Business Intelligence Solutions for Wind Power Plants Operation

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The European Union energy strategies imply significant changes in the power systems. These should contribute to sustainable development and protection of the environment by enabling the EU to achieve its targets set in the third package of legislative proposals for electricity and gas markets. Renewable energy sources (RES) in Romania have been encouraged since 2007 and this lead to a large volume of projects. It took several years to have the first MW installed in wind power plants (WPP). Nowadays, the installed wind power in Romania is about 2642 MW, most of them (about 85%) being concentrated in the south-eastern part of the country. Based on recorded data during four years in Romania, a couple of analyses have been performed. They contribute to a better integration of wind energy into power systems. This paper will describe how business intelligence solutions are applied on data regarding wind power plants operation and main conclusions that could be drawn.

Keywords: *Business Intelligence, Wind Power Plants Operation, Data Integration, Average/Maximum Output*

1 Introduction

The EU's energy and climate policy objectives consist in completing the internal market in energy, guaranteeing security of supply, notably for gas and oil, reducing greenhouse gas emissions by 20%, increasing the share of renewable energy in the final energy consumption to 20% and achieving a 20% increase in energy efficiency by 2020 [1].

Romania as one of the State Members has to fulfil its obligations related to EU's targets in terms of RES integration. The incentive support scheme for RES has been enacted by Law no. 220/2008 for establishing the promoting scheme for energy produced out of RES, Law no. 139/2010 (modifying Law 220/2008) and a series of four governmental orders dated November 2011 [2]. As a result of the supporting scheme mainly based on green certificates, since 2007, a large number of projects have been noticed. Most of them are located in Dobrogea, Moldova and Banat areas as in Figure 1 [3].

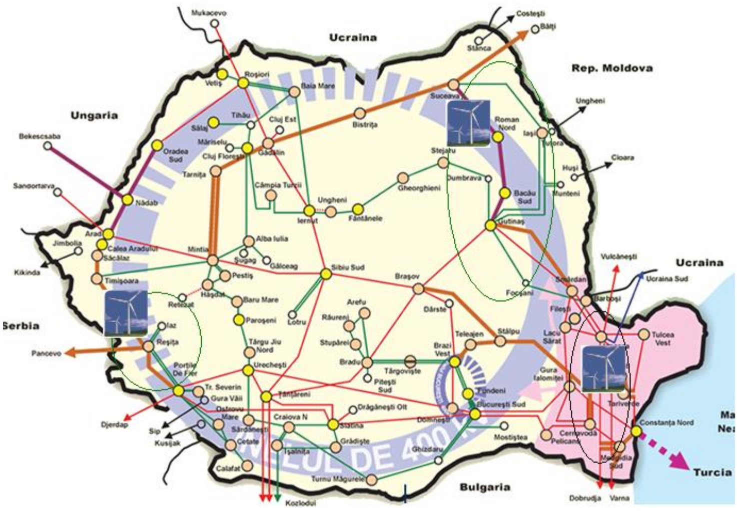

Fig. 1. Areas with large projects in Romania

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This concentration of interest from the private investors coincides with the wind potential map as in Figure 2 [4].

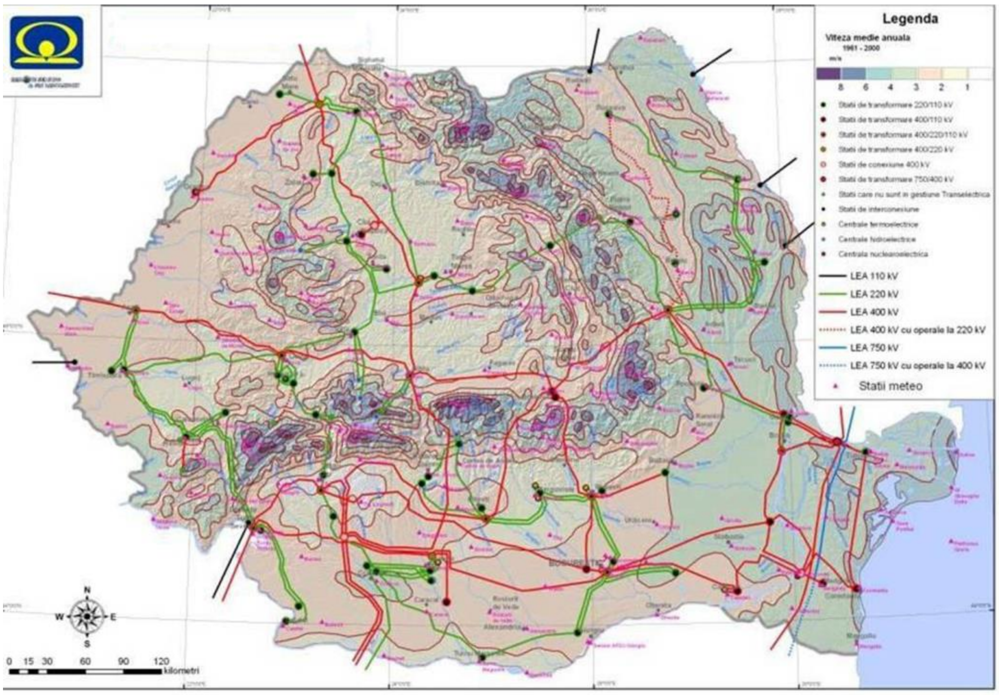

Fig. 2. Wind potential in Romania

Starting from 2010, installed power increased from 13 MW to about 400 MW by the end of the year. In 2011, the installed power was almost double (700 MW) compared with the previous year. The maximum installed power was recorded in 2012 (800 MW), then in 2013 it decreased up to 500 MW and in 2014 as forecast it will decrease even more (270 MW). This evolution is well-related to the specific legislation that incentives RES development. These figures are given in Table 1. Due to the fact that the installing process is very dynamic, the total figures are approximate.

Table 1. Installed power in 2010 – 2014

	MW	*Winter*	*Autumn*	*Summer*	*Spring*
Total 2010	***400***	January 2010/ 13 MW	October 2010/ 322 MW	-	-
Total 2011	***700***	January 2011/ 424 MW February 2011/ 424 MW	November 2011/ 780 MW	June 2011/ 518 MW August 2011/ 563 MW	March 2011/ 518 MW
Total 2012	***800***	December 2012/ 1941 MW January 2012/ 1140 MW	-	June 2012/ 1314 MW	-
Total 2013	***500***	December 2013/ 2507 MW	October 2013/ 2325 MW	July 2013/ 2123 MW	April 2013/ 2095 MW
Total 2014	***270*** *(forecast)*	-	-	July 2014/ 2642 MW	-

Figure 3 shows the WPP installed power evolution from 2010 until 2014.

