100% RENEWABLE ENERGY FOR RESIDENCES IN SEVEN COUNTIES IN OHIO

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100% RENEWABLE ENERGY FOR RESIDENCES IN SEVEN COUNTIES IN OHIO

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ABSTRACT

100% RENEWABLE ENERGY FOR RESIDENCES IN SEVEN COUNTIES IN OHIO

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The objective is to research the possibility of achieving 100% renewable energy for electricity demand and hot water for residences in seven areas in Ohio by utilizing three locally- available renewable energy sources. These areas are chosen because they are generally rural and thus can potentially provide biomass energy in the form of crop residue. Hourly electricity demand based on OpenEI data for this region is utilized to determine hourly renewable energy expected to meet hourly demand. The three renewable energy sources locations solar energy, wind energy, and biomass energy from residues located in the seven counties. Three alternatives are examined for proposed power plant configurations with sustainable power sources. These cases rely upon Biomass used to create power and hot water and either utilize all of the accessible biomass in the regions to generate electricity and waste heat, or utilize biomass to provide heat for hot water, or use biomass to meet remaining electricity demand after estimating the solar and wind power plant outputs. The levelized cost of energy in each scenario is calculated as well.

Dedicated to my parents and my Family

ACKNOWLEDGMENTS

My special thanks are in order to Dr. Robert Brecha, my advisor, for providing the time and equipment necessary for the work contained herein, and for directing this thesis and bringing it to its conclusion with patience and expertise.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

As the human populace expands, our rate of utilization of fossil fuels additionally increments. Geologists and others whose occupation it is to find and gain access to these pockets of crude petroleum are discovering it gradually hard to find and obtain new sources. Regardless of whether we have 1 year or 100 years left of oil, many claims that what is left ought to stay in the ground since it is unsustainable - it will run out in the end, thus we ought to get ready for a post-fossil fuel world at this point [1].

The United States as of now depends primarily on coal, oil, and natural gas for its energy. Fossil fuels are non-renewable, that is, they draw on limited assets that will in the long run decrease, turning out to be excessively costly or too environmentally harmful to retrieve. Conversely, the many sorts of renewable energy assets, for example, wind and sun based energy are continually recharged and will never run out [2]. Creating power from renewable resources instead of fossil sources also offers important public health advantages. The air and water contamination given out by coal and natural gas plants is connected to breathing issues, neurological harm, heart attacks, and disease. Supplanting fossil power with renewable energy has been found to lessen untimely mortality and lost workdays, and it decreases general human healthcare costs [3].

The most power consumed by the world is from fossil fuel. It knows one day that power will be depleted. Then, the alternative energy source should be found. Renewable energy: sun, wind, and biomass are endless energy.

In Ohio, power is basically created utilizing assets like coal, natural gas and nuclear power. While these assets are actually discovered in the earth and create a lot of power, nonrenewable assets set aside a long time to form, and there is a limited supply existing for individuals to use for power generation. Renewable assets, including hydropower, wind, biomass and solar energy are likewise used to deliver power, however frequently on a little scale. These assets are promptly accessible in nature and can be renewed moderately rapidly or are continuously available [4].

In this work the goal is to investigate the possibility of achieving 100% renewable energy for electricity and hot water demand for residences in seven counties in Ohio: Auglaize, Shelby, Mercer, Darke, Fayette, Preble, and Union by using three locally-available renewable power plants sources: sun, wind, and biomass. The hourly energy produced from these three renewable energy sources for the seven counties should meet the hourly electricity consumed by these counties currently from the grid we concentrate in this thesis on energy for households because of the availability of standardized data, as described below.

These countries are chosen because they are mostly rural containing crop residue so that biomass is potentially available. See Figure 1.

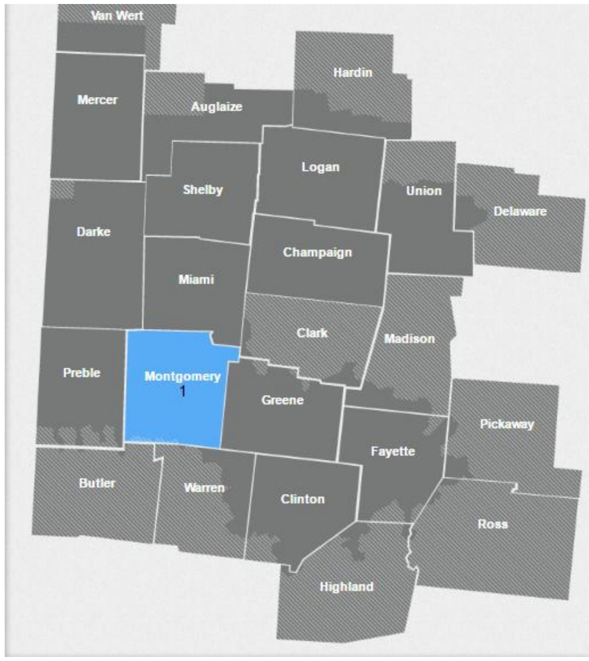


Figure 1: Counties chosen [5]

The hourly electricity demand, which is in described in Chapter 2, is the dataset that contains hourly load profile data for residential building types (based off the Building America House Simulation Protocols) [6]. These hourly demand of residential load for the region of southwest Ohio, based on Data in the OpenEI database for households is located in Dayton Airport are used as the basis determine hourly renewable energy needed to meet hourly demand.

For the solar energy resource, which is in Chapter 3, the hourly solar radiation data is taken from National Renewable energy Laboratory (NREL) that is updated in 1991–2010 using a new model, Meteorological-Statistic (METSTAT) [7]. The solar energy data is located on the Dayton airport location and Wilmington Park. These sites are chosen as the closest solar data location to the counties of interest in this study. The data for solar energy is converted form data on a horizontal surface to insolation on a tilted surface at 30-degrees, and then converted to solar electricity output using an efficiency factor 0.17 for solar modules.

For wind power, discussed in Chapter 4, two sites are chosen that are close to the seven counties. Depending on the annual average wind speed following the classes described in the International Electro-technical Commission (IEC), Class I, Class II, or Class III, the wind resource used in this work is described as Class III [8]. The corresponding data for specific turbines is utilized in this work to provide wind power.

For biomass discussed in Chapter 4, the data for available biomass is taken form National Renewable Energy Laboratory. Total crop production, crop to residue ratio, and moisture content were used to estimate crop residues for each county. The crop residue could be collected as biomass was around 35% of the total residue, and the left portion is left for maintain ecological purpose [9]. Because the residue of Wheat-Straw and Corn-Stover are available with abundant quantity in the counties, then they are used in this work as a biomass to provide electricity and hot water.

The cost of energy is an important factor in this work for comparing existing systems to the proposed renewable energy-based system. The levelized cost of representative plants is calculated for each of the three renewable power plants sources $ per kWh. A weighted-average cost is then used as the basis for comparison.

CHAPTER 2

ENERGY DEMAND

2.1: Electricity Demand

The electricity demand dataset contains an hourly load profile of data for Dayton Airport regional location for residential buildings types based from the Building America House Simulation Protocols [6].

The hourly and daily residential demand for household is plotted in Figure (2 &3). The demand is for electricity facility usage, which includes some parts of the heating system, such as fan electricity, and lights.

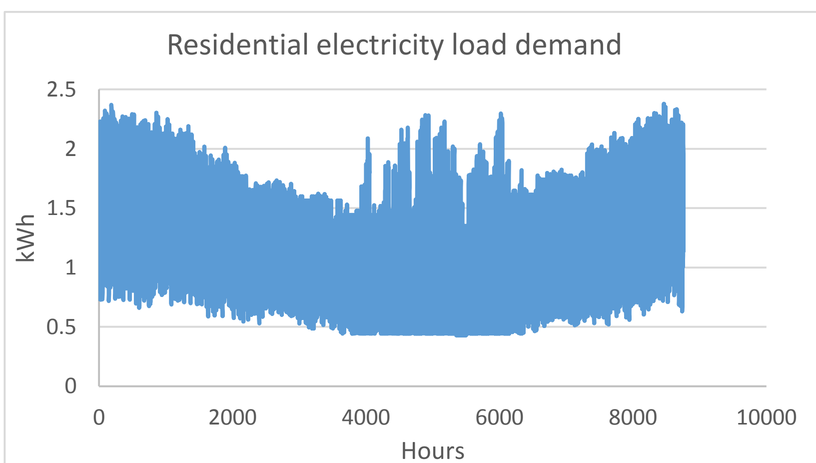


Figure 2: Hourly Electricity Demand per Households [9]

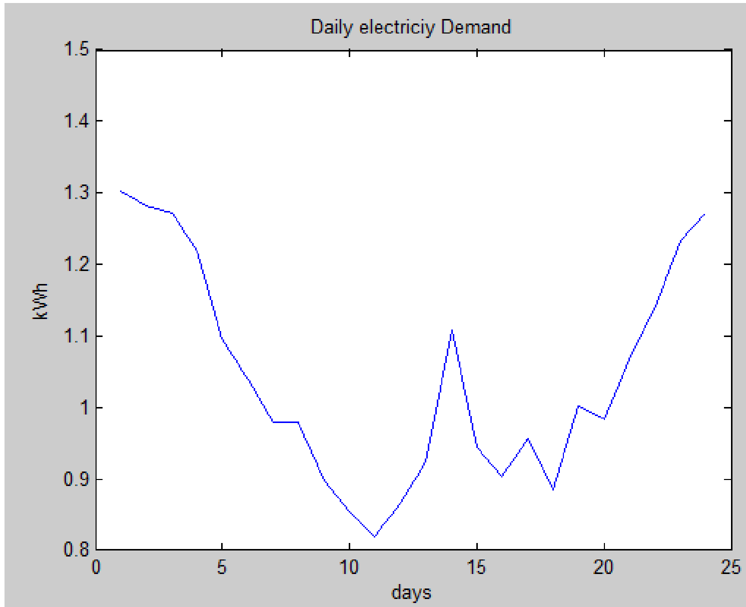


Figure 3: Daily electricity demand per households

Figure 2 & 3 show that the hourly mean demand for each households is high in winter and summer.

Data in the OpenEI database for households are divided into different components, representing different household loads. The separated yearly and daily electricity is for each part of equipment is presented in Figure (4 &5).

Figure 4: Hourly electricity demand for Individuals equipment

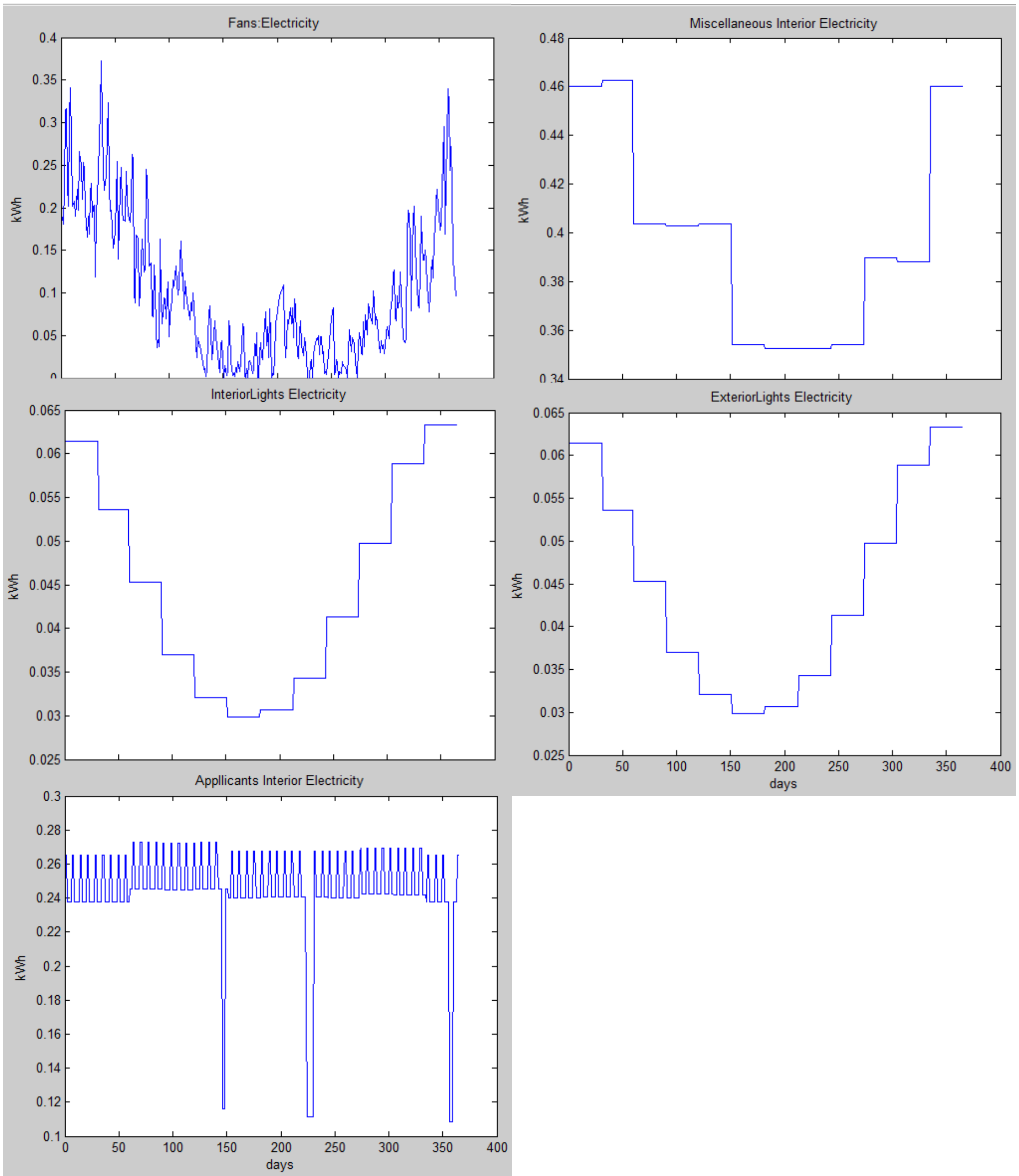


Figure 5 : Daily electricity demand for Individuals equipment.

The electricity demand for residential houses in this region is used to represent households for the seven counties: Auglaize, Darke, Shelby, Mercer, Fayette, Preble, and Union. Because these counties are rural, biomass in these counties is available in enough quantity to produce electricity and heat. Therefore, to satisfy energy demand, we assume that in these counties biomass combined heat and power plants can be built to provide electricity and heat.

The number of houses and populations for the counties are presented in Table 1. The houses numbers and populations are provided from the United States Census Bureau that provides statistics for all states and counties [10].

Table 1: Population and number of people for each households [11]

Nu.	County	Population	Total houses numbers	Demand (MWh/yr.
1-	Auglaize	45,876	19,665	166543
2-	Shelby	48,901	20,190	167182
3-	Mercer	40,968	17,702	144722
4-	Darke	52,076	22,716	189688
5-	Fayette	28,679	12,670	105124
6-	Preble	41,329	17,837	148255
7-	Union	54,277	20,277	166315

The total electricity for each county also is shown in Table 1. The calculations of yearly demand for each county is found by multiplying the total houses in Table 1 by the summation of hourly electricity demand for each households in Figure 2.

2.2: Heating Hot Water Demand

The heating hot water demand is provided for Residential Hourly Load Profiles for all TMY3 Locations in the United States [6]. The hourly mean electricity demand needed in 2010 for hot water for each households is plotted in Figure 6. Figure 6 shows that the hourly hot water demand is started higher in the winter than summer.

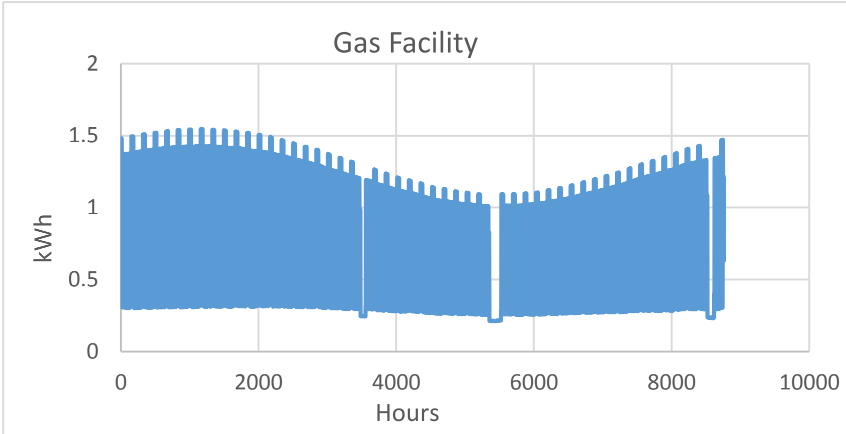


Figure 6: mean electricity Demand needed for hot water for each households [6].

The heating (kBtu) demand needed for each county for hot water is calculated by multiplying hourly energy demand shown in Figure 6 by the 3412 Btu/kWh. The mean heating demand required for each households is plotted in Figure 8.

