0.170	78.5
Targovishte	Solar and Wind	22 678	0.169	78.6
Shumen	Solar and Wind	22 574	0.168	79.0
Burgas	Solar and Wind	23 130	0.176	76.7
Sliven	Solar and Wind	22 853	0.172	77.9
Stara Zagora	Solar	23 987	0.191	73.0
Yambol	Solar	23 987	0.191	73.0
Blagoevgrad	Solar and Wind	23 403	0.181	75.6
Kustendil	Solar	24 122	0.191	72.2
Pernik	Solar	24 106	0.190	72.2
Sofia	Solar	24 057	0.189	72.4
Kardjali	Solar	23 073	0.189	72.3
Pazardjik	Solar	23 614	0.183	74.6
Plovdiv	Solar	23 200	0.194	72.0
Smolyan	Solar	24 197	0.194	72.0
Haskovo	Solar	23 582	0.183	74.7

Various sources studying energy efficiency behaviour of Bulgarian households show that energy poverty is a serious issue in the country. According to statistics, 46.6 % of the total population of Bulgaria cannot maintain adequate thermal comfort in their households. The rising electricity and district heating prices in the last years have forced many households towards using coal and wood for heating which further worsens air and living quality. The electricity prices for households in Bulgaria have increased to 9.55 eurocents/kWh in 2017. Although the prices are still the lowest in the whole EU around 444 000 households are claimed to be highly vulnerable to increases in electricity prices [19].

Economic development is a multilayered process endeavors the growth of labor productivity the improvement of the standard of living of the population a highly profitable economy. Overall our country's GDP has been growing steadily since 2013 with wide variations across regions. Bulgaria's GDP per capita is growing slightly faster than the EU average reaching 50 % of the EU average in 2017 but remains rather low [9].

At the district level the highest average annual financial incomes are in the districts of Sofia-city, Varna, Stara Zagora, Gabbrovo, Razgrad, Plovdiv, Burgas, and Ruse (> 1 100 BGN). The incomes in

the districts of Vidin, Blagoevgrad, and Smolyan are low (< 950 BGN). The difference between the district with the highest (Sofia-city) and the one with the lowest (Vidin District) average annual household income remains over 2 times financial income Figure 5 [9]. An important economic indicator for assessing the possibility of introducing renewable energy sources in single-family residential buildings is the cost of fixed assets. According to the National Statistical Institute at the national level the Southwestern region of Bulgaria is characterized by the highest costs for the fixed assets.



**Figure 6.** Average month salary in Bulgaria by cities in 2019 [20].

## 5. Conclusions

Additional efforts could therefore be envisaged to improve energy intensity in various demand sectors. Furthermore the implementation of the national energy efficiency actions and programs needs to be pursued. By 2050 the country's decarbonised electricity mix would include 53÷54 % renewable generation. The rising carbon coal and natural gas prices would lead to an increase of Bulgarian wholesale electricity prices from an average of 34 EUR /MWh in 2016 to over 74 EUR/MWh in the decarbonisation scenario in 2050. The current assessment shows that alternative solutions exist to replace current generation capacity by 2050 with different implications for affordability sustainability and security of supply. The utilizations of the solar PV ST and GSHP are believed to be the most promising technologies in the future. The decentralized production of energy from renewable sources and depending on the local potential and needs is a sector with great prospects in the country. This is a way to avoid the cost of networking and the loss of transmission and distribution of energy. Lower solar PV module prices and ongoing reductions in balance of system costs remain the main driver of reductions in the cost of electricity from solar PV. The proposed solution for supplying electricity to single-family homes is fully in accordance with the national strategy for increasing the share of renewable energy sources in the overall energy mix of our country.

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