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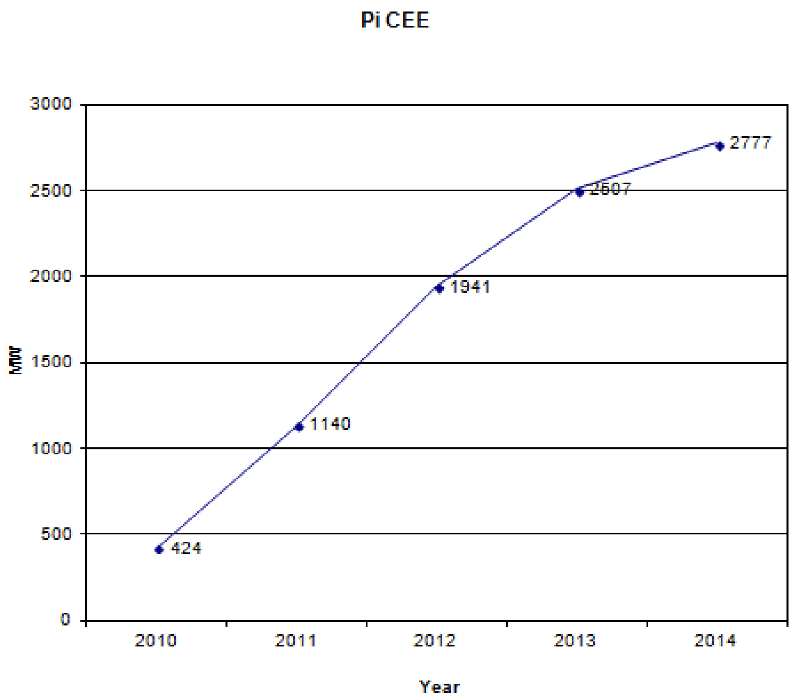

Fig. 3. Installed power evolution from 2010 up to 2014

Its trend is ascending, but in the last two years, it has been moderated by legislative means. For 2014 the increase for the first half of the year was double so that to get an approximate value for entire year.

2 Data Integration and Analysis Models

In the research project [5] we aim to develop a set of templates for data integration in a central database within the online platform, to define a set of performance indicators at macro level and to develop analytical and interactive reports for monitoring these indicators intended for supporting decisions. We'll propose simulation models of the operation of power plants at regional and national level, models that are based on data mining techniques and developed with geospatial elements for tracking indicators through interactive maps. A particularly important indicator on which to base an accurate forecast of the produced energy from renewable sources is the degree of simultaneity of operation of wind power plants located in different geographical areas. Wind energy production is conditioned by several factors factors such as: slipstream effect, soil orography, power characteristics, losses up to the connection point of etc. These factors are identified and detailed in the fundamental works [6], [7].

The analytical component developed for national authorities will contain a model for determining the degree of simultaneity which will allow a more accurate dimensioning of power reserves in the system. Thus, if some of the production companies in a given area will have an accurate prediction system, based on the degree of simultaneity of the model we will be able to determine and correct the estimation of production for those power plants without efficient prediction systems (for e.g. undispatchable units or units that have systems with big errors) as described in [8].

The proposed model will have advanced data analysis capabilities and it can be used to improve decision-making and ensure knowledge management. The component for national operators will allow the streamlining of the information flow, required statements and reports being obtained automatically via the online platform.

The prototype's interfaces will be developed so as to allow users single access to the system via mobile devices, and the use of the Cloud Computing platform will allow the connecting of servers, services and applications necessary for the prototype, thus

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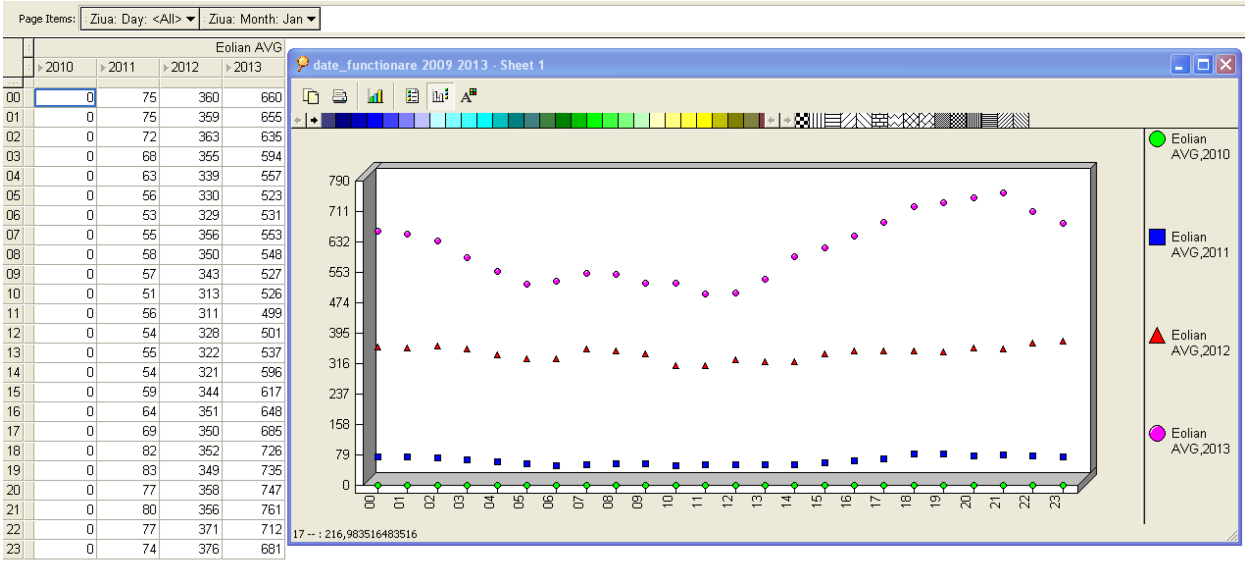
streamlining access to information to decision makers and reducing infrastructure costs. The system will enable effective and real-time analysis of the operation of renewable power plants. Also, using an integrated platform, through which there are monitored and analyzed in real time all the renewable power plants included in the system provides a competitive advantage when integrating with similar networks in the European Union. The first phase of the project involves identifying and analyzing the data sources, by designing the conceptual database diagrams and mappings between data. The conceptual data model will be designed. The system must implement the features of an integrated decision support system, using multidimensional models through which we can implement technological and business workflows. We will define the Business Intelligence methods and technologies used for analysis and data presentation and we'll define the main components of the system based on the following levels: the data level, the model analysis level and the presentation level. But first of all, an analyses of the WPP operation over time is needed, based on the data series recorded in the last 4 years.

3 Business intelligence analyses of WPP operation

Taking into account the large available recorded data set that describes the global operation of WPP between 2010 and 2013 (over 200000 records), business intelligence solutions will be used. No business intelligence technique has been applied for wind power plants operation until now. Out of data set some interesting results are found such as hourly average WPP output grouped by studied years, comparison among curves that describe hourly average WPP output, relation between WPP output and installed power in WPP in terms of maximum and average values and seasonal analyses on each studied year.

Figure 4 depicts average WPP output hour by hour in January. The first three studied years WPP output was almost flat, but in 2013 lower values were recorded around 5 and 12 o'clock and higher values were recorded at 21. Some similarities are identified between 2012 and 2013 curves up to 12 o'clock.