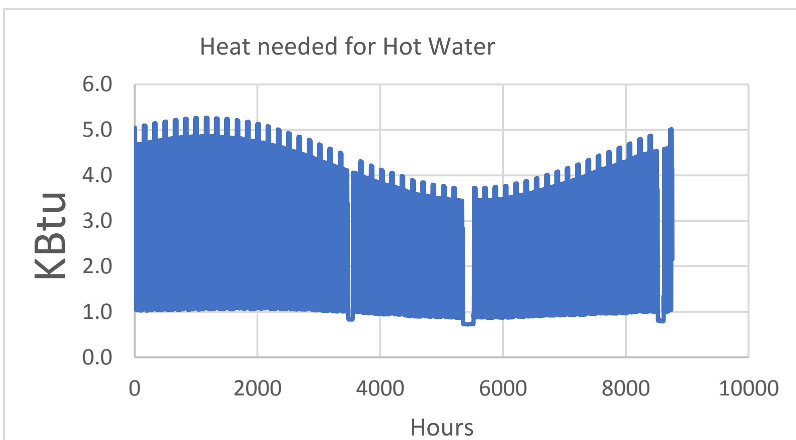


Figure 7: Hourly heating for hot water for each households

For each county, hot water demand is calculated by multiplying the heating demand for each households by the number of households for each county that is provided in Tale 1. The total heating, hot water demand for each county is shown in Figure 8.

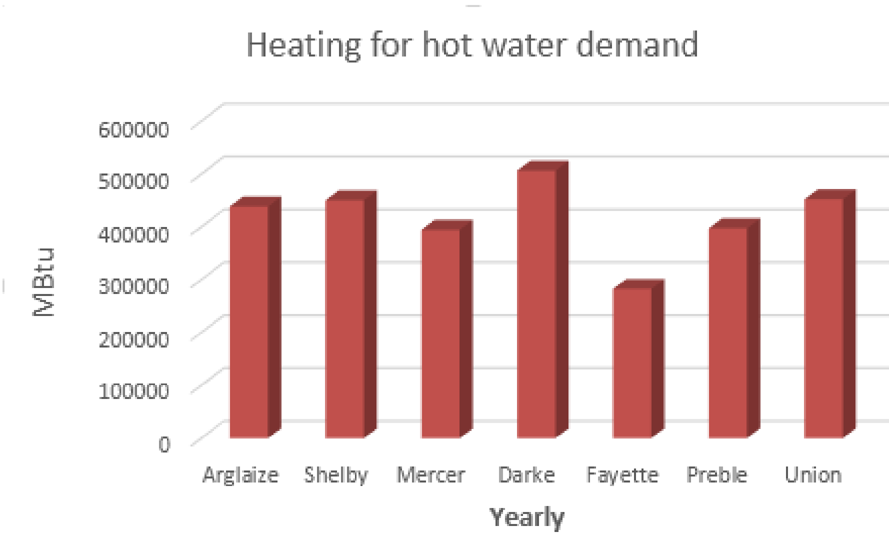


Figure 8: Total yearly heating Demand for hot water for each county

CHAPTER 3

SOLAR ENERGY

(Hourly solar data for 2010 is taken from the National Renewable Energy Laboratory NREL) using the METSATA model, which is based on estimates from meteorological data and the attendant statistical modifications included in the METSTAT model. Solar data are available from 1991–2010. In 2003, NREL investigated the feasibility of updating the National Solar Radiation Database (NSRDB) and began collaborative work with several agencies, including the National Aeronautics and Space Administration (NASA), the National Climatic Data Center (NCDC), the Northeast Regional Climate Center, the State University of New York at Albany (SUNY), the University of Oregon, the University of Wisconsin, and the private firm Solar Consulting Services. The new model, Meteorological-Statistical (METSTAT), was used to produce the original NSRDDB (NREL 1995) which, in turn, was developed using National Weather Service (NWS) observations of total and opaque cloud cover and measured solar data from the SOLRAD (Solar Radiation) network [7].

The hourly solar insolation data used is taken from Dayton airport location and Wilmington Airborne Park, OH. These two sites are chosen as being representative solar sites for the chosen counties. The Dayton Airport site is located at Latitude 39.9 and longitude -84.2. The Dayton airport location for actual solar 2010 data [12] is used as solar energy available to provide energy for six counties: Auglaize, Shelby, Mercer, Darke, Preble, and Union. The hourly global horizontal solar insolation that includes direct and diffuse solar (given in W/m^2) is shown in Figure 9. The total yearly solar radiation on a horizontal surface at Dayton Airport is 1.36 MMh/m2-yr.

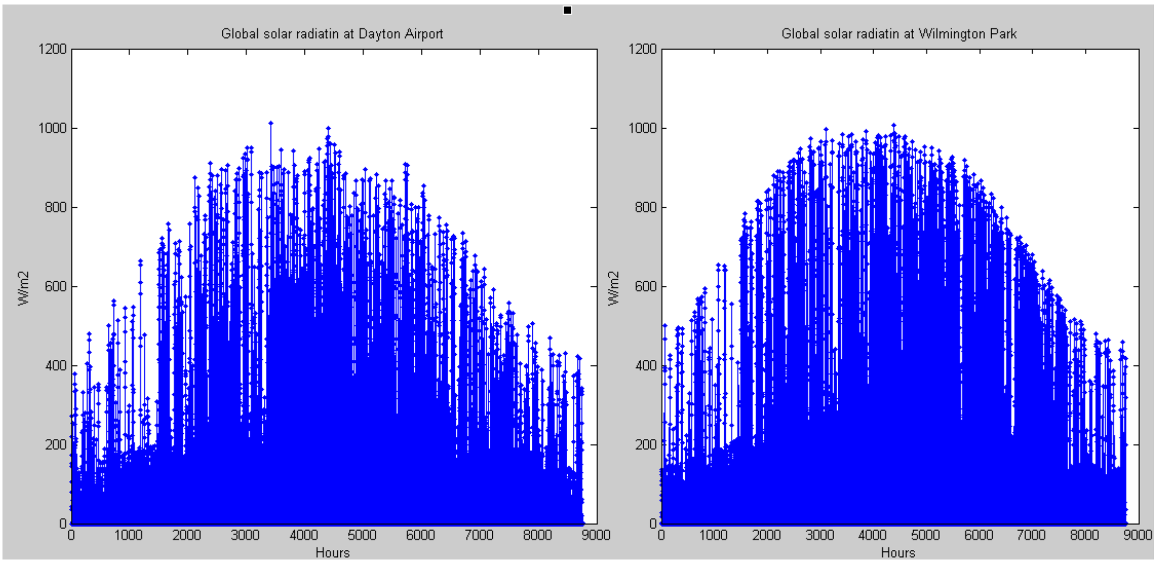


Figure 9: Hourly solar insolation data on a horizontal surface for Dayton Airport and Wilmington Airborne Park, OH [13]

Wilmington Airborne Park, OH.is located at Latitude 39.4 and longitude -83.7. Wilmington Airborne Park data is used as solar energy available to provide energy for Fayette County. The hourly global horizontal solar insolation that includes direct and diffuse solar (W/m2) is shown in Figure 9. The total yearly solar radiation on a horizontal surface at Dayton Airport is 1.57 (MMh/m2-yr).

To calculate total global solar insolation on a tilted surface, next equations are used:

Surface Azimuth (ψ) =0, the surface is due south.

Tilt angle of surface (Σ) = 30-degree

Surface Solar Azimuth (γ) = $\varphi - \psi$..1

β= Solar altitude angle = 90 – solar zenith angle..2

Incident Angle (θ): $\cos(\theta) = \cos(\beta)\cos(\gamma)\sin(\Sigma) + \sin(\beta)\cos(\Sigma)$..3

The total Global on a tilted surface, $G_t = G_{bn} \cdot \cos(\theta) + G_d \cdot (1+\cos(\Sigma))/2 + (G_{bn} + G_d) \cdot \rho_g \cdot (1-\cos(\Sigma))/2$ ………..4

Where:

Φ = Solar Azimuth angle

ρ_g = ground reflectivity

The hourly solar azimuth angle and zenith angle are given in solar data sheet as explained in Figure 10, and the solar, and the ground reflectivity varies from 0.2 at monthly average air temperatures above 0 C, to 0.7 at monthly average air temperatures below -5 C.

From solar data sheet located on Dayton international airport, METSTAT-modeled direct normal (Gbn) and METSTAT-modeled diffuse (Gd) horizontal on a horizontal surface, are taken to calculate the total global solar insolation on the tilted surface. See Figure 10.

1	YYYY-MM-	HH:MM	Zenith (de	Azimuth (	ETR (Wh E	SUNY	SU	SUNY G	SUNY	SUNY	SUNY D	SUNY I	SUN	SUNY D	METSTAT Glo (	MET	METSTAT Dir	METSTA	METSTAT Dif	METSTA
2	1/1/2010	1:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
3	1/1/2010	2:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
4	1/1/2010	3:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
5	1/1/2010	4:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
6	1/1/2010	5:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
7	1/1/2010	6:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
8	1/1/2010	7:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
9	1/1/2010	8:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
10	1/1/2010	9:00	85.5	125	110	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	36	25	18	28	35	25
11	1/1/2010	10:00	77	135.8	319	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	78	25	16	28	74	25
12	1/1/2010	11:00	69.9	148.2	486	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	172	25	180	28	110	25
13	1/1/2010	12:00	65.1	162.1	596	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	220	25	125	28	168	25
14	1/1/2010	13:00	63	177.3	642	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	271	25	111	28	221	25
15	1/1/2010	14:00	64	192.6	620	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	143	25	97	28	101	25
16	1/1/2010	15:00	67.9	207.1	532	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	152	25	153	28	94	25
17	1/1/2010	16:00	74.2	220.1	384	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	106	24	117	27	74	24
18	1/1/2010	17:00	82.4	231.4	187	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	43	24	23	27	40	24
19	1/1/2010	18:00	88.5	238.3	13	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	3	24	1	27	3	24
20	1/1/2010	19:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
21	1/1/2010	20:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
22	1/1/2010	21:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0
23	1/1/2010	22:00	99	-99	0	-9900	99	-9900	-9900	99	-9900	-9900	99	-9900	0	0	0	0	0	0

Figure 10 : Solar data spread sheet located at Dayton Airport.

By applying equation 1 through 3 for the entire year 2010, the hourly solar insolation on a tilted angle by 30-degree with zero azimuth angle is presented in Figure (11&12).

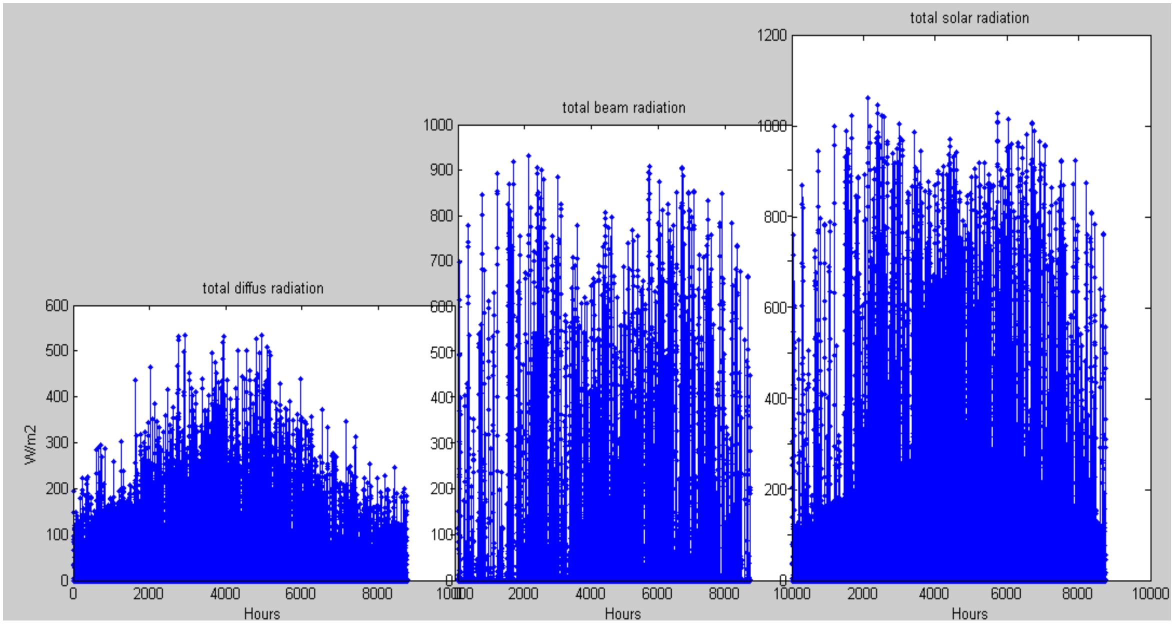


Figure 11: Hourly total, beam, and diffuse solar radiation on a tilted angle by 30-degree at Dayton Airport.

Figures 11 presents total solar radiation with beam and Diffuse at Dayton Airport location. The total year solar insolation on tilted surface with 30-degree at Dayton Airport is 1.5 MWh/m2-yr.

The solar insolation on a tilted surface for the Wilmington Airborne Park location is calculated by repeating the same equations 1 and 2 after using the actual data for Wilmington area with same azimuth and tilted angles, using the Latitude for Wilmington is 39.4 and the global beam insolation and the global diffuse from solar insolation sheet. See Figure 12.

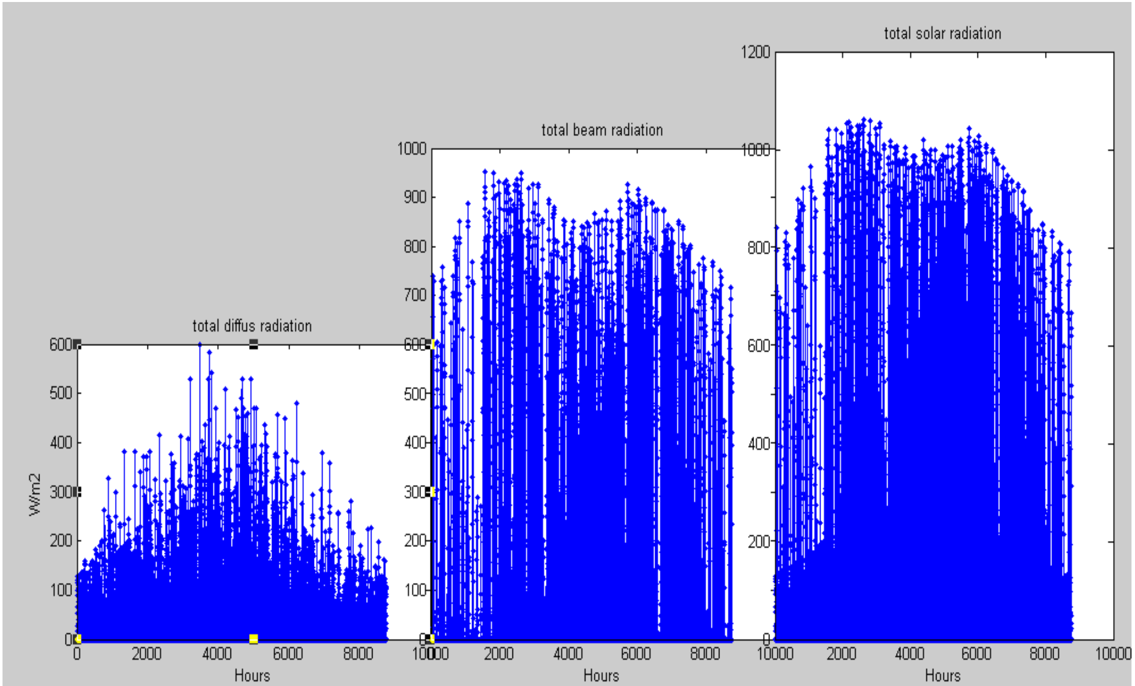


Figure 12: Hourly total, beam, and diffuse solar radiation on a tilted angle by 30-degree for Wilmington Airborne Park.

Figures 12 presents total solar radiation with beam and Diffuse at the Wilmington Airborne Park location. The total year solar insolation on a tilted surface with 30-degree at Wilmington Park is 1.79 MWh/m2-yr.

Comparing the total solar radiation on a horizontal surface with the total solar radiation on 30-degree tilted angle surface facing south at different two cites, Dayton Airport and Wilmington, shows different total yearly solar insolation. At Dayton Airport, the solar insolation is increased from (1.36 to 1.5) MMh/m2-yr after changing a surface from horizontal to tilled surface, and at Wilmington Park , the total solar radiation is increased from 1.57 to 1.79 MWh/m2-yr.

CHAPTER 4

WIND ENERGY

Since the data for solar energy and biomass is used from 2010, the hourly wind data will be used for the same year in this work. Hourly wind data is used from the Wind Integration National Data set (WIND) Toolkit. For more than 126,000 sites in the continental United States for the years from 2007 to 2013, meteorological conditions and turbine power data are included in the WIND Toolkit. See Figure 13.

	A	B	C	D	E	F	G
1	SiteID	52975					
2	Longitude	-84.4254					
3	Latitude	40.00917					
4	Year	Month	Day	Hour	Minute	density at	power (MW)
5	2010	1	1	0	0	1.23	7.026
6	2010	1	1	0	5	1.231	6.755
7	2010	1	1	0	10	1.232	6.32
8	2010	1	1	0	15	1.232	6.407
9	2010	1	1	0	20	1.232	6.78
10	2010	1	1	0	25	1.233	7.263
11	2010	1	1	0	30	1.233	7.576
12	2010	1	1	0	35	1.233	7.266
13	2010	1	1	0	40	1.233	6.661
14	2010	1	1	0	45	1.234	6.529
15	2010	1	1	0	50	1.234	6.664
16	2010	1	1	0	55	1.234	6.711
17	2010	1	1	1	0	1.235	7.043
18	2010	1	1	1	5	1.235	7.474
19	2010	1	1	1	10	1.236	7.683
20	2010	1	1	1	15	1.236	7.49
21	2010	1	1	1	20	1.237	6.842
22	2010	1	1	1	25	1.238	6.641
23	2010	1	1	1	30	1.238	6.078

Figure 13: Wind data spread sheet.