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	Eolian AVG 2010	2011	2012	2013
00	0	75	360	660
01	0	75	359	655
02	0	72	363	635
03	0	68	355	594
04	0	63	339	557
05	0	56	330	523
06	0	53	329	531
07	0	55	356	553
08	0	58	350	548
09	0	57	343	527
10	0	51	313	526
11	0	56	311	499
12	0	54	328	501
13	0	55	322	537
14	0	54	321	596
15	0	59	344	617
16	0	64	351	648
17	0	69	350	685
18	0	82	352	726
19	0	83	349	735
20	0	77	358	747
21	0	80	356	761
22	0	77	371	712
23	0	74	376	681

Fig. 4. Hourly average WPP output in January 2010-2013

Table 2 shows average and maximum values for WPP output in January in 2011 and 2012. It shows the difference between two consecutive years. Average output in 2012 is double compared with 2011.

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Table 2. Average and maximum values in January 2011 and 2012

2011 JAN	2011 JAN	2012 JAN	2012 JAN
%AVG(Pi)	%MAX(Pi)	%AVG(Pi)	%MAX(Pi)
15	82	30	73

Figure 5 depicts average WPP output hour by hour in February. The middle two studied years (2011 and 2012) WPP output is quite similar.

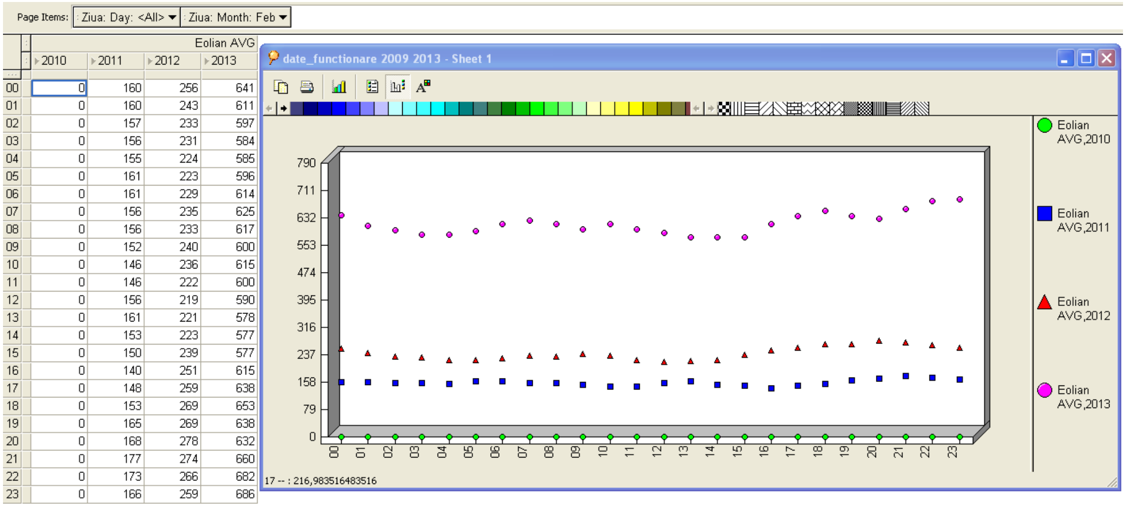

Fig. 5. Hourly average WPP output in February 2010-2013

Figure 6 depicts average WPP output hour by hour in March. The last two studied years (2012 and 2013) WPP output was similar between 6 and 15 o'clock. The rest of time intervals trends are different. As for WPP output in 2011 is quite flat.

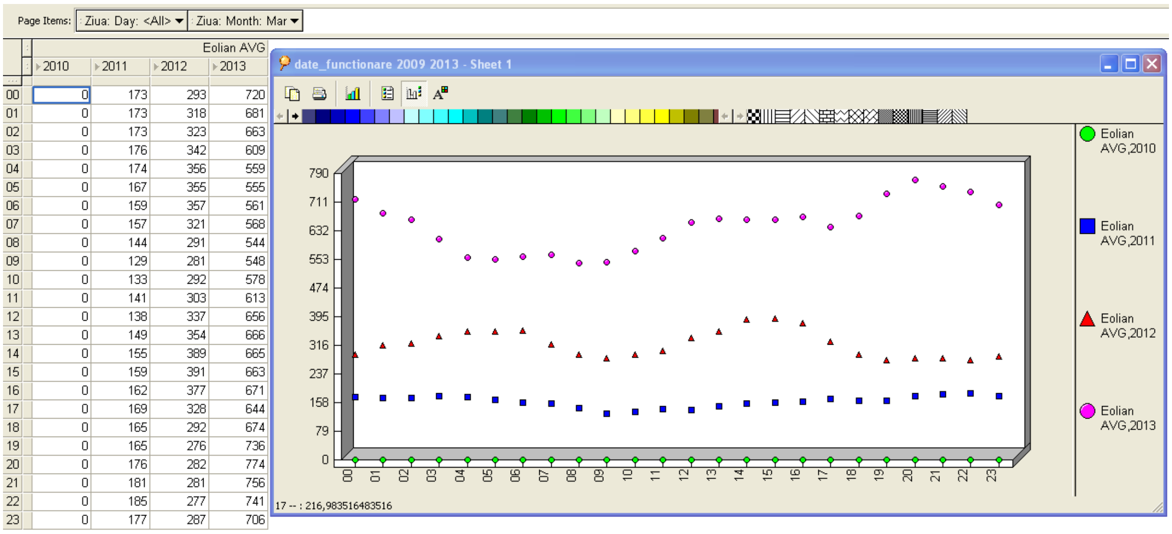

Fig. 6. Hourly average WPP output in March 2010-2013

Table 3 shows average and maximum values recorded in March. The maximum value shows that for short time intervals WPP output was almost equal to installed power.

Table 3. Average and maximum values in March 2011

2011 MAR	2011 MAR
%AVG(Pi)	%MAX(Pi)
31	98

Figure 7 depicts average WPP output hour by

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hour in April. WPP output in 2011 and 2013 was slightly similar. WPP output in 2013 has many windings. WPP output in 2011 and 2012 are quite different, but with little windings. As for WPP output in 2010 is quite flat up to June-July when significant power was installed.

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	Eolian AVG			
	2010	2011	2012	2013
00	0	136	302	622
01	0	149	298	611
02	0	157	284	588
03	0	170	261	568
04	0	168	252	552
05	0	175	262	575
06	0	177	261	585
07	0	177	250	570
08	0	148	258	520
09	0	139	262	513
10	0	143	293	541
11	0	142	334	575
12	0	148	353	602
13	0	156	363	620
14	0	161	353	655
15	0	164	355	662
16	0	153	362	670
17	0	135	356	669
18	0	112	349	624
19	0	110	337	589
20	0	111	339	621
21	0	120	333	654
22	0	126	323	658
23	0	134	302	639

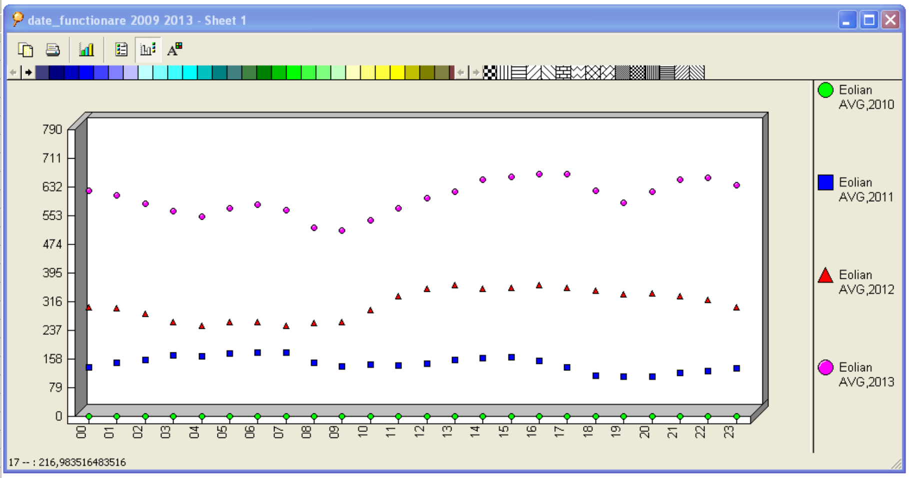

Fig. 7. Hourly average WPP output in April 2010-2013

Table 4 shows average and maximum values recorded in April.

Table 4. Average and maximum values in April 2011

2013 APR	2013 APR
%AVG(Pi)	%MAX(Pi)
29	88

These values are significant because in 2013 the installed power increased over 2000 MW. Average values of WPP output is about 30% and maximum value is almost 88% of installed power.

Figure 8 depicts average WPP output hour by hour in May. WPP output in 2013 is opposite with load curve and it does not help balance of the power system. WPP output in 2011 and 2012 are similar, but with little windings.

Page Items: Ziua: Day: <All> Ziua: Month: May

	Eolian AVG			
	2010	2011	2012	2013
00	0	86	249	432
01	0	94	222	400
02	0	98	273	390
03	0	102	269	368
04	0	100	269	365
05	0	101	295	367
06	0	105	300	373
07	0	102	293	354
08	0	84	258	329
09	0	76	227	347
10	0	81	228	366
11	0	84	214	445
12	0	94	226	503
13	0	100	227	554
14	0	102	224	571
15	0	100	238	581
16	0	96	245	567
17	0	89	238	568
18	0	81	222	536
19	0	66	205	450
20	0	66	207	433
21	0	70	224	467
22	0	73	237	468
23	0	73	258	463

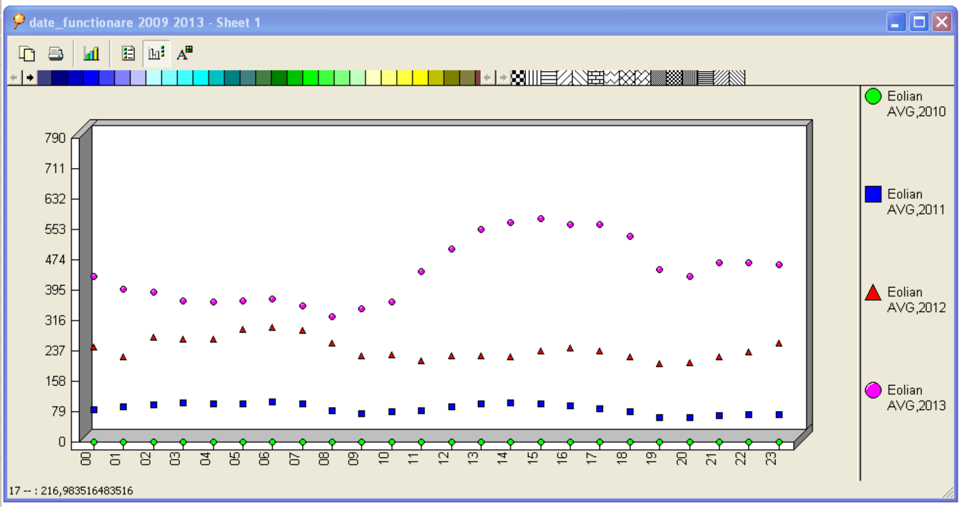

Fig. 8. Hourly average WPP output in May 2010-2013

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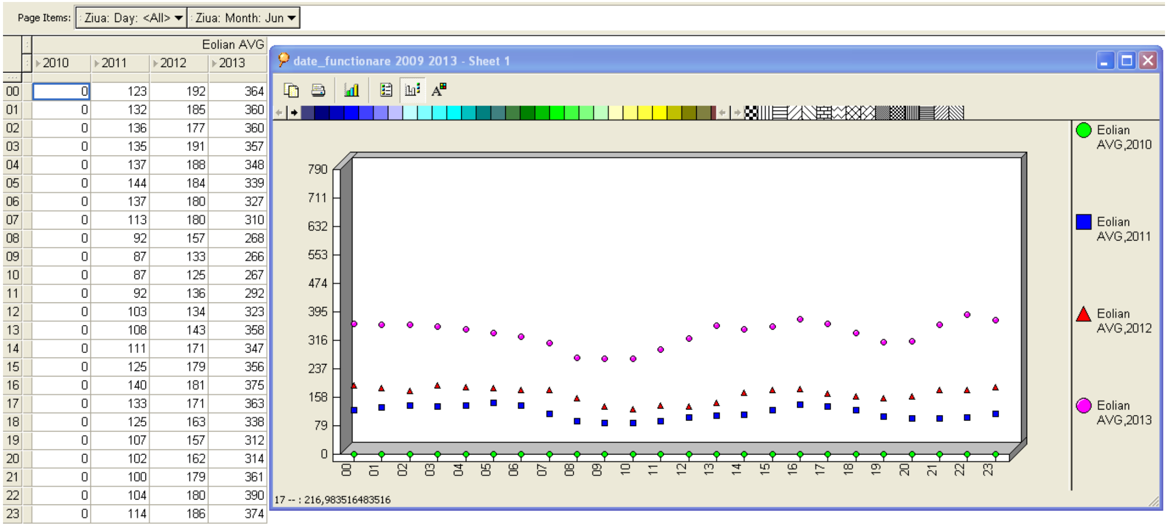
Figure 9 depicts average WPP output hour by hour in June. All three important curves are similar and again they are opposite with load curve and do not help balance of the power system. This month the level of output is much smaller than in winter and spring time.