On site with different average annual wind speeds for turbines, generic turbine power curves were develop used to estimate the power that might be available at different locations across the United State. Depending on the annual average wind speed following the classes described in the International Electro-technical Commission (IEC), Class I, Class II, or Class III. In this work the turbine is described as Class III [8]. Two sites, Site-52976 and 50412, are chosen that they are close to the seven counties. Each site has 8 turbine with 2 MW capacity for each turbine.

4.1: Wind Turbine Performance and Locations

4.1.1: Wind Turbine Locations:

Two sites are chosen to represent wind energy for the seven counties Site 52975 is located at Latitude 40.2 and -84.24 Longitude and the site 50412 is located at Latitude 39.86 and -84.02 Longitude. Depending on sites' longitude and latitude, the site 52975 is located on or close to five counties: Auglaize, Shelby, Mercer, Darke, and Fayette, then this site will provide wind energy for these five counties. For the site 50412 located close to Preble and Union, this site will provide wind energy for these two counties. See Table 2.

Table 2: Longitude and latitude for counties [14]

The County,	County latitude	County longitude	Site
Auglaize	40.57	-84.35	52975
Shelby	40.36	-84.22	
Mercer	40.59	-84.68	
Darke	40.1	-84.68	
Fayette	41.67	-84.32	
Preble	39.77	-84.68	50412
Union	39.89	-84.3	

4.1.2: The Wind Turbine Performance:

The turbine types and performance detail for winds turbines that could be used at both locations are presented in Table 4. The turbine types are Vestas V100, GW1.6-100, or Repower 3.2 M. The generic power curves have cut-in wind speeds, rated power, Cut-out wind speed, and rated speeds that are similar to commercially available turbines (Table 3).

Table 3: Wind turbines used to create the wind power [8]

Class	Turbine	Rated power(MW)	Cut-in wind speed (m/s)	Wind speed at rated power (m/s)	Cut-out wind speed (m/s)
3	Vestas V100	1.8	3	12	20
	GW1.6-100	1.6	3	12	25
	Repower 3.2 M	3.2	3	12	22
	WIND Tookit Class 3				22

A rated power of 2.0 MW and a hub height of 100 m are assumed to have each turbine [8]. In this work, different turbines capacities are used for each site to generate power different maximum capacities that are around 16 MW of wind energy. See Figure 14.

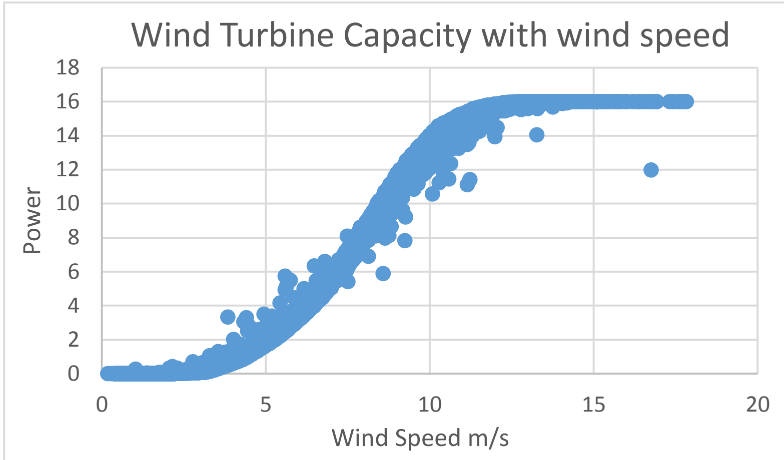


Figure 14: Wind turbine power curve site 52975.

As shown in the wind turbine power curve, the performance of the wind turbines is: cut-in Wind Speed is 3 (m/s), Wind Speed at Rated Speed Power is 12 (m/s), and Power capacity is 16 MW.

The Wind Turbine Power site 50412 has almost the same performances as the wind turbine power performances for site 50412 as shown is Figure 15. The one different performance between the site 50412 and the site 52975 is that the site 50412 produces less energy than the site 52975 at wind speed more than 15 m/s. See Figure 15.

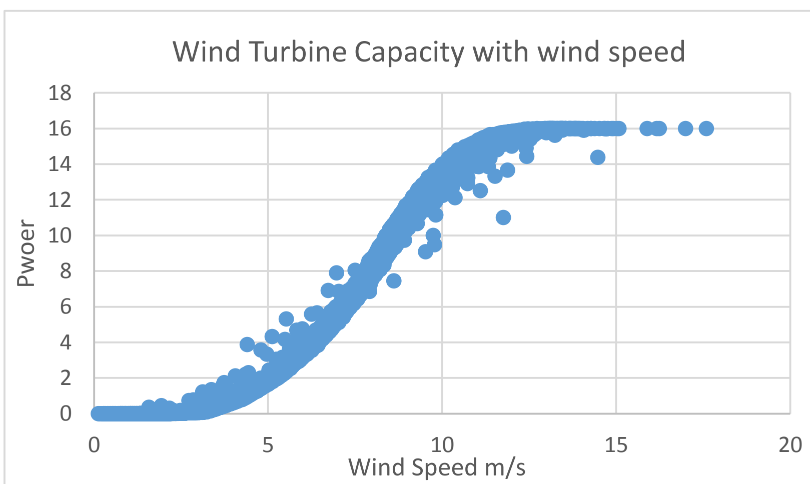
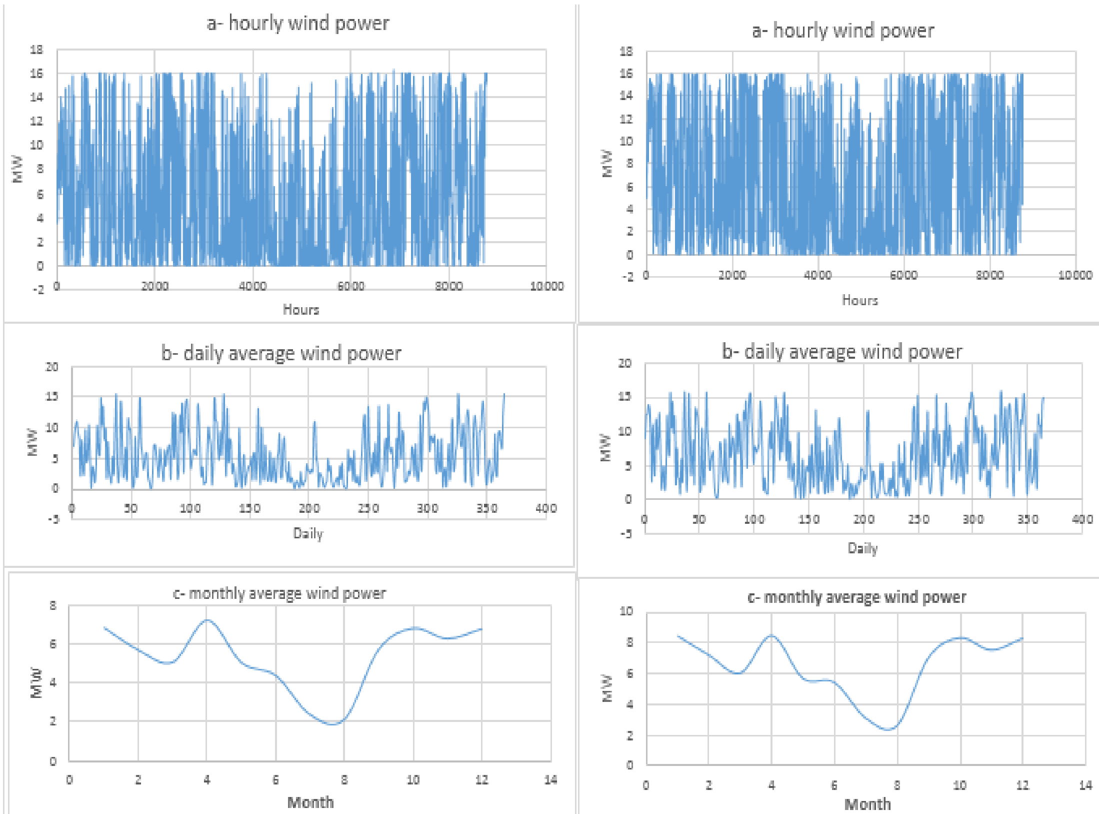


Figure 15: Wind turbine power curves site 50412

The next Figures 16 is the hourly, daily, and monthly wind power data for site 52975 and site 50412. The total energy produced for site 52975 in 2010 is 57257.57 MWh / year, and the total energy produced for site 50412 in 2010 is 46974.04 MWh / year.



Site-52975 Site-50412

Figure 16: Hourly, daily, and monthly wind energy for Site-52975 & Site 5412 [15]

Figure 16 is presented hourly, daily, and Monthly wind energy data for 2010 on Site-52975 which is located on right side, and on Site 5412, which is located on left side. These hourly data will used to feed most of hourly consumption. These data will be changed depending on wind capacity used for each county. See Chapter 7.

CHAPTER 5

BIOMASS

Available biomass data for the counties is taken form National Renewable Energy Laboratory. Geographic information systems (GIS) were used to analyze the biomass feedstock data both statistically and graphically. Estimating the biomass resources available in the United States and map the results was achieved depending on the GIS system [16]. Total grain production, crop to residue ratio, moisture content, and taking into consideration the amount of residue left on the field for soil protection, grazing, and other agricultural activities were used to estimate the quantities of crop residues that can be available in each county. For 2002 reported to the U.S. Department of Agriculture, total grain production by county is used to develop all estimates. Therefore, the crop residue could be collected as biomass was around 35% of the total residue [17].

Since corn stover and wheat straw are the most common crop residues in rural Ohio, we chose these as potential biomass energy sources to determine how much energy can be provided for each county. The next equations are used to calculate how much energy (MWh) is potentially available, given the biomass residue data for each county.

The heat rate for Biomass = 12350 (Btu/kWh) [18]

LHV for Corn-Stover= (15.2 - 15.9) MBtu/ton [19]

LHV for Wheat-Straw= (13.9 - 16.3) MBtu/ton [19]

*Energy (kWh/Yr) = LHV*feed-rate /heat-rate 5*

The corn-stover and wheat-straw availability for each county are shown in Table 4. Also, the total yearly electrical output energy provided by wheat straw and corn stover for each county can be calculated by applying equation 4. See Table 4 and Figure 14.

Table 4: Yearly feed rate and energy provided by corn Stover and wheat straw for each count [20]

Nu	County	Corn-stover (tonnes/yr)	Wheat-straw (tonnes/yr)	Total energy (MWh/year)	kWh / yr.households
1-	Auglaize	54400	10720	81730	4156
2-	Shelby	70770	8108	98996	4903
3-	Mercer	80380	13840	118252	6680
4-	Darke	95940	9508	132343	5826
5-	Fayette	72030	3413	94686	7473
6-	Preble	61250	3747	81575	4573
7-	Union	75270	5574	78873	3889.8

To find how much electricity provided of biomass for each households per year, which is shown in Table 4, the electricity (MWh/year) that is presented in Table 4 is divided by the total houses that is in Table 1, after multiplying it by 1000 to convert to kWh to be kWh /households. Yr.

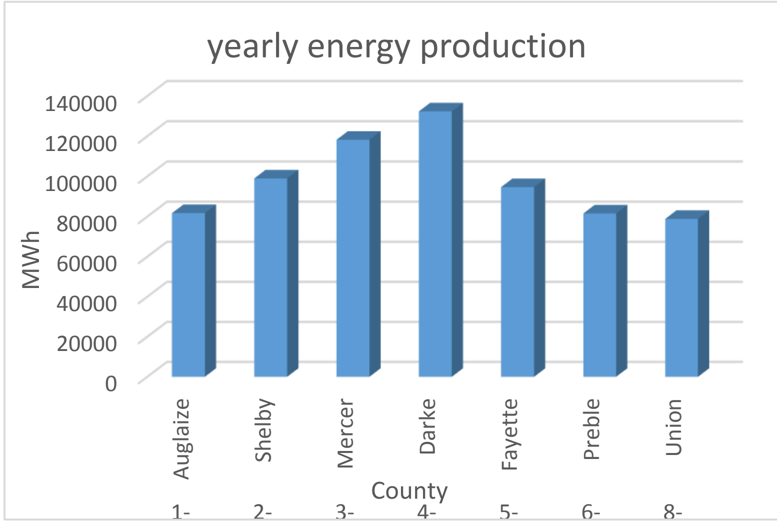


Figure 17: Yearly energy provided by wheat straw and corn-stover

The total percentage electricity provided by biomass is calculated by dividing total electricity produced of biomass for each county by the electricity demand. See Table 5.

Table 5: The maximum electricity percentage provided of biomass for each county

County	Electricity produced of Biomass (MWh/yr)	Electricity Demand (MWh/yr)	Percentage electricity produced of Biomass (MWh/yr)
Auglaize	81729	166543	0.49
Darke	132343	189688	0.69
Fayette	94685	105125	0.9
Union	78873	166315	0.47
Mercer	118252	144722	0.8
Shelby	98995	167182	0.59
Preble	815745	148255	0.55

CHAPTER 6

THERMAL CALCULATIONS

Heat required for hot water is an additional cost for energy cost for households. Finding a new source of heat to provide hot water might mean economic savings. In this section, hot water for each county is calculated for all households to size a biomass power plant covering all heat needed for the hot water. A combined heat and power plant is proposed that will be used to capture waste heat from biomass electricity production and used to provide all heat needed for hot water for the seven counties.

6.1: Hot Water and Wasted Heat

6.1.1: Hot Water.

Heat required for hot water needed for each county is calculated by using this equation [21]:

$Q = m \cdot Cp \cdot \Delta T$ ……6

Where…..

Q = Heat required (BTU)

m = mass of water heated

Cp = the heat capacity of water (1 BTU / lb ºF)

ΔT = temperature difference (ºF).

For typical homes hot water is 20-35 gallons/ day [21] (Conversion factor 1 gal has 8.3 lbs of water), and Cp is the heat capacity of water (1 BTU/lb/F) [6]. Assuming, for main water temperature supplied is 50 F, and the temperature of the hot water needed is 120. Also assume each households 2.5 persons in each household.

Now, by applying the equations 6 with the assumptions, the heat required for each households will be:

Q = (8.3 Ib/gall)*(24 gall/person. day)*(2.5 person/households) * (1 BTU/lb/F)*(120F -50 F) = 34.86 (kBtu /household. day)

Calculate how-much Btu needed for hot water for each family.

To calculate heat consumption by each county for hot water, using the equation:

Q ((MBtu/ county. Day) = Q (kBtu /households. day)* Total houses numbers (households/ County).

The number of houses in each county is shown in Table 1, and the heat required for each county per day is presented in Table 6.

Table 6: Heat required for hot water for each county

Nu	County	Hot water (MBtu / Day)
1-	Auglaize	685
2-	Shelby	703
3-	Mercer	617
4-	Darke	792
5-	Fayette	441
6-	Preble	622
7-	Union	706

Comparing calculated heat need for per households that is in Table 6 with heat needed for hot water given for form OpenEI for hourly hot water demand that is in Figure 7, the amount of heat need for hot water is different that heat need per households in Figure 7 is more than the calculated heat in Table 6. Therefore, to figure out more accurate result by using input heat used for hot water, the hourly hot water demand that is presented in Figure 7 is used in this work calculations to figure out how much biomass need to generate all heat needed for hot water and to calculate total energy cost including hot water as it is explained in Chapter 8.

6.1.2: Wasted Heat

6.1.2.1: Wasted Heat by Using the Biomass:

The total wasted heat coming from biomass electricity production is calculated depending on how much total biomass is used to produce electricity, then calculating the amount needed for producing electricity, with the remainder being left over for potential thermal energy use. Calculating energy produced and energy wasted of Biomass is depending on the unit's conversion between Btu and kWh and the heat rate. The unit's conversions are 3412 Btu/kWh [22] and the heat rate is 12350 Btu/ kWh.

By multiplying this heat rate by the total MWh produced by the biomass for each county that is shown in table 5 after converting it from MWh to kWh and hourly to daily, the total wasted MBtu for each county per day will be calculated. See Table 7.

Table 7: Total wasted heat from biomass.

Number	County	MBtu /county. day
1-	Auglaize	2765
2-	Shelby	3350
3-	Mercer	4001
4-	Darke	4478
5-	Fayette	3204
6-	Preble	2760
7-	Union	2669

However, the amount of the waste heat that will use for each county will be depending on the hot water needed for each county.

6.2: Electricity Produced From Biomass Depending On Hot Water

After sizing a combined heat and power plant that provided at least all heated needed for hot water, the hourly electricity produced from that power plant for each county is calculated by the equation:

Generated electricity (MWh) = wasted heat (MBtu)/ [1- (0.003412 (MBtu/kWh)/ heat rate)].