	Eolian AVG 2010	2011	2012	2013
00	0	123	192	364
01	0	132	185	360
02	0	136	177	360
03	0	135	191	357
04	0	137	188	348
05	0	144	184	339
06	0	137	180	327
07	0	113	180	310
08	0	92	157	268
09	0	87	133	266
10	0	87	125	267
11	0	92	136	292
12	0	103	134	323
13	0	108	143	358
14	0	111	171	347
15	0	125	179	356
16	0	140	181	375
17	0	133	171	363
18	0	125	163	338
19	0	107	157	312
20	0	102	162	314
21	0	100	179	361
22	0	104	180	390
23	0	114	186	374

Fig. 9. Hourly average WPP output in June 2010-2013

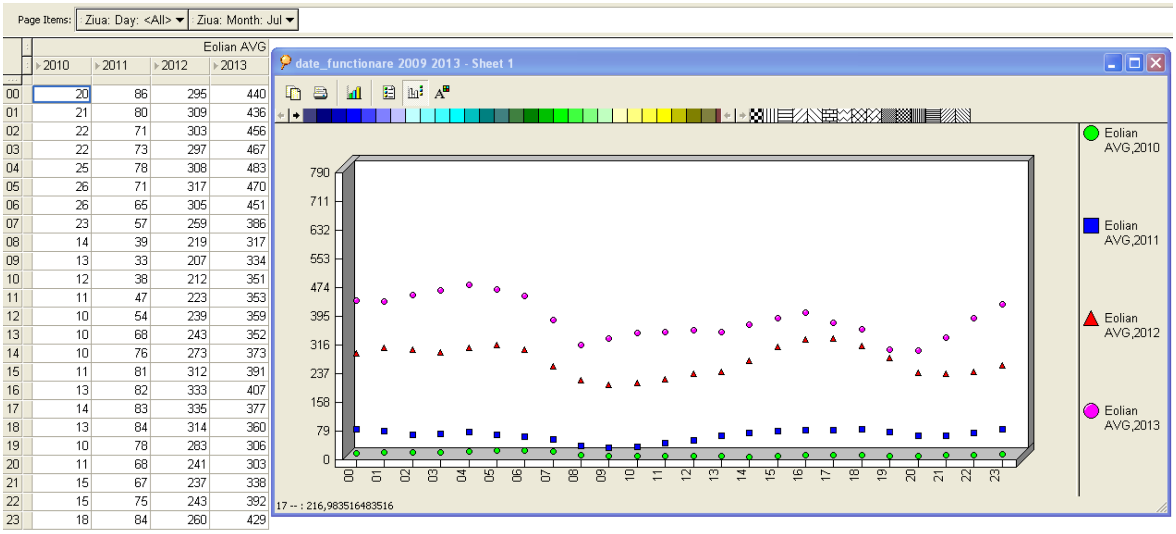
Table 5 shows average and maximum values recorded in June.

Table 5. Average and maximum values in June 2012

2012 IUN	2012 IUN
%AVG(Pi)	%MAX(Pi)
13	65

Average value of WPP output is about 13% and maximum value is almost 65% of installed power.

Figure 10 depicts average WPP output hour by hour in July. All three important curves are similar and again they are opposite with load curve and do not help balance of the power system. This month the level of output is much smaller than in winter and spring time. WPP output in July is similar with WPP output in June.



	Eolian AVG 2010	2011	2012	2013
00	20	86	295	440
01	21	80	309	436
02	22	71	303	456
03	22	73	297	467
04	25	78	308	483
05	26	71	317	470
06	26	65	305	451
07	23	57	259	386
08	14	39	219	317
09	13	33	207	334
10	12	38	212	351
11	11	47	223	353
12	10	54	239	359
13	10	68	243	352
14	10	76	273	373
15	11	81	312	391
16	13	82	333	407
17	14	83	335	377
18	13	84	314	360
19	10	78	283	306
20	11	68	241	303
21	15	67	237	338
22	15	75	243	392
23	18	84	260	429

Fig. 10. Hourly average WPP output in July 2010-2013

Table 6 indicates average and maximum percentage of installed power recorded in July 2013.

Figure 11 depicts average WPP output hour by hour in August.

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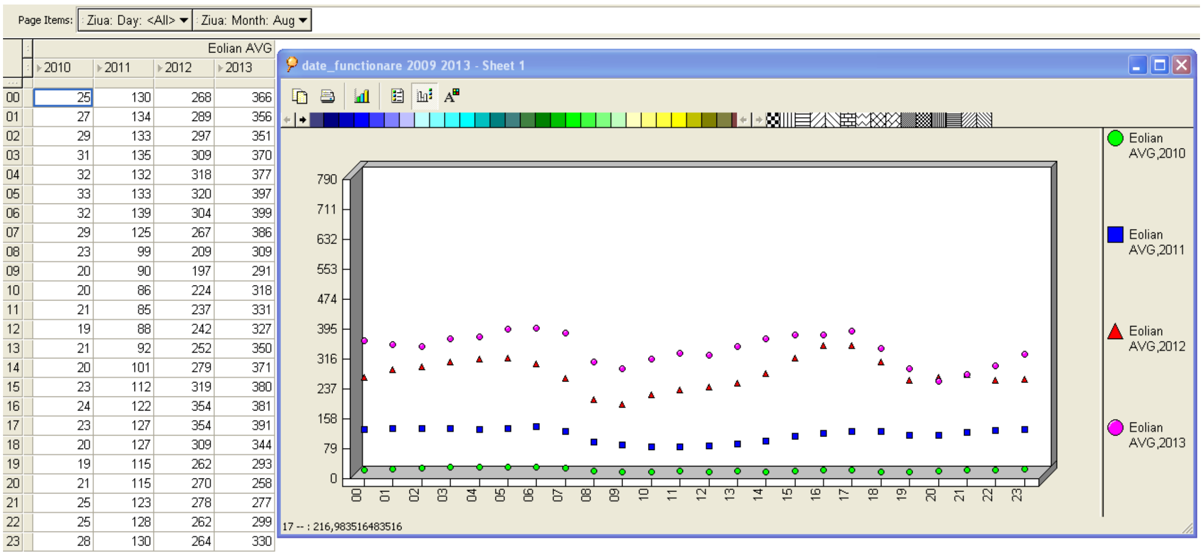
Table 6. Average and maximum values in July 2013

2013 IUL	2013 IUL
%AVG(Pi)	%MAX(Pi)
18	89

WPP output in 2012 and 2013 are similar. WPP output in summer is similar.



	2010	2011	2012	2013
00	25	130	268	366
01	27	134	289	356
02	29	133	297	351
03	31	135	309	370
04	32	132	318	377
05	33	133	320	397
06	32	139	304	399
07	29	125	267	386
08	23	99	209	309
09	20	90	197	291
10	20	86	224	318
11	21	85	237	331
12	19	88	242	327
13	21	92	252	350
14	20	101	279	371
15	23	112	319	380
16	24	122	354	381
17	23	127	354	391
18	20	127	309	344
19	19	115	262	293
20	21	115	270	258
21	25	123	278	277
22	25	128	262	299
23	28	130	264	330

Fig. 11. Hourly average WPP output in August 2010-2013

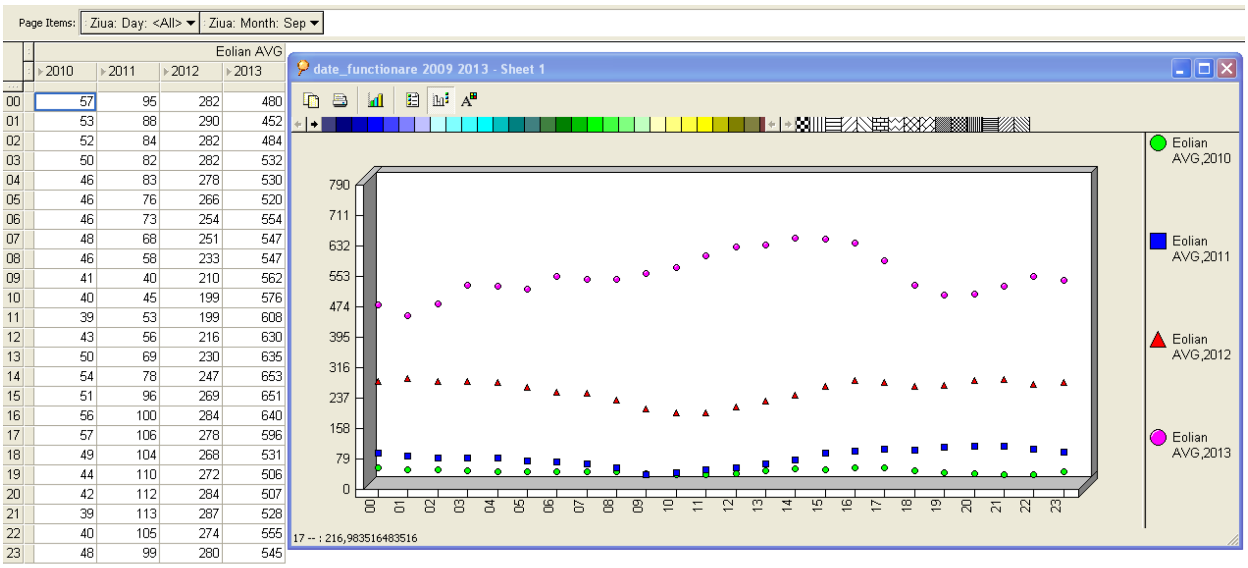
Table 7 indicates average and maximum percentage of installed power recorded in August 2011.

Figure 12 depicts average WPP output hour by hour in September. This month the level of WPP output is increasing.

Table 7. Average and maximum values in August 2011

2011 AUG	2011 AUG
%AVG(Pi)	%MAX(Pi)
21	94

In 2011 and 2012 the curves are similar, but different from 2013 curve.



	2010	2011	2012	2013
00	57	95	282	480
01	53	88	290	452
02	52	84	282	484
03	50	82	282	532
04	46	83	278	530
05	46	76	266	520
06	46	73	254	554
07	48	68	251	547
08	46	58	233	547
09	41	40	210	562
10	40	45	199	576
11	39	53	199	608
12	43	56	216	630
13	50	69	230	635
14	54	78	247	653
15	51	96	269	651
16	56	100	284	640
17	57	106	278	596
18	49	104	268	531
19	44	110	272	506
20	42	112	284	507
21	39	113	287	528
22	40	105	274	555
23	48	99	280	545

Fig. 12. Hourly average WPP output in September 2010-2013

Figure 13 depicts average WPP output hour by hour in October. This month the level of

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WPP output is higher than WPP output of the previous month. In 2010 and 2011 the curves are similar and flat. In 2012 and 2013 the curves are very similar.

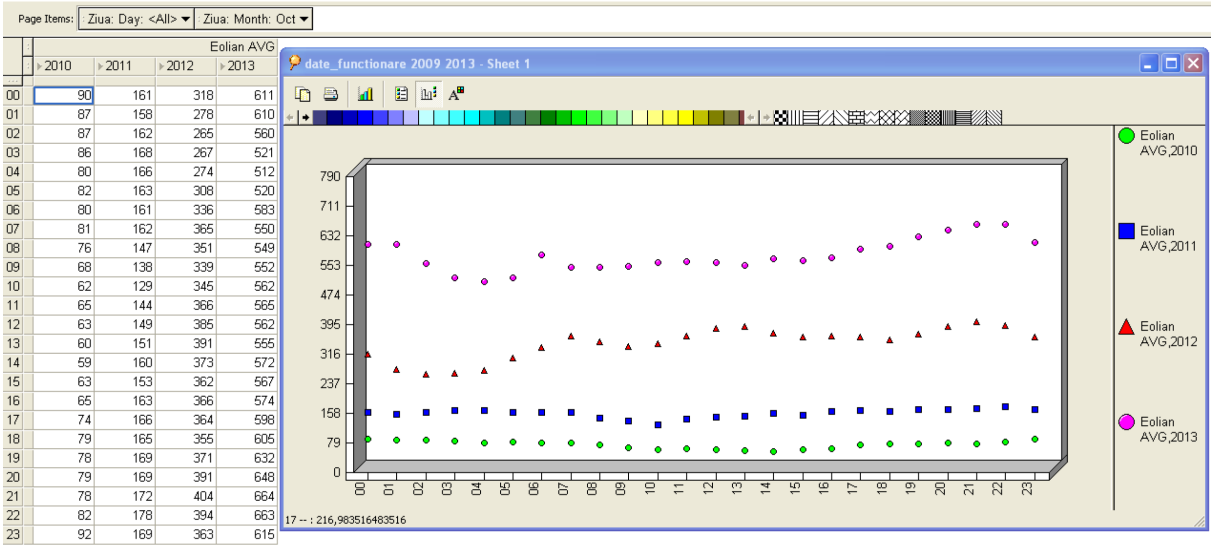

Fig. 13. Hourly average WPP output in October 2010-2013

Table 8 indicates average and maximum percentage of installed power recorded in October 2010 and 2013.

Table 8. Average and maximum values in October 2010 and 2013

2010 OCT	2010 OCT	2013 OCT	2013 OCT
%AVG(Pi)	%MAX(Pi)	%AVG(Pi)	%MAX(Pi)
23	77	25	85

Figure 14 depicts average WPP output hour by hour in November. This month the level of WPP output is the higher than WPP output of the previous months. In 2010 and 2011 the curves are similar and flat. In 2012 and 2013 the curves are very similar.