Heat rate is 0.01234 MBtu/kWh and the wasted heat needed for hot water is given in Figure 7. Then the electricity produced with hot water is presented in Table 8.

Table 8: Yearly heat demand with electricity Energy generated related to the hot water

Nu	County	Heating needed for hot water (Mbtu)	Electricity produced with hot water Demand (MWh/yr)
1	Auglaize	438400	49104
2	Shelby	450104	50415
3	Mercer	394638	44202
4	Darke	506417	56722
5	Fayette	282457	31637
6	Preble	397647	44539
7	Union	452043	50632

CHAPTER 7

OPTIMIZE ENERGY

Depending on hourly electricity demand, solar, wind, and biomass power plants are sized to produce 100% of hourly energy met hourly electricity demand. The three power plants' capacities are chosen depending on biomass used for three cases: First, using all the biomass available in the seven counties, second, using biomass to depending on heat needed for hot water, third, using certain amount of biomass to meet what leftover of electricity demand after using specific capacity of wind and solar power planet.

7.1: Used All Available Biomass

After calculating biomass available in the counties as shown in Table 9 and using all that biomass to generate electricity, the biomass power plants' capacity will be known by looking at the maximum value of hourly electricity produced of the biomass. While for wind and solar power plants, the capacities are found depending on electricity demand that is leftover after using the biomass power plant. See Table 9.

Moreover, Table 9 shows the capacity factor for each county and for each renewable sources. The capacity factor is calculated by using the equations:

Capacity factor = total yearly energy produced/ plant capacity 8760 ……………………………………………………………………….. 7*

Table 9: Power plants capacities and yearly productions after using all available biomass

County	Renewable Sources								
	Solar			Wind			Biomass		
	Capacity (MW)	Capacity factor	MWh/yr	Capacity (MW)	Capacity factor	MWh/yr	Capacity(MW)	Capacity factor	MWh/yr
Auglaize	14	0.17	21083	18	0.41	64415	31	0.30	80934
Darke	10	0.17	15059	14	0.41	50100	43	0.33	124792
Fayette	2	0.17	3162	2	0.41	7157	27	0.40	94805
Mercer	4	0.17	6024	6	0.41	21472	37	0.36	117258
Preble	12	0.17	18071	18	0.34	52846	29	0.31	78188
Shelby	12	0.17	18071	14	0.41	50100	35	0.32	97907
Union	12	0.17	18071	24	0.34	70461	30	0.30	78639

Table 9 shows the capacities for biomass power plant capacity, which is around (27 to 43) MW, is greater than solar and wind power plants capacities that because using all the biomass available in the seven counties to produce maximum electricity for demand. On the other hand, Wind power plants capacity that is from (2 to 24) MW, is more than the solar power plant that about (2 and 14) MW. The wind capacity is chosen to produce most energy after biomass because the power generated of wind is lowest cost comparing with solar and biomass energy as shown in Chapter 8.

The next Figures (18 to 24) present monthly power plants productions, cumulative energy, and import / export energy at every hour for the seven counties. The monthly power plant plot shows the monthly electricity demand with monthly wind, solar, and biomass energy production. The monthly power plants productions figures have colored lines to present the electricity demand, which is presented with blue dots comparing with electricity produced of solar, wind, and biomass. The blue base line is shown electricity produced of solar, and the black line is for electricity generated of solar plus wind. The red line is combined of electricity generated of wind, solar, and all available biomass.

The import and export energy plot presents energy at every hour, which is importing energy when generated energy of the renewable sources is less than electricity consumption and export energy when the produced energy more electricity consumption. The import and export energy plot at every hour for the counties, shows that the three power plants do not produce energy met for the electricity demand. However, the total yearly energy produced of the renewable sources are same as the total yearly electricity demand.

The cumulative energy at every hour is present that most of the counties started with energy less than zero because the electricity demand is stated at high point as explained at Figure 2