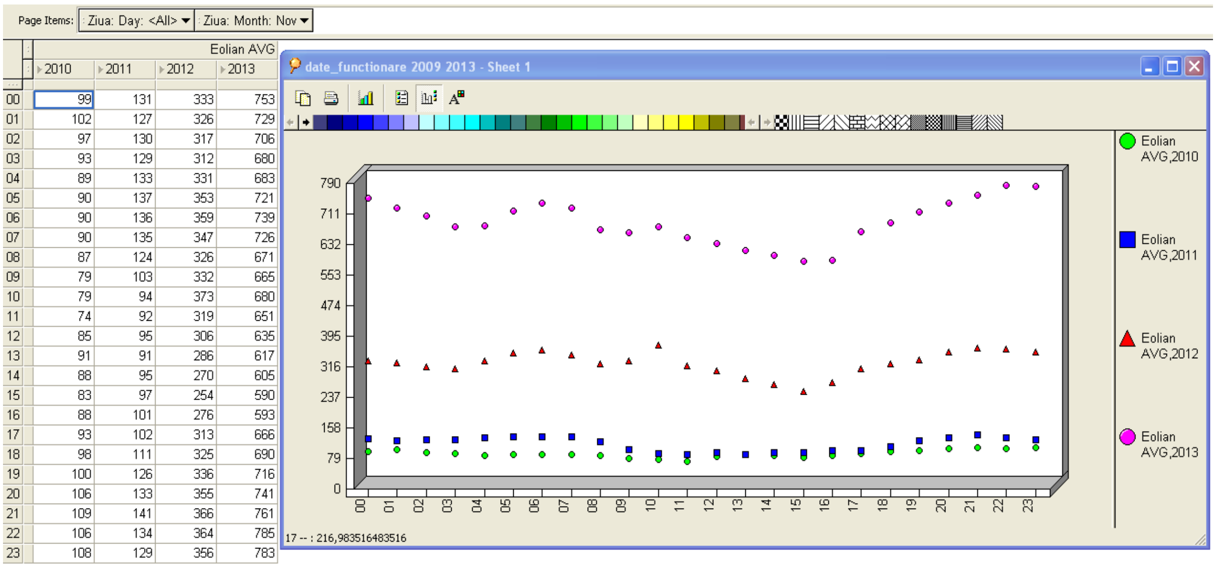

Fig. 14. Hourly average WPP output in November 2010-2013

Table 9 indicates average and maximum percentage of installed power recorded in Octo-

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ber 2010 and 2013.

Table 9. Average and maximum values in November 2010 and 2013

2011 NOV	2011 NOV
%AVG(Pi)	%MAX(Pi)
15	72

Figure 15 depicts average WPP output hour by hour in December. This month the level of WPP output is much higher than WPP output of the previous months. In 2010 and 2011 the curves are similar and flat. In 2012 WPP output is almost flat, but in 2013 the curve has more windings.

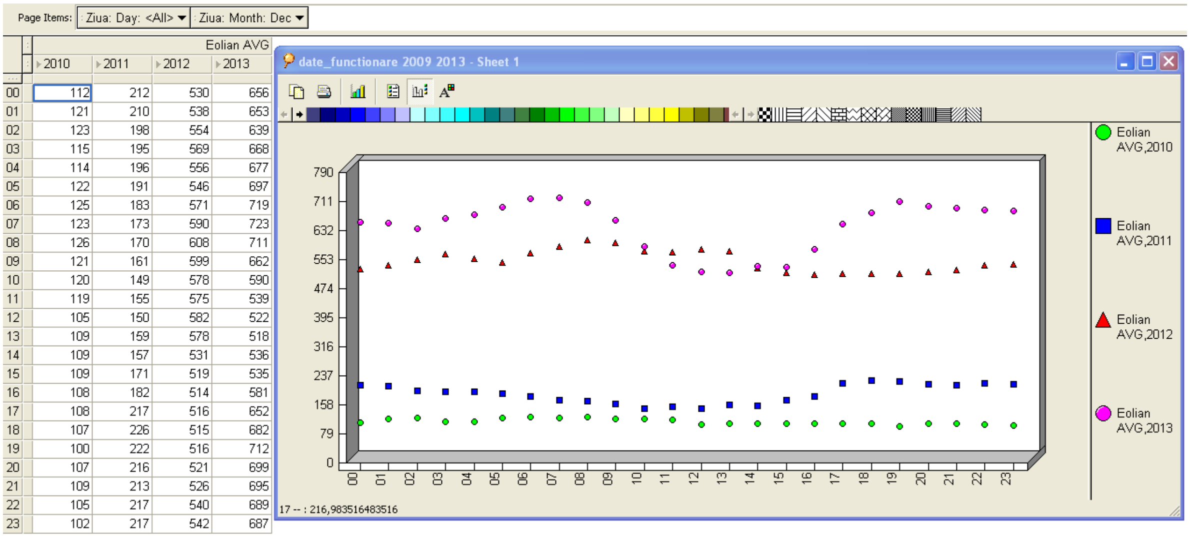

Fig. 15. Hourly average WPP output in December 2010-2013

Table 10 indicates average and maximum percentage of installed power recorded in December 2012 and 2013.

Table 10. Average and maximum values in December 2012 and 2013

2012 DEC	2012 DEC	2013 DEC	2013 DEC
%AVG(Pi)	%MAX(Pi)	%AVG(Pi)	%MAX(Pi)
28	81	26	91

Maximum values recorded in December reveals that even if they are taken from two consecutive years, differences can be significant. Figure 16 depicts average WPP output hour by hour each month in 2013. At the beginning of the year about 2000 MW have been installed. By the end of the year about 2500 MW have been installed. In this figure WPP monthly output is compared. In winter time the level of WPP output is much higher (more than double) than WPP output in summer time. The lowest level is about 240 MW and the highest level is about 790 MW.

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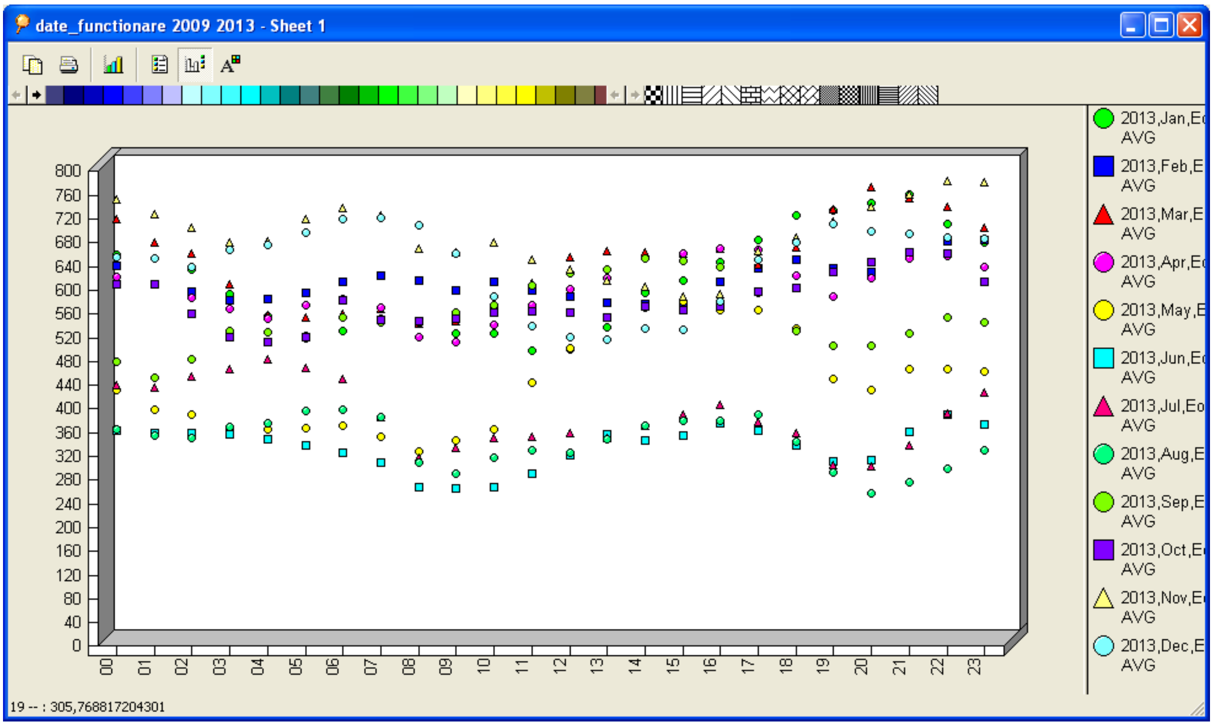

Fig. 16. Hourly average WPP output each month in 2013

Figure 17 depicts average WPP output hour by hour each month in 2012. At the beginning of the year about 1100 MW have been installed. By the end of the year about 1900 MW have been installed. In this figure WPP monthly output is compared. In winter time the level of WPP output is much higher than WPP output in summer time. The lowest level is about 120 MW recorded in June and the highest level is about 600 MW recorded in December. As for the rest of the months, the curves are quite close and compact.