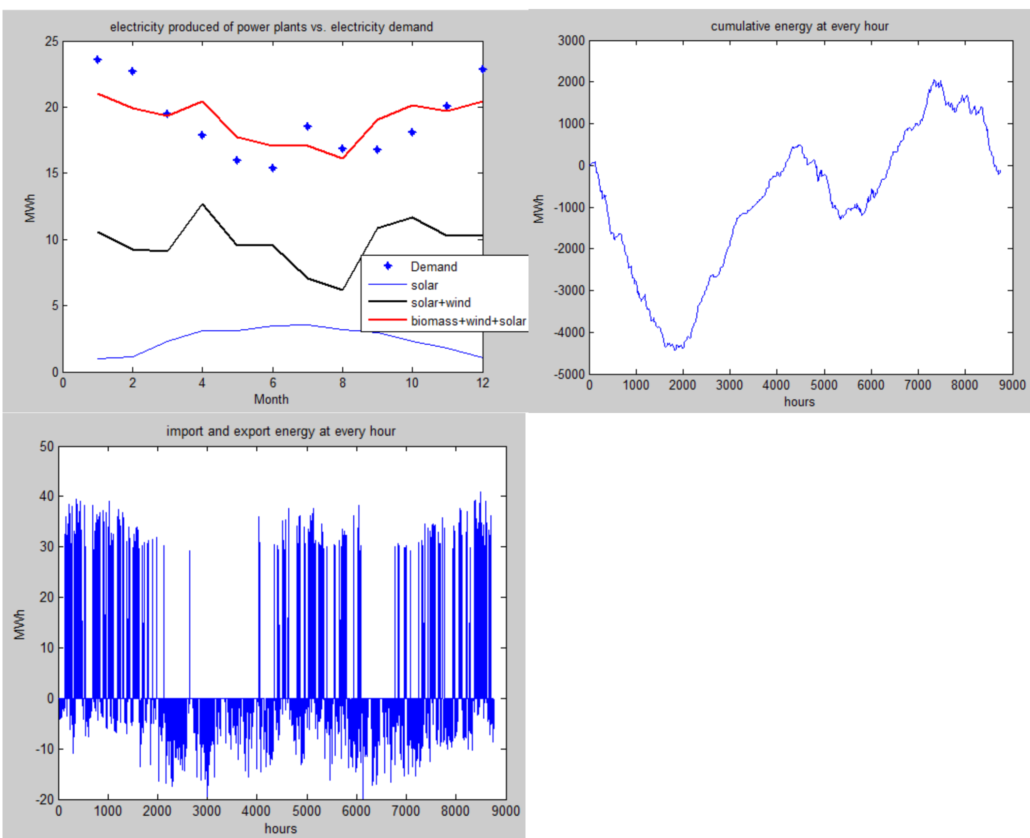


Figure 18: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Auglaize

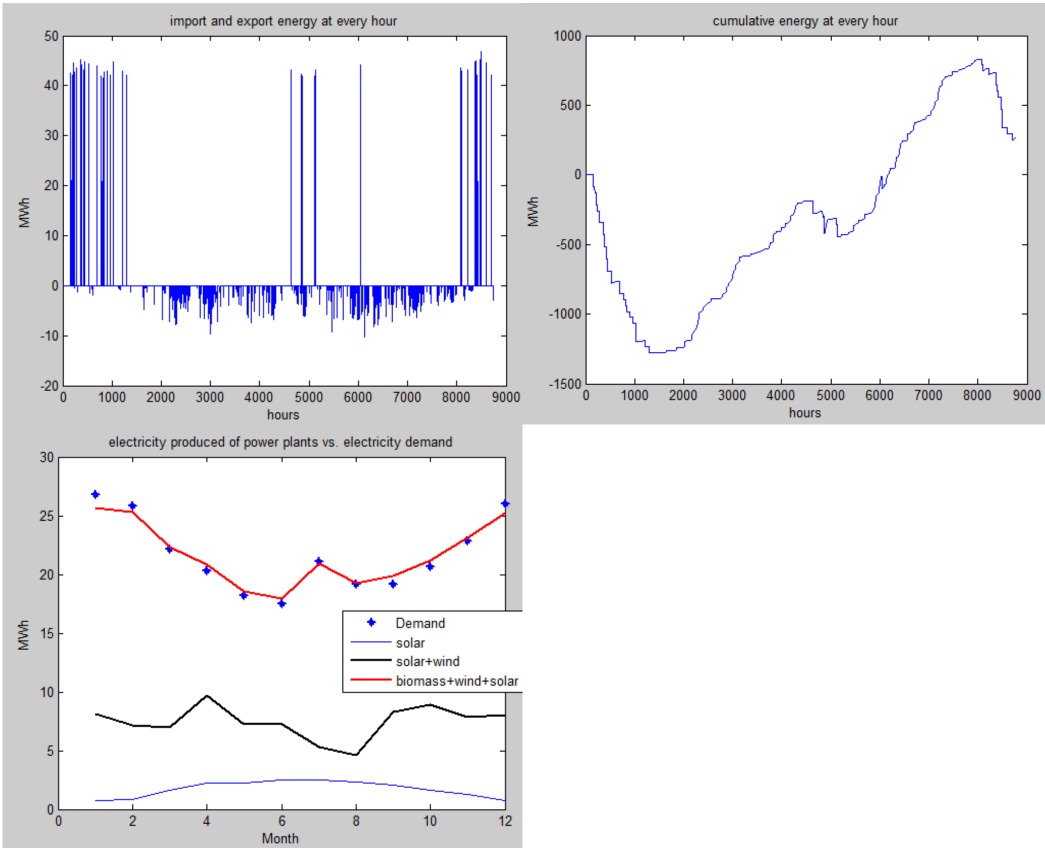


Figure 19: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Darke

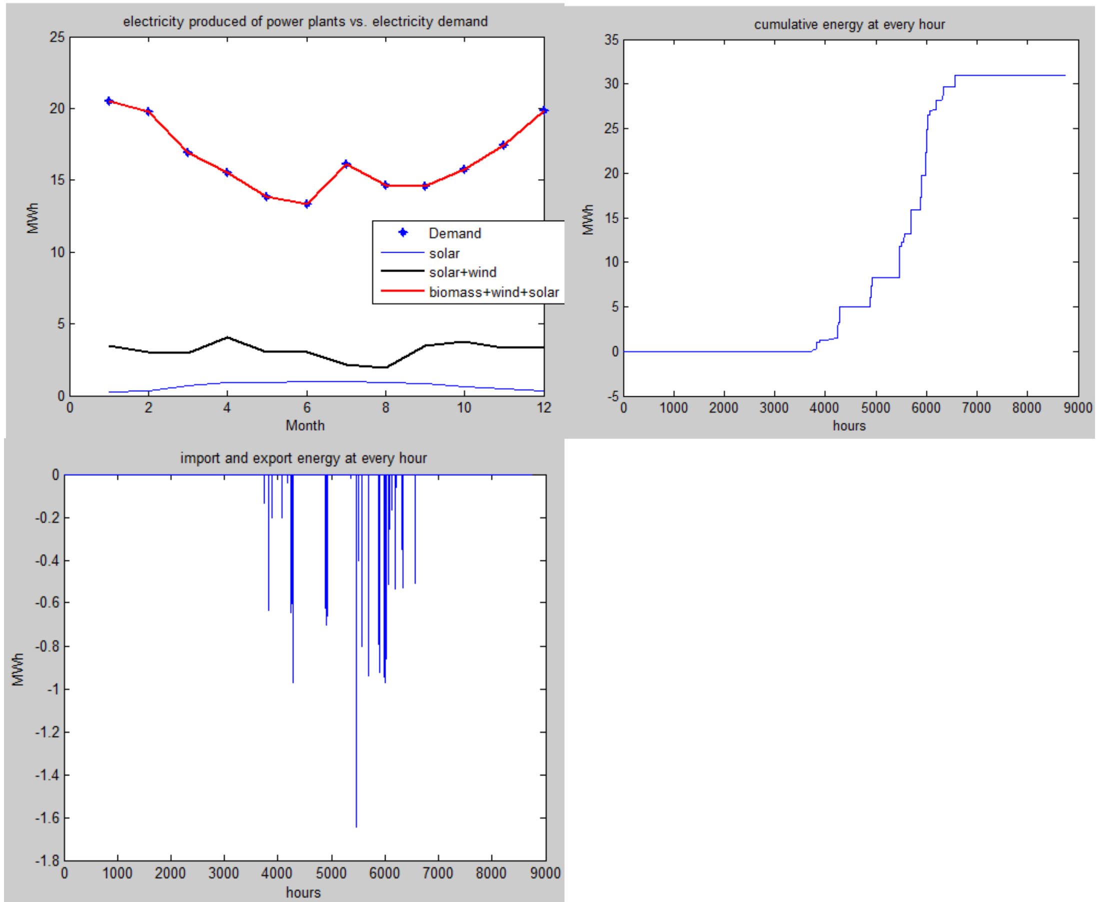


Figure 20: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Mercer

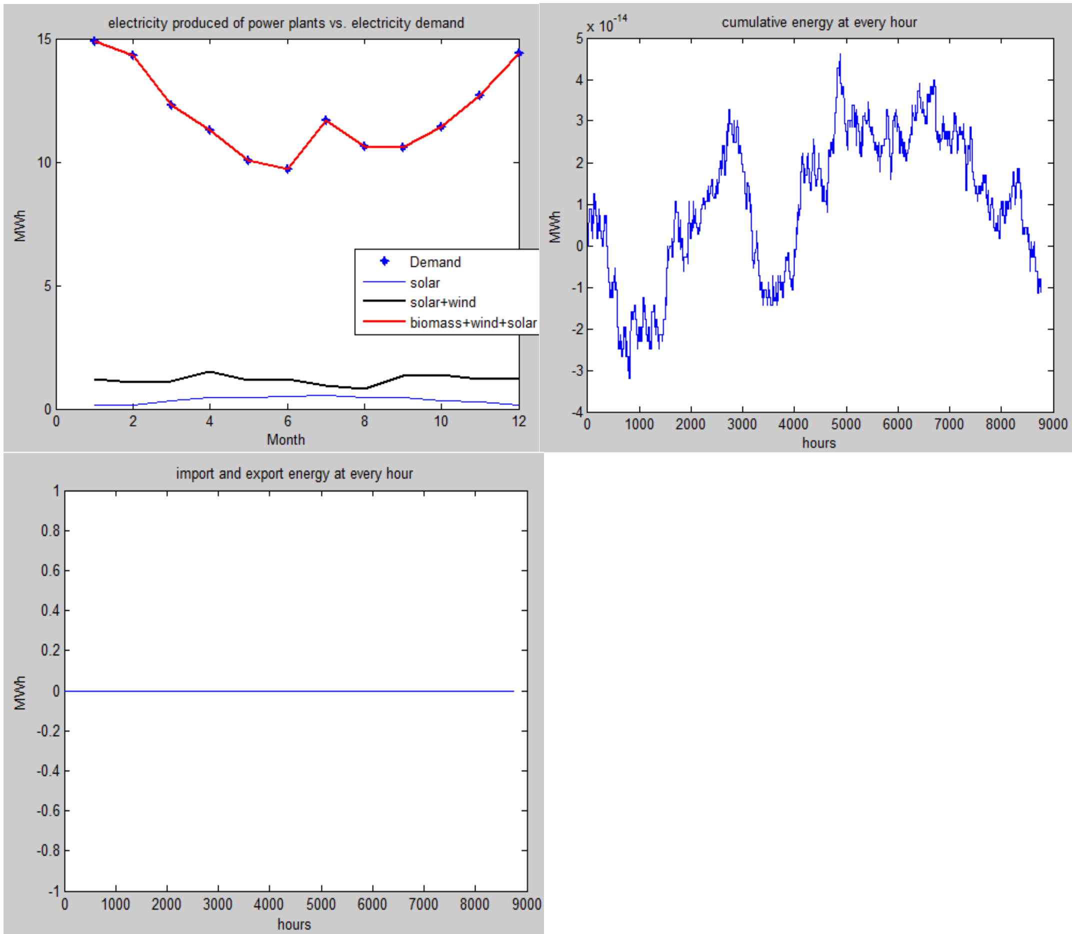


Figure 21: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Fayette

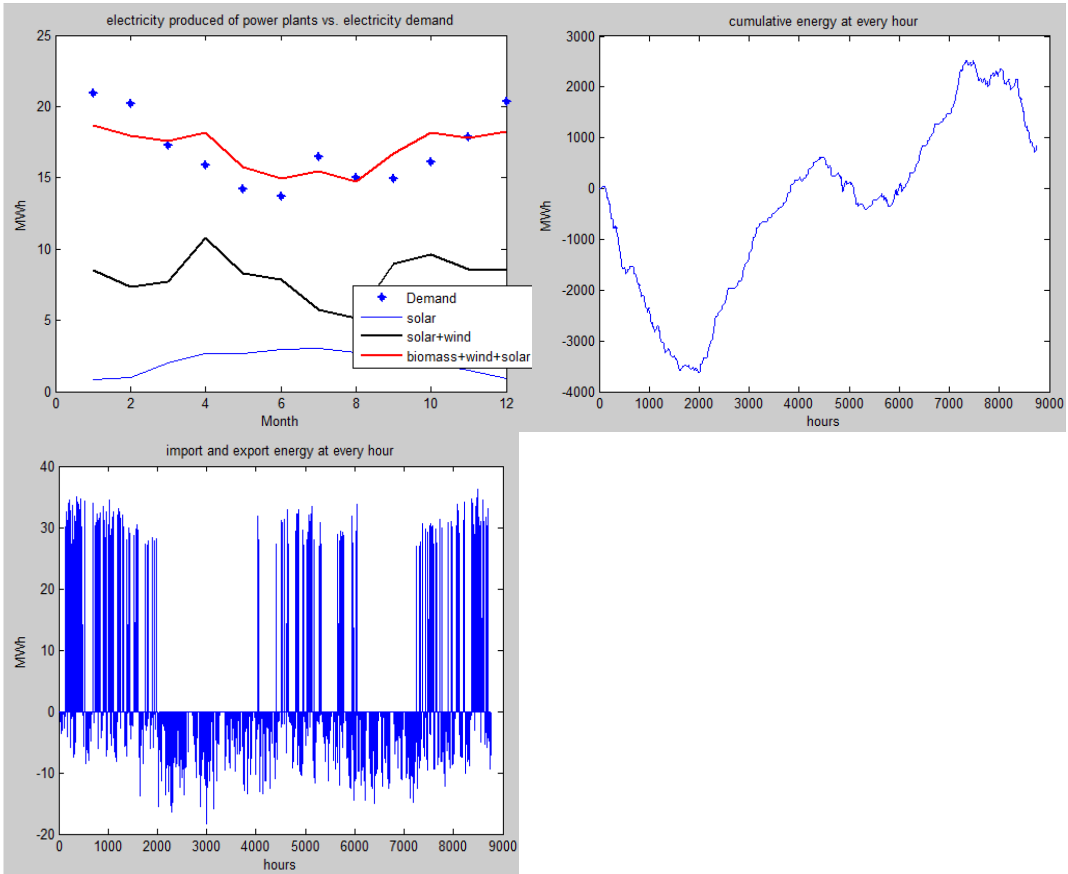


Figure 22: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Preble

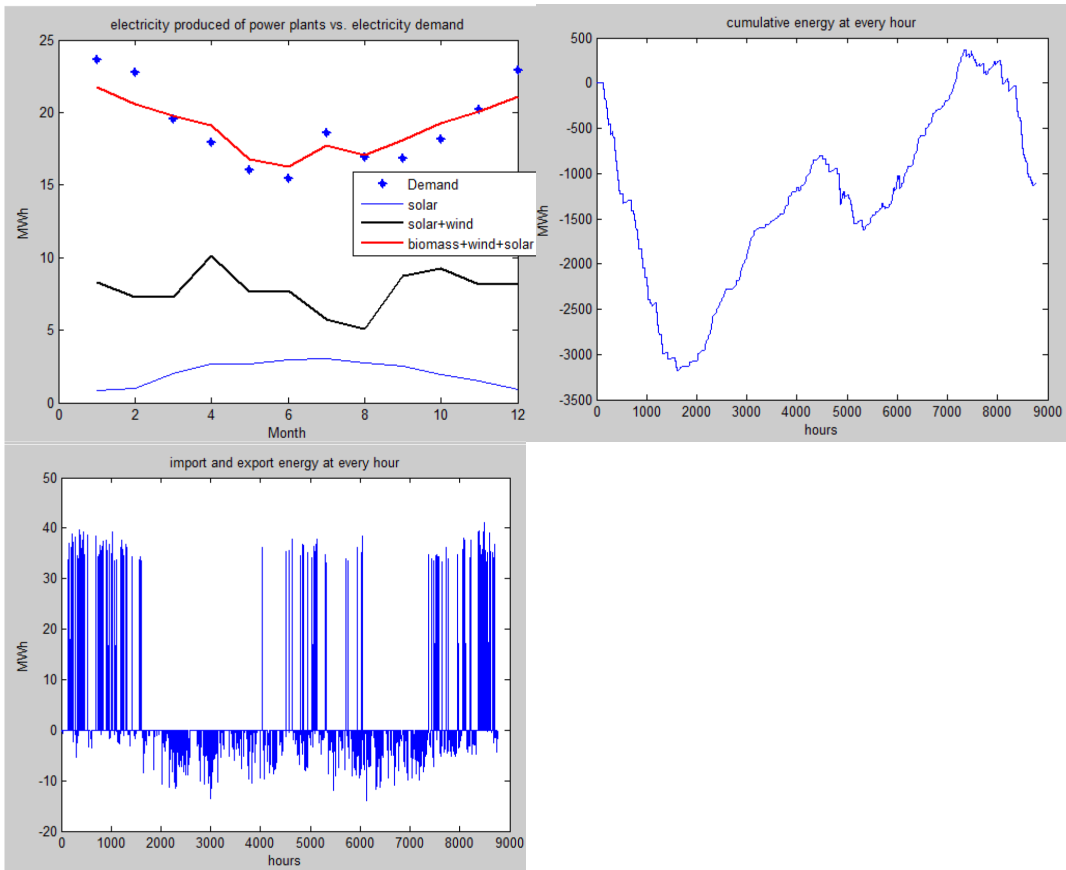


Figure 23: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Shelby

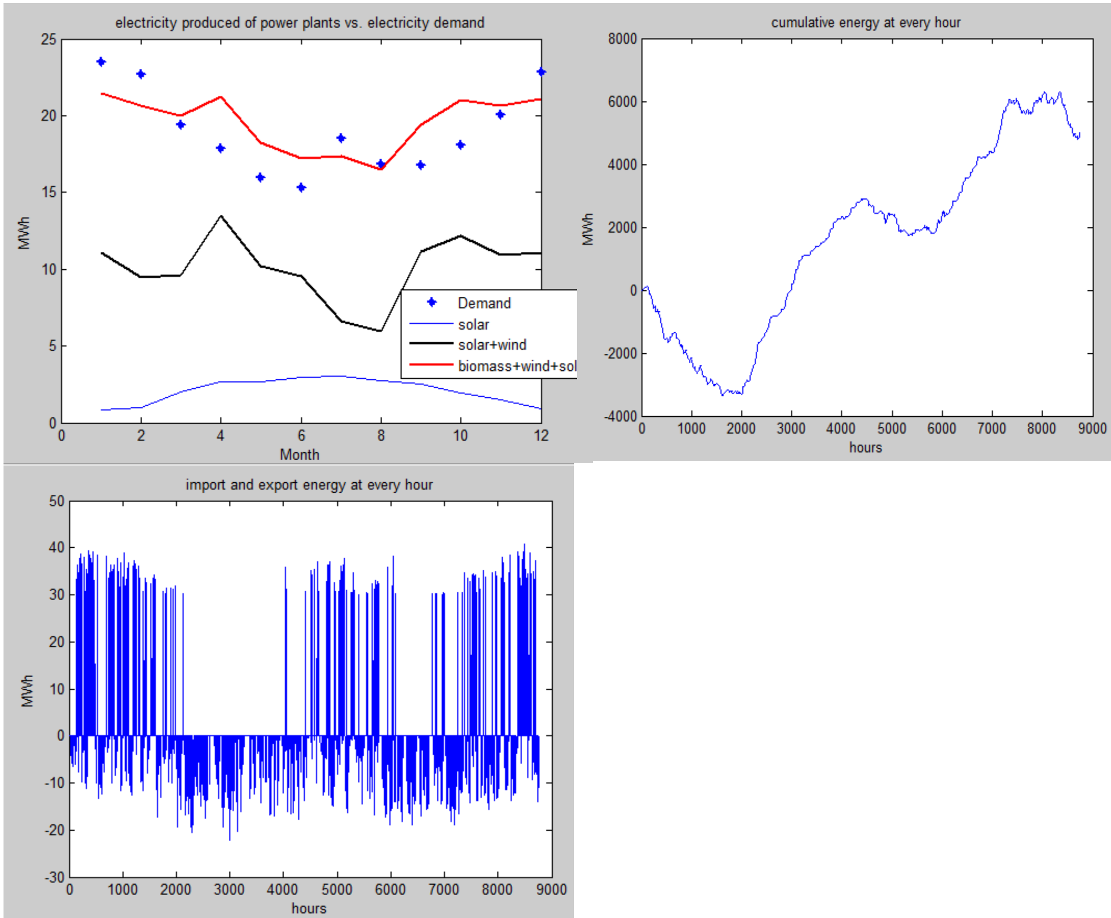


Figure 24: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Union

7.2: Using Biomass to Produce Hot Water

The second case to size the new system of power plants is depending on the hot water. After sizing a combined heat and power to provide heat for hot water, the electricity generated by that system is can be calculated as is presented in Table 10.

The capacity of biomass power plant is found by looking at the maximum value of electricity produced by using biomass used hourly hot water. After finding the biomass plant capacity and calculate energy produced, the wind and solar power plant capacities are sized to meet electricity demand that is leftover. See Table 10.

Also, the table shows the capacity factors that is calculated using equation 7.

Table 10: Power plants capacities and yearly productions using biomass depending on hot water needed

County	Renewable Sources								
	Solar			Wind			Biomass		
	Capacity (MW)	Capacity factor	MWh/yr	Capacity (MW)	Capacity factor	MWh/yr	Capacity (MW)	Capacity factor	MWh/yr
Auglaize	16	0.17	24095	26	0.41	92757	12	0.48	49050
Darke	18	0.17	27107	29	0.41	103922	13	0.48	56660
Fayette	10	0.17	15059	16	0.41	57258	8	0.48	31918
Mercer	10	0.17	15059	24	0.41	85886	10	0.48	44154
Preble	14	0.17	21083	28	0.34	82205	11	0.48	44490
Shelby	16	0.17	24095	26	0.41	93044	12	0.48	50359
Union	20	0.17	30118	28	0.34	82205	12	0.48	51082

In a case of using biomass depending on hot water as shown in Table 10, the capacities for biomass power plant capacity, which is around (8 to 13) MW, is less than solar and wind power plants capacities that because using biomass at least to provide heat for hot water demand for the counties. On another hand, Wind power plants capacity that are from (16 to 28) MW, is more than biomass and solar power plant capacities that is abound (10 and 20) MW. The reason for choosing wind energy capacity it is same for other cases, which is wind energy produced is less cost than energy produced by solar and biomass.

In case used biomass depend on hot water needed, the next Figures (25 to 31) present monthly power plants productions, cumulative energy, and import / export energy at every hour for the seven counties. The monthly power plant plot shows the monthly electricity demand with monthly wind, solar, and biomass energy production. The monthly power plants productions figures, which is presented in different colored lines, is shown electricity consumption with comparing with electricity produced from solar, wind, and biomass. The green line is shown electricity produced of solar, and the black line is for electricity generated of solar plus wind. The red line is combined of electricity generated of wind, solar, and all available biomass.

The import and export energy plot at every hour for the counties, shows that the three power plants do not produce energy met for the electricity demand. However, the total yearly energy produced of the renewable sources are same as the total yearly electricity demand.

The cumulative energy at every hour is present that the energy at some hours is less than zero because the electricity consumptions at some hours are more than generated energy from the renewable energy sources. See Figure 10

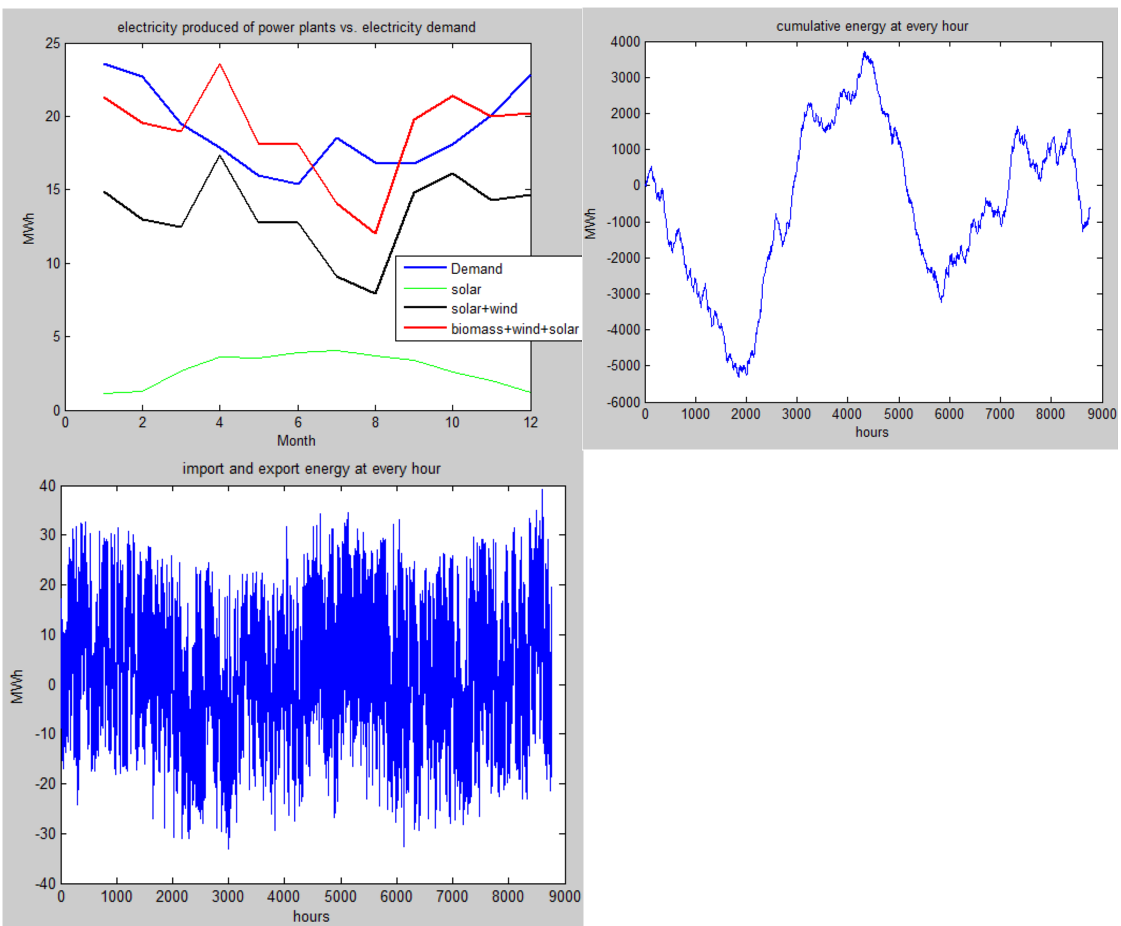


Figure 25: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Auglaize

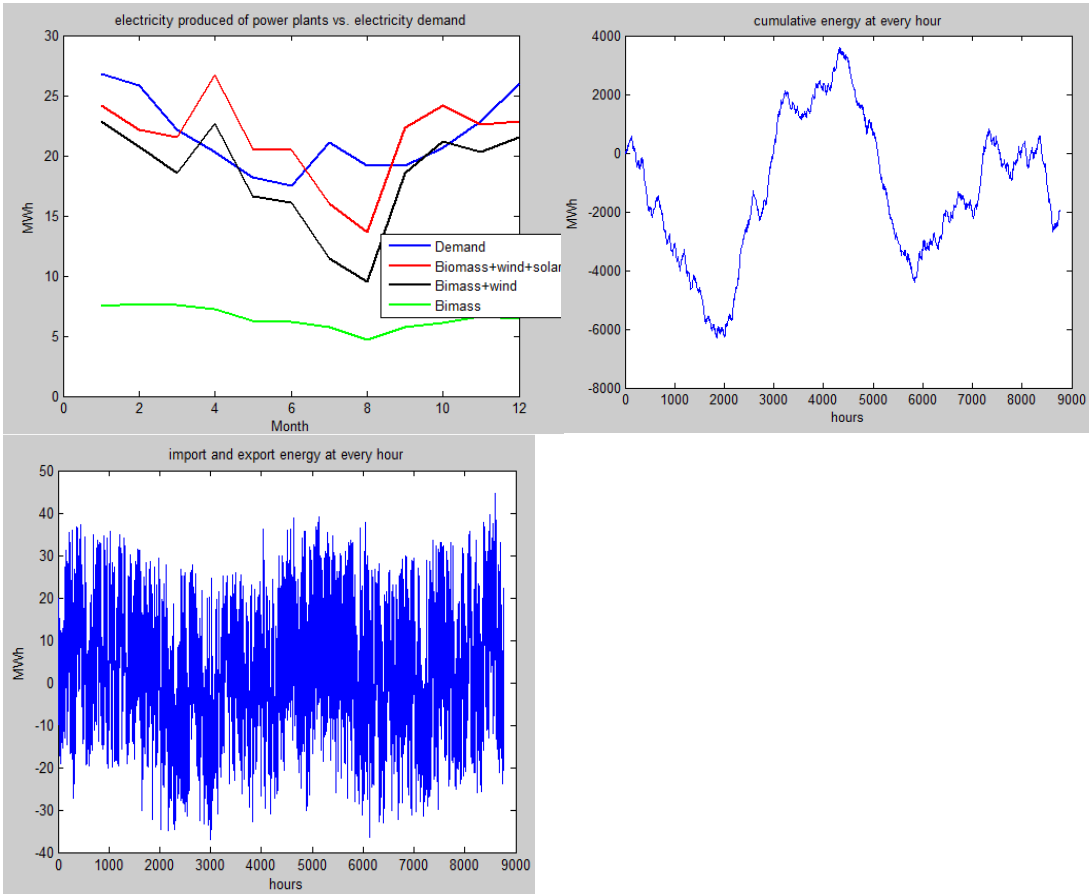


Figure 26: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Darke

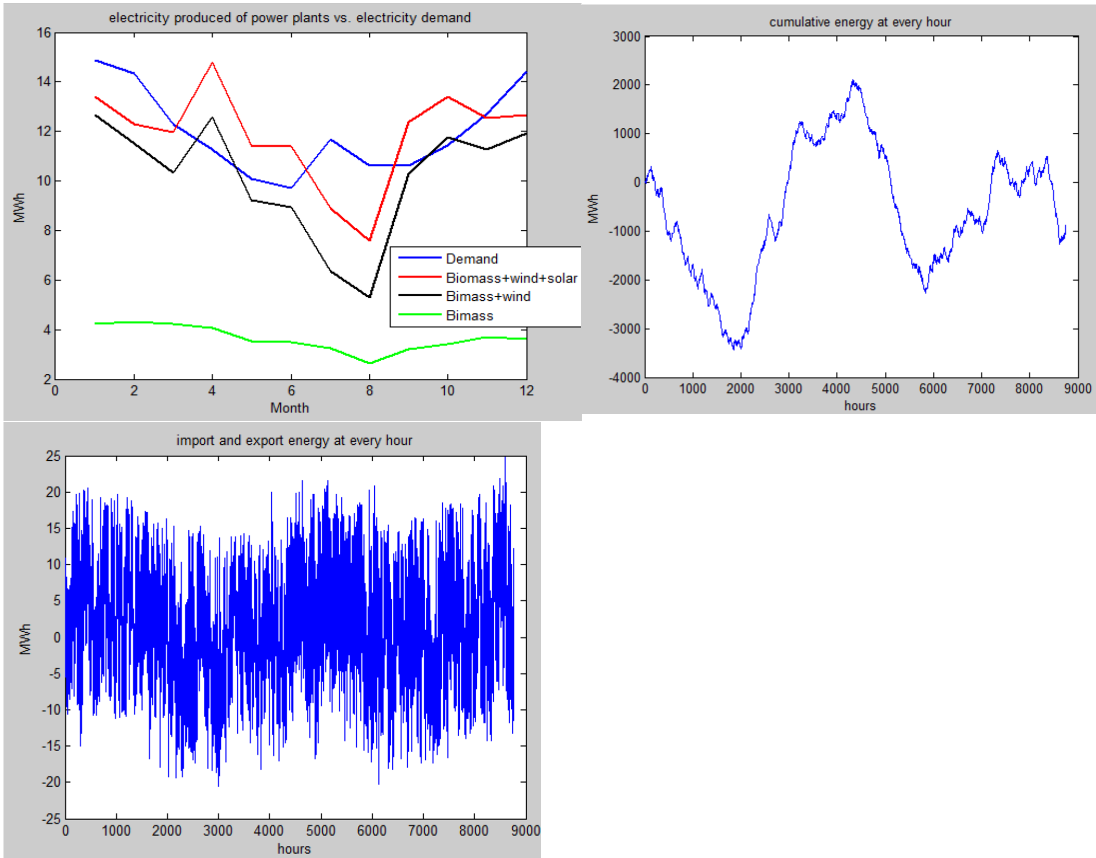


Figure 27: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Fayette

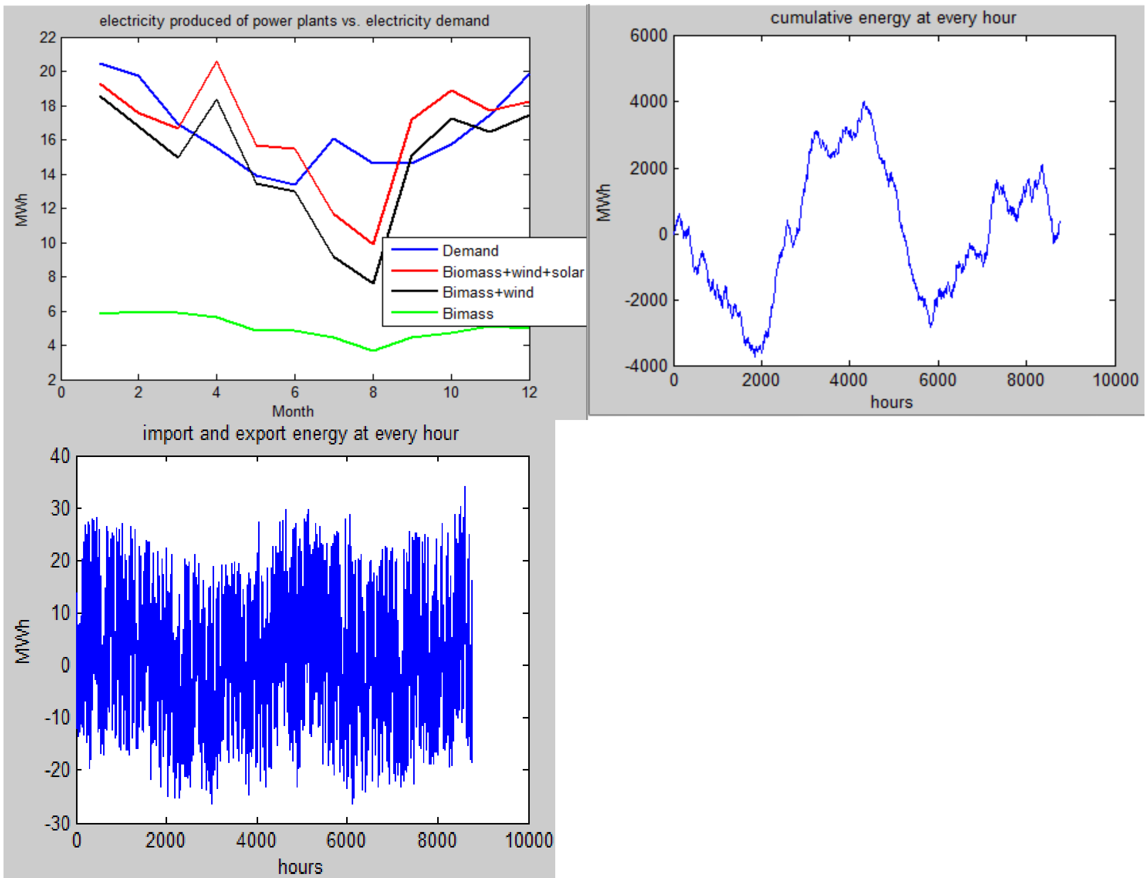


Figure 28: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Mercer

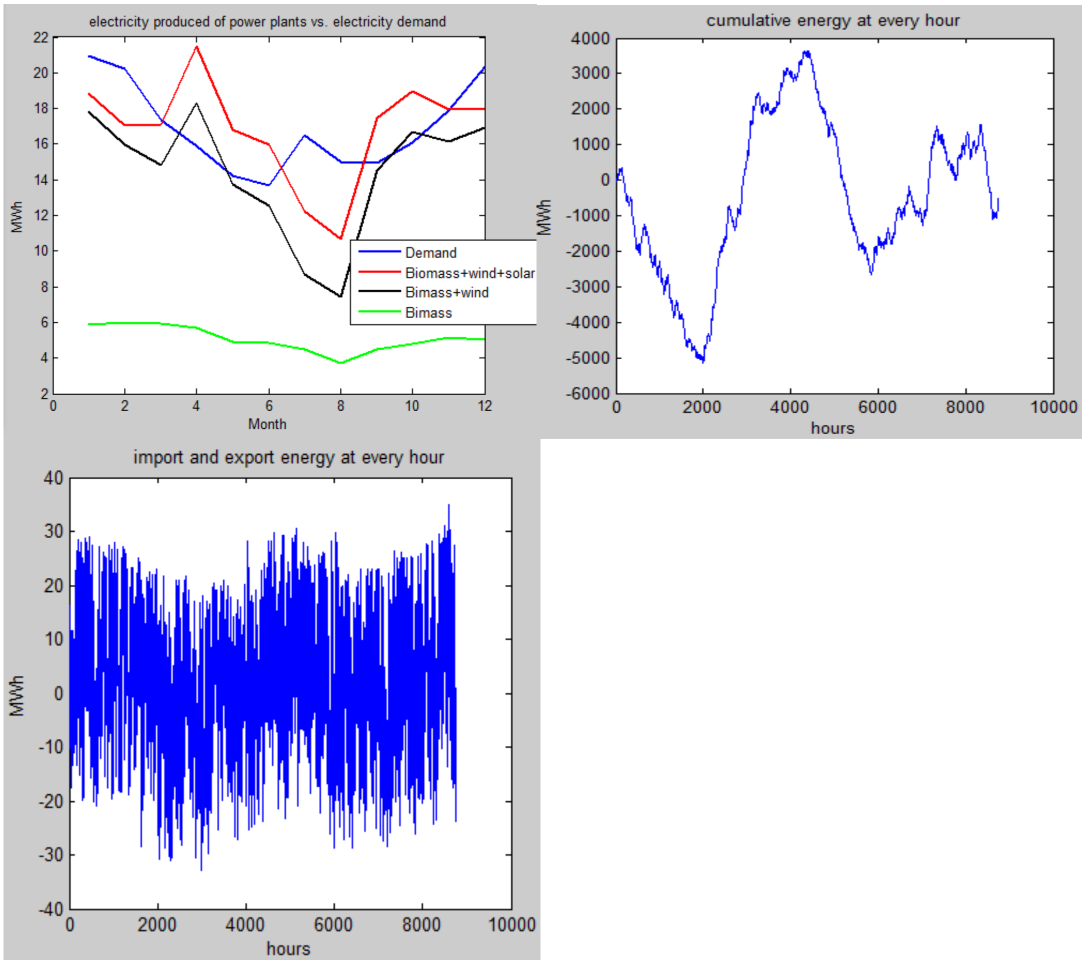


Figure 29: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Preble

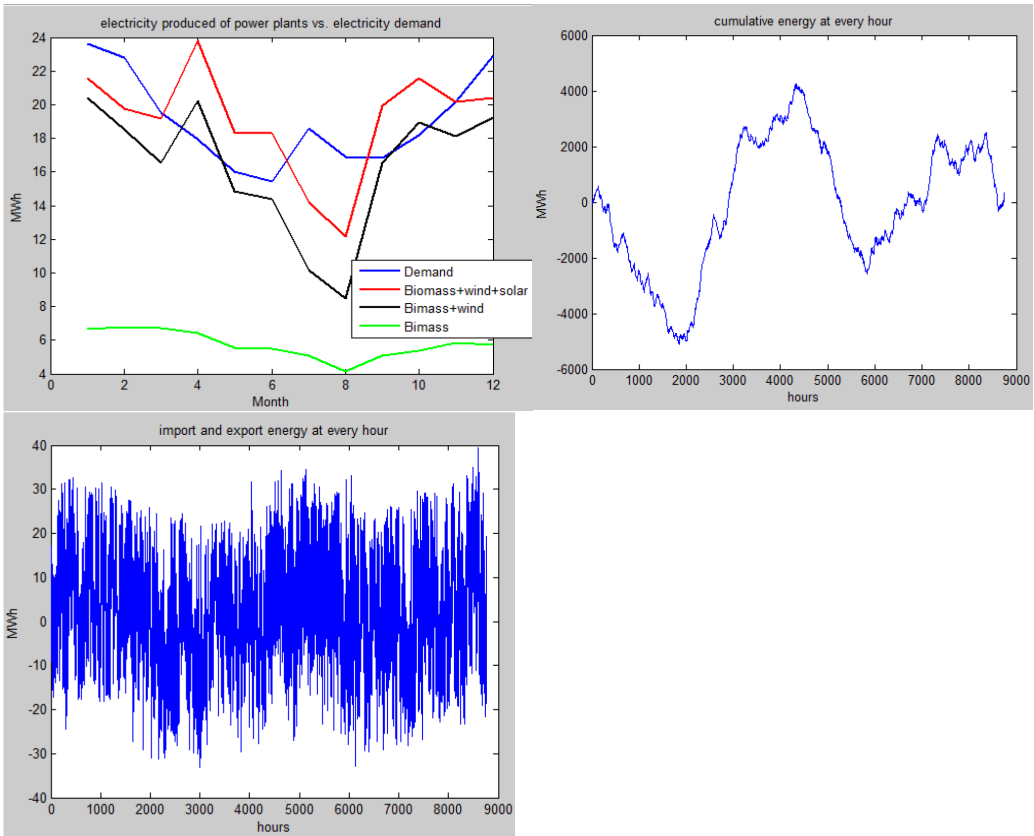


Figure 30: Monthly power plants productions and import / import energy at every hour for Shelby

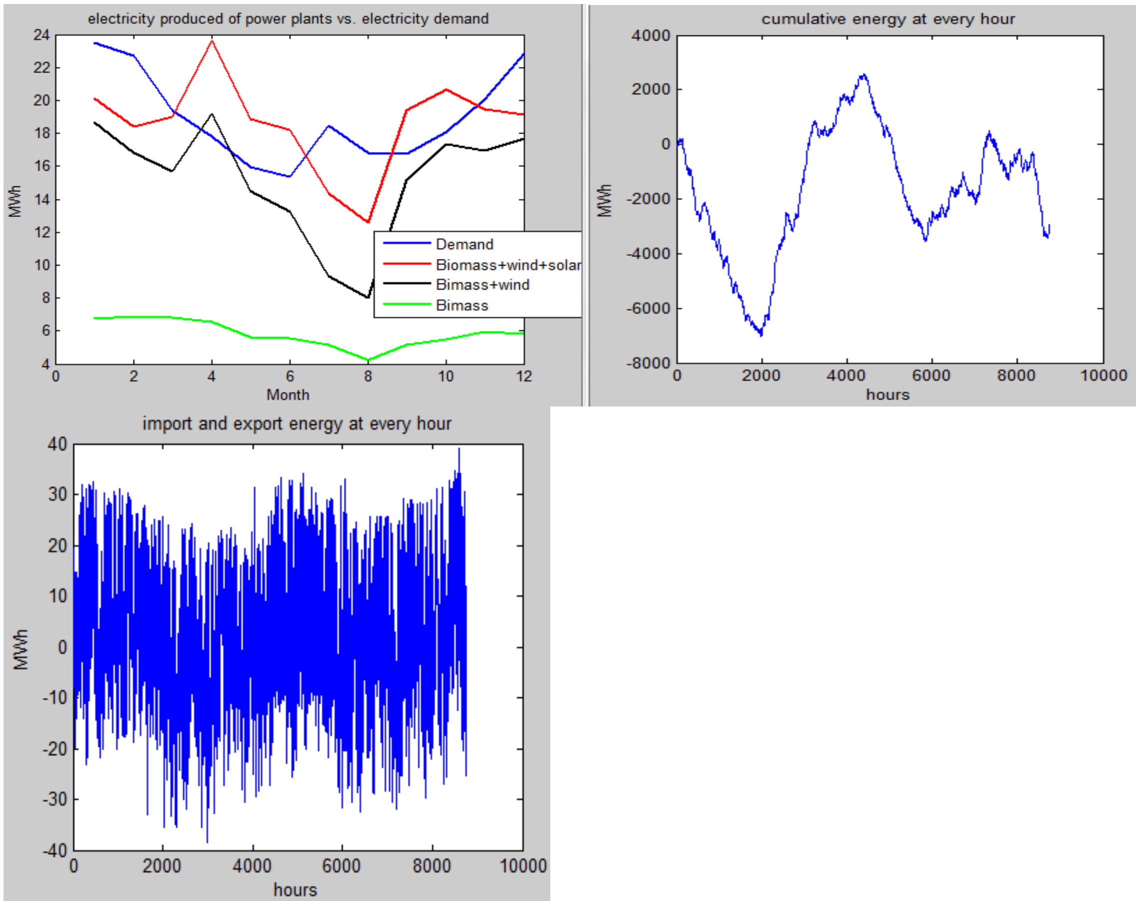


Figure 31: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Union

7.3: Using Certain Amount of Biomass

In this case, the capacity of wind and solar power plants will be sized before the biomass plant capacity. Because the wind energy is cheaper than solar as it explains in Table 15, choosing Wind power plant capacity is choosing to be more than solar capacity as shown in Table 11. The rest of the electricity demand will be fed by sizing a combined heat and power. See Table 11.

Table 11: Power plants capacities and yearly productions using certain amount of biomass

County	Renewable Sources								
	Solar			Wind			Biomass		
	Capacity (MW)	Capacity factor	MWh/yr	Capacity (MW)	Capacity factor	MWh/yr	Capacity (MW)	Capacity factor	MWh/yr
Auglaize	12	0.17	18071	20	0.41	71572	30	0.29	77088
Darke	16	0.17	24095	24	0.41	85886	32	0.28	79518
Fayette	8	0.17	12047	14	0.41	50100	15	0.33	43873
Mercer	12	0.17	18071	18	0.41	64415	24	0.29	61991
Preble	12	0.17	18071	22	0.34	64589	24	0.30	63487
Shelby	12	0.17	18071	20	0.41	71572	30	0.29	77320
Union	12	0.17	18071	24	0.34	70461	30	0.30	78639

Table 11 presents the case of using biomass depending electricity demand leftover after using wind and solar energy, the capacities for biomass power plant capacity, which is around (15 to 30) MW, is a little more than solar and wind power plants capacities. On another hand, Wind power plants capacity that is from (14 to 28) MW, is located between the biomass and solar power plant capacities that are abound (8 and 16) MW.

The next Figures (32 to 38) present monthly power plants productions, cumulative energy, and import / export energy at every hour for the seven counties. The monthly power plant plot shows the monthly electricity demand with monthly wind, solar, and biomass energy production. The monthly power plants productions figures have colored lines to present the electricity demand, which is presented with blue dots comparing with electricity produced of solar, wind, and biomass. The blue base line is shown electricity produced of solar, and the black line is for electricity generated of solar plus wind. The red line is combined of electricity generated of wind, solar, and all available biomass.

The import and export energy plot at every hour for the counties, shows that the three power plants do not produce energy met for the electricity demand. However, the total yearly energy produced of the renewable sources are same as the total yearly electricity demand.

The cumulative energy at every hour is present that most of the counties started with energy less than zero because the electricity demand is stated at high point as explained at Figure 10

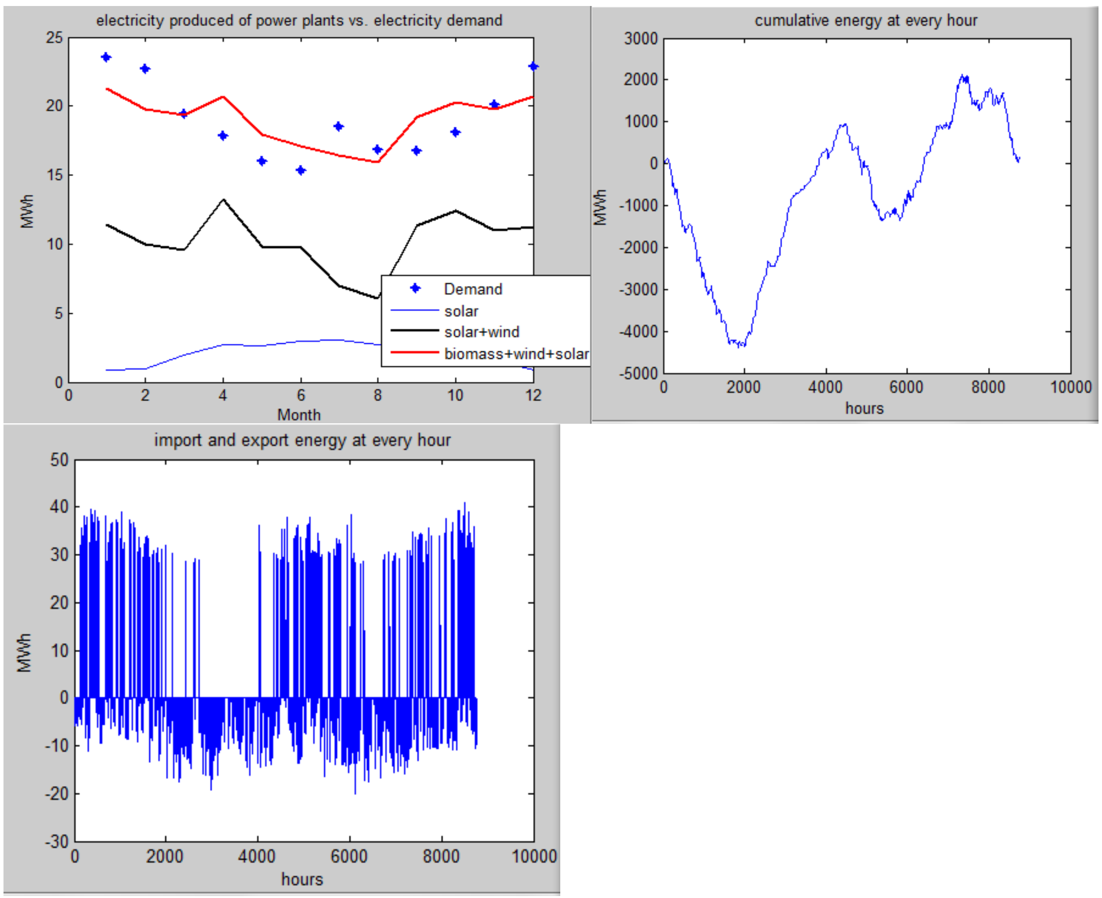


Figure 32: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Auglaize

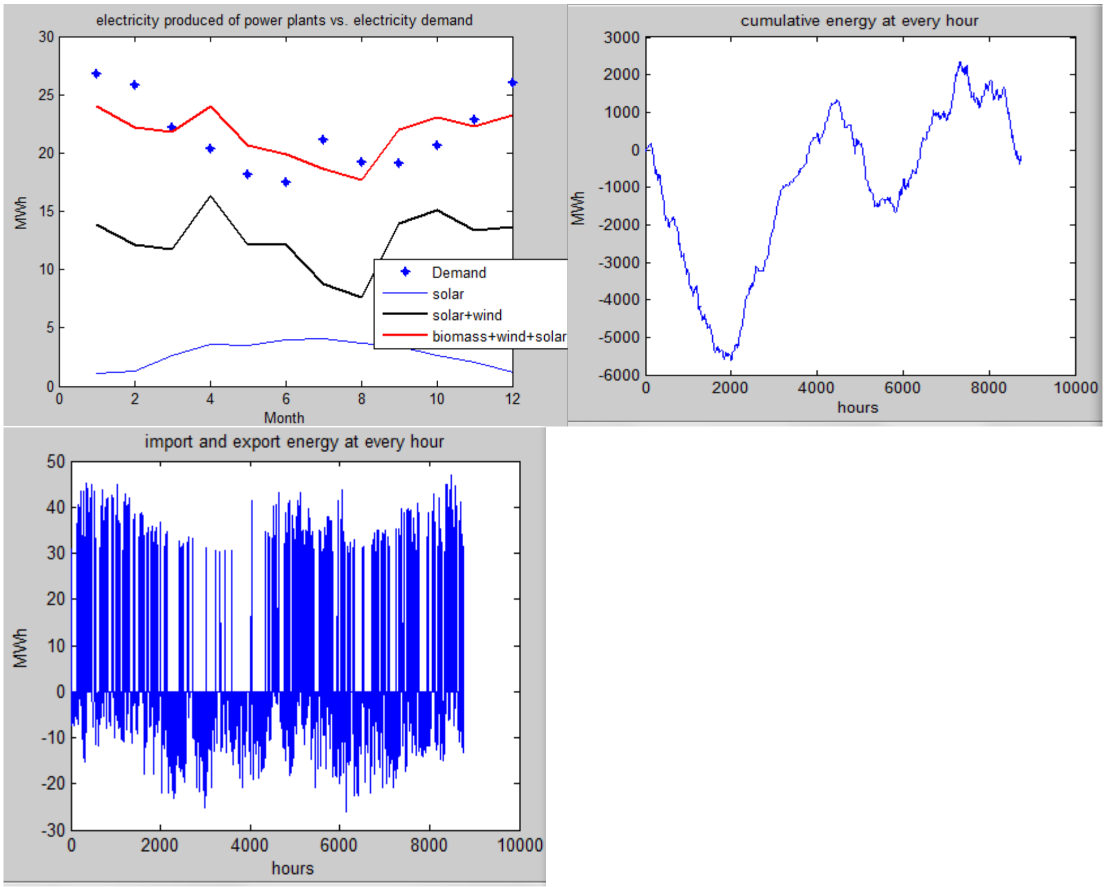


Figure 33: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Darke

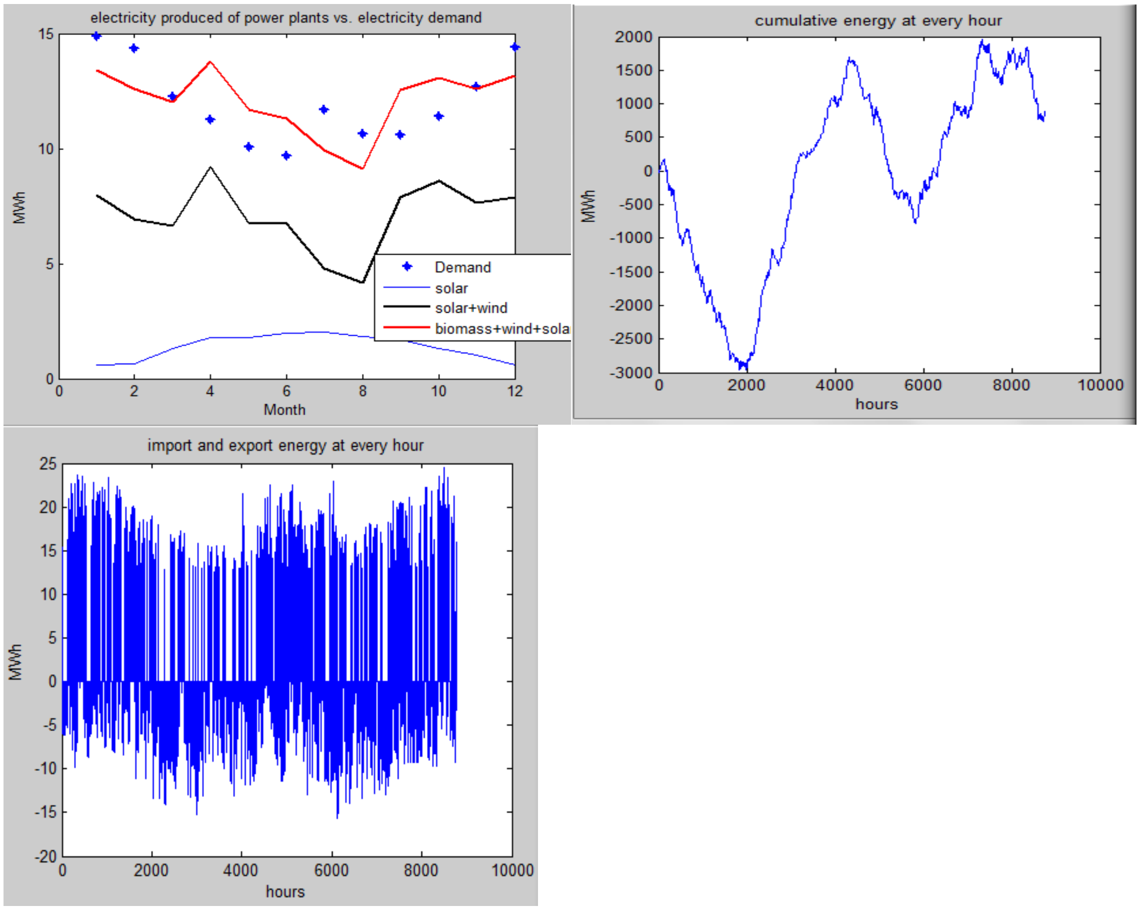


Figure 34: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Fayette

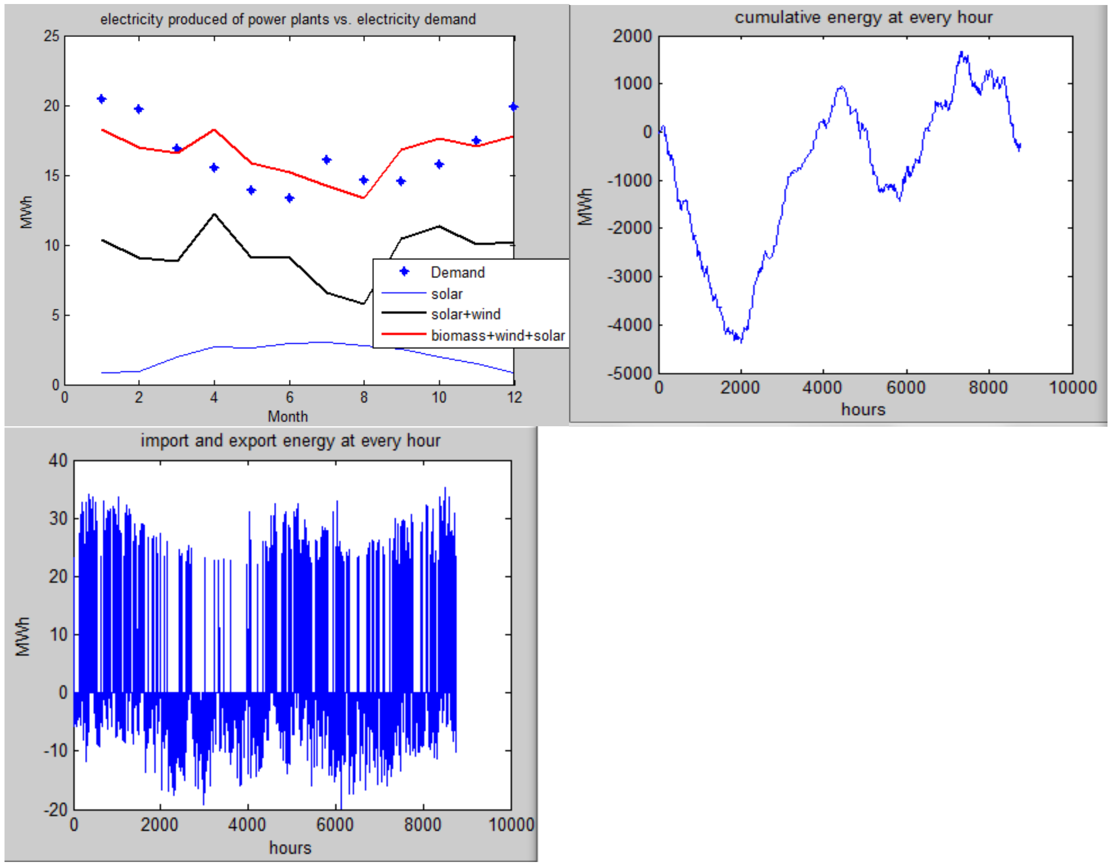


Figure 35: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Mercer

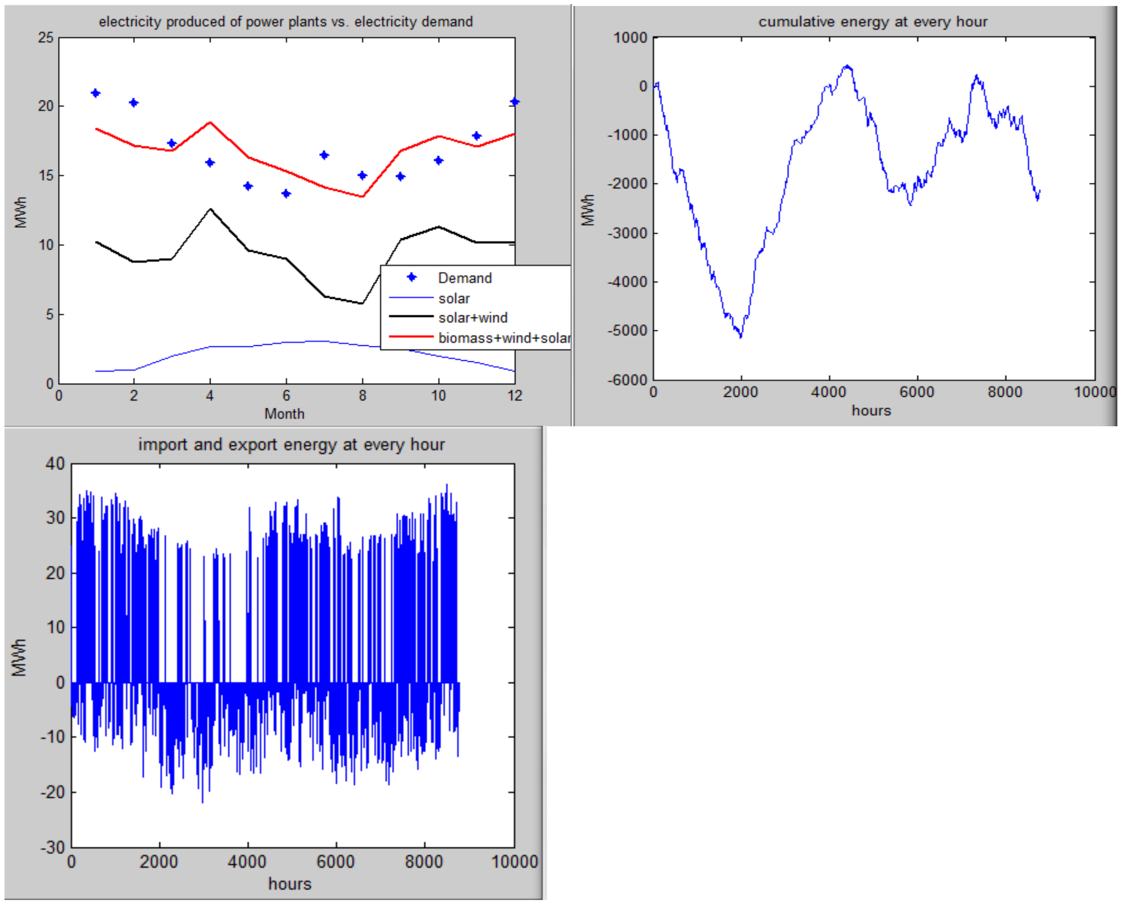


Figure 36: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Preble

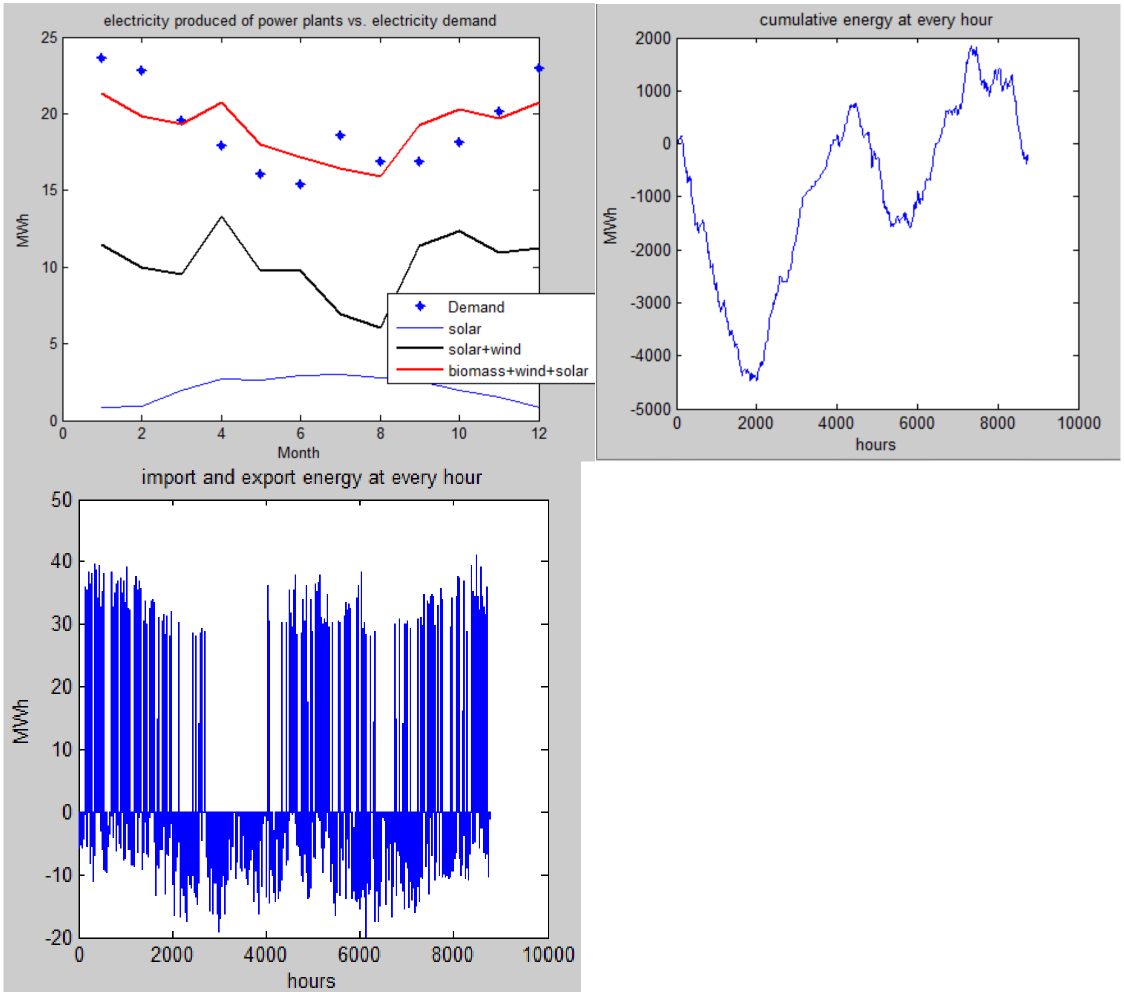


Figure 37: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Shelby

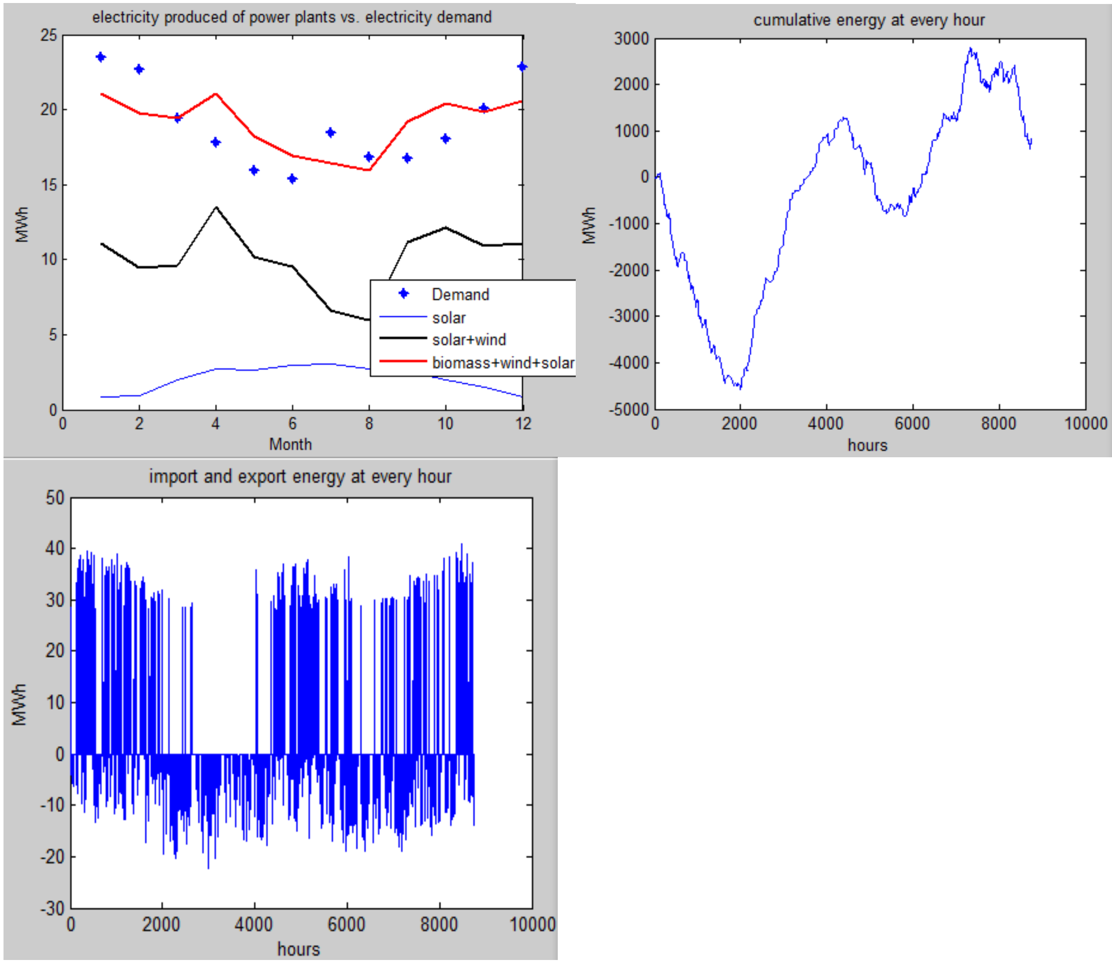


Figure 38: Monthly power plants productions, cumulative energy, and import / import energy at every hour for Union

CHAPTER 8

POWER PLANT COST

8.1: Levelized Cost of Energy

Calculating the Levelized Cost of Energy (LCOE) for energy produced from sun, wind and biomass is done by the equation:

*sLCOE = {(overnight capital cost * capital recovery factor + fixed O&M cost)/ (8760 * capacity factor)} + (fuel cost * heat rate) + variable O&M* 8

According to [23] "Where overnight capital cost is measured in dollars per installed kilowatt ($/kW), capital recovery factor is a fraction calculated as described above. Fixed Operation and Maintenance (O&M) costs in dollars per kilowatt-year ($/kW-yr) and variable O&M costs in dollars per kilowatt-hour ($/kWh). In the denominator 8760 is the number of hours in a year and capacity factor is a fraction between 0 and 1 representing the portion of a year that the power plant is generating power. Fuel cost is expressed in dollars per million British thermal units ($/MMBtu) and heat rate is measured in British thermal units per kilowatt-hour (Btu/kWh). Fuel cost is optional since some generating technologies like solar and wind do not have fuel costs."

CRF = {i (1 + i) ^n} / {[(1 + i) ^n]-1}.. 9

According to NERL [23] “where n is the number of annuities received. This is related to the annuity formula, which gives the present value in terms of the annuity, the interest rate, and the number of annuities.”

Assuming, the number of annuities received is 20 and interest rate is 0.3, then:

Capital recovery factor (CRF) = (0.03*(1+0.03) ^20)/ (((1+0.03) ^20)-1) = 0.067

The Capacity factor= total energy produced (MWh)/ (plant capacity * 7860).

1.1.1 Levelized Cost of Solar,

Overnight capital cost (installing cost) = 2025 $/kW [24]

Fixed O&M costs= 16 ($/kW-yr.) [24]

Fuel cost, heat rate, and variable O&M for solar energy is zero [24]

1.1.2 Levelized Cost of Wind:

Overnight capital cost (installing cost) = 2346 $/kW [24]

CRF = (0.03*(1+0.03) ^20)/ (((1+0.03) ^20)-1) = 0.067

Fixed O&M costs= 33 ($/kW-yr.) [24]

Fuel cost, heat rate, and variable O&M for wind energy is zero [24]

1.1.3 Levelized Cost of Biomass Combustion Combined Heat & Power:

Overnight capital cost (installing cost) = 5792 $/kW [24]

CRF = (0.03*(1+0.03) ^20)/ (((1+0.03) ^20)-1) = 0.067

Fixed O&M costs= 98 ($/kW-yr.) [24]

Heat rate =0.012300 MBtu/kWh

Variable O&M = 0.04 $/kWh [24]

Fuel and/or water cost = 0.04 (\$/kWh) = 0.04\$/kWh /heat rate= 3.25 \$/MBtu

Then, by using equation 8 to find the electricity cost for solar, wind, and biomass plants, the prices are presented in Tables 12, 13, and 14 for the three cases of using the biomass .

Table 12: Solar, wind, and biomass prices for the counties using all biomass

County	Solar		Wind		Biomass	
	percentage	$/kWh	percentage	$/kWh	percentage	$/kWh
Auglaize	0.13	0.10	0.39	0.05	0.49	0.26
Darke	0.08	0.10	0.26	0.05	0.66	0.25
Fayette	0.03	0.10	0.07	0.05	0.90	0.21
Mercer	0.04	0.10	0.15	0.05	0.81	0.23
Preble	0.12	0.10	0.36	0.06	0.53	0.26
Shelby	0.11	0.10	0.30	0.05	0.59	0.25
Union	0.11	0.10	0.30	0.05	0.59	0.26

Table 13: Solar, wind, and biomass prices for the counties using biomass depending on hot water

County	Solar		Wind		Biomass	
	percentage	$/kWh	percentage	$/kWh	percentage	$/kWh
Auglaize	0.14	0.10	0.56	0.05	0.29	0.19
Darke	0.14	0.10	0.55	0.05	0.30	0.194
Fayette	0.14	0.10	0.54	0.05	0.30	0.19
Mercer	0.10	0.10	0.59	0.05	0.31	0.19
Preble	0.14	0.10	0.55	0.06	0.30	0.19
Shelby	0.14	0.10	0.56	0.05	0.30	0.19
Union	0.18	0.10	0.49	0.06	0.31	0.19

Table 14: Solar, wind, and biomass prices for the counties using certain amount of biomass.

County	Solar		Wind		Biomass	
	percentage	$/kWh	percentage	$/kWh	percentage	$/kWh
Auglaize	0.11	0.10	0.43	0.05	0.46	0.27
Darke	0.13	0.10	0.45	0.05	0.42	0.275
Fayette	0.11	0.10	0.48	0.05	0.42	0.24
Mercer	0.12	0.10	0.45	0.05	0.43	0.26
Preble	0.12	0.10	0.44	0.06	0.43	0.26
Shelby	0.11	0.10	0.43	0.05	0.46	0.268
Union	0.11	0.10	0.42	0.06	0.47	0.26

The three tables are shown that the cost for energy produced is cheaper when used biomass depend on hot water needed for the counties. See Table 13.

8.2: Total Electricity Cost

To find the mean prices solar, wind, and before all counties, the next equation is used:

$/ kWh= (solar cost solar percentage) + (wind cost* wind percentage) + (Biomass cost * Biomass percentage)……10*

Table 15: Total electricity prices for different Biomass amount

County	Used all biomass ($/kWh)	Biomass for hot water needed ($/kWh)	Biomass for electricity needed ($/kWh)
Auglaize	0.160	0.100	0.16
Darke	0.187	0.101	0.15
Fayette	0.196	0.101	0.14
Mercer	0.198	0.100	0.15
Preble	0.172	0.107	0.15
Shelby	0.173	0.101	0.16
Union	0.15	0.109	0.16

The final prices for the three cases are shown in table 15. The best price of new system of renewable sources is when use biomass depending on heat provided for hot water demand used by the counties.

8.3: Comparing Current Energy Prices With Power Plants Energy Produced Prices.

Calculating current energy yearly cost for electricity per households is by using the equation:

Total current energy cost ($/yr.) = [Electricity cost ($/kWh) Yearly electricity consumption (kWh/yr)] + [Heating cost ($/MBtu)* heat needed for hot water (MBtu/yr)………………………………………………………………………………………..……11*

Where:

Assumed, Electricity cost = 0.06 $/kWh

Heating cost = 9 $/MBtu [25]

The yearly electricity consumption for each households is shown in Figure 2, which is 9130 (kWh/yr-households), and the yearly heat needed for hot water is presented in figure 7.

Then the yearly current energy cost for electricity and hot water is shown in Table 16.

For the yearly energy produced of three renewable energy sources for electricity and hot water, the next equation is used:

Electricity cost for new system ($/yr) = Electricity cost for the one of the cases ($/kWh) yearly electricity consumption (kWh/yr)………12*

Where:

Electricity cos for the one of the cases ($/kWh) is presented in Table 15, and yearly electricity consumption (kWh/yr) per households is shown in Figure 2.

Comparing yearly prices for three options of using renewable energy for electricity and hot water with current energy cost is present in Table 16.

Table 16 : Yearly prices for electricity produced of renewable energy for the three cases and current electricity

Nu.	County	Used all biomass ($/yr. households)	Biomass for hot water needed ($/yr. households)	Biomass for electricity needed ($/yr. households)	Current Energy ($/yr. households)
1-	Auglaize	1461	913	1461	669
2-	Darke	1707	922	1370	669
3-	Fayette	1790	922	1278	669
4-	Mercer	1808	913	1370	669
5-	Preble	1570	977	1370	669
6-	Shelby	1580	922	1461	669
7-	Union	1370	995	1461	669

Table 16 shows that the total yearly energy cost per households for new system by using all biomass is more expensive .The total yearly cost for option using certain amount of biomass is less than cost using all biomass but higher than case using biomass depending on hot water. Build a power plant using biomass depending on hot water is best economical option as it is shown in Table 6. However, Table 16 shows that the yearly current cost per households, which is 593 $/yr, is lower than total yearly energy cost for three case of using new systems of renewable energy sources

CHAPTER 9

CONCLUSION

The object of this research is to examine the possibility of providing 100% renewable energy for electricity and hot water demand for residences in seven areas by utilizing three locally- available renewable energy sources. These areas are chosen because they are generally rural and have enough crop residue that biomass as an energy resource is potentially available. . In addition to readily available data at an hourly resolution for wind and solar insolation, hourly electricity demand and hourly heat needed for hot water is obtained from the OpenEI database, based on the Building America House Simulation Protocols [6].

The chosen region is based on TMY3 weather data for the area closest to the counties under investigation. The three renewable energy resources are solar energy as estimated for two locations in the region from National Renewable energy Laboratory (NREL), wind energy located in two locations in the region from the Wind Integration National database, and the available biomass located in the seven counties, as found in the National Renewable Energy Laboratory database.

Taking biomass as the resource to vary under different assumptions as to mode of use, three cases are chosen to determine power capacity for the three renewable energy sources. These three cases are: First, utilize all of the accessible biomass in the regions to generate electricity, and secondarily, to use the waste heat for hot water; second, scale the biomass power plant (assumed to be combined heat and power) to provide enough heat to cover for the total hot water demand; and third, to use biomass to meet residual electricity demand after estimating the solar and wind power plant outputs. For this thesis, there was no attempt made to cover electricity demand on an hourly basis, but rather as an average over the whole year.

The results of this work show that electricity costs are different from case to case, as determined by calculating a weighted, levelized cost of electricity for the system. The cost ($/kWh) for the second case, utilizing biomass to provide heat to cover total hot water demand, is the lowest price case. This result is not surprising, since biomass electricity was found to be more expensive per kWh, and the second case uses less biomass electricity.

Future work related to 100 % renewable energy for the same areas will be energy optimization. Energy shares of wind, solar and biomass should be formally optimized, independent of the scale at which one chooses to work (county, city, etc.). Energy optimization can include four potential criteria. First, the hourly predicted data for electricity demand, wind, solar, and biomass for each county will be calculated depending on several previous years. Second, by looking at every specific hour to compare generated electricity price for each renewable source at the same hour, the renewable energy source produced energy with a lower cost at specific hour will be used to provide electricity demand at the same hour. Third, costs for installing different configurations of power plants will need to be considered – whether larger, more centralized biomass plants are best, how best to transport heat, how the costs of district heating systems limit their applicability, and whether it is best to convert heating systems to heat pumps and other electricity-based technologies rather than natural gas. Finally, the role of storage must be considered, and how the fluctuating sources wind and solar PV will necessitate that the new system be able to store energy at those times when energy production is higher than demand, to be used at times when the energy produced is less than the electricity demand. All of these ideas will be pursued in further work.

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