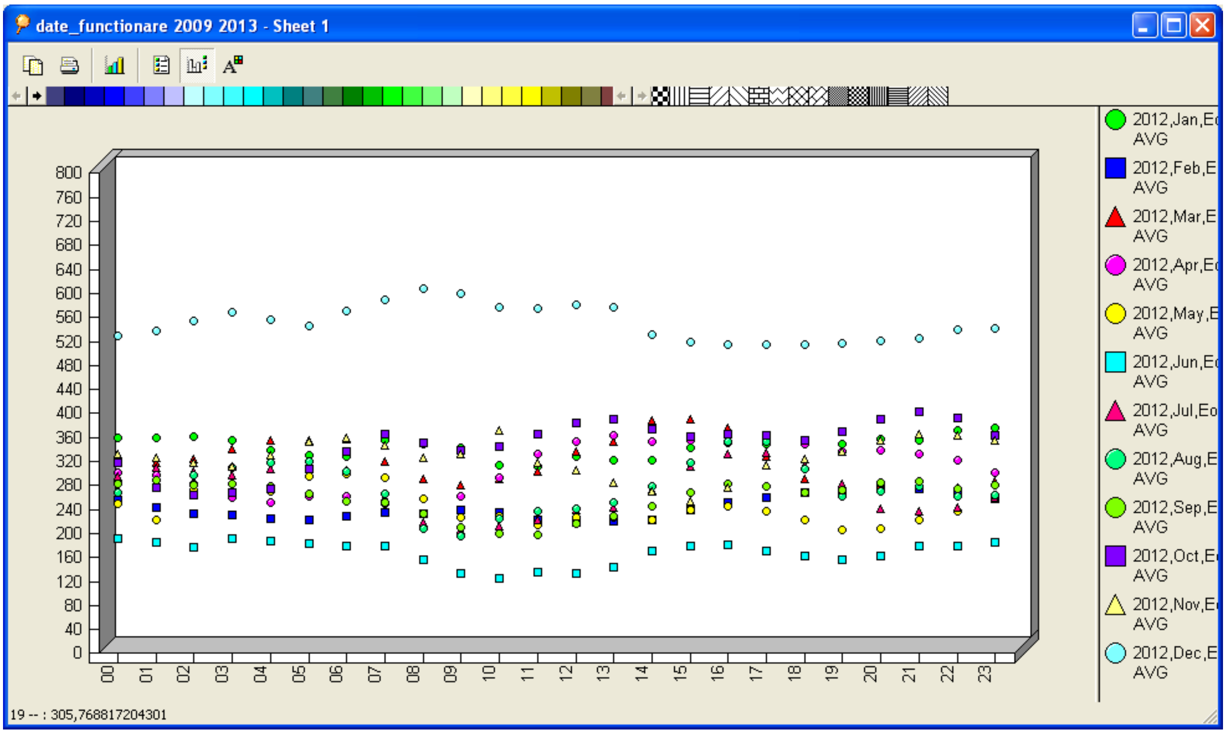

Fig. 17. Hourly average WPP output each month in 2012

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Figure 18 shows the same average WPP output hour by hour each month in 2012 at smaller scale.

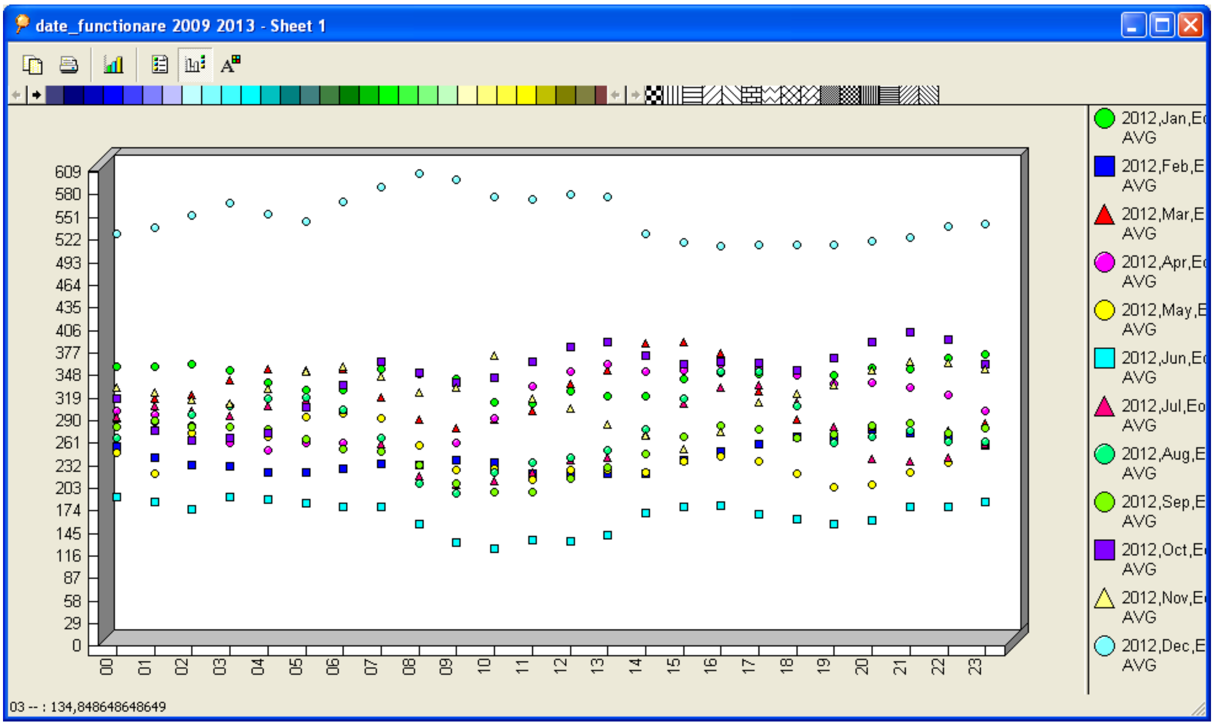

Fig. 18. Hourly average WPP output each month in 2012

Figure 19 depicts average WPP output hour by hour each month in 2011. At the beginning of the year about 400 MW have been installed. By the end of the year about 1100 MW have been installed. In this figure WPP monthly output is compared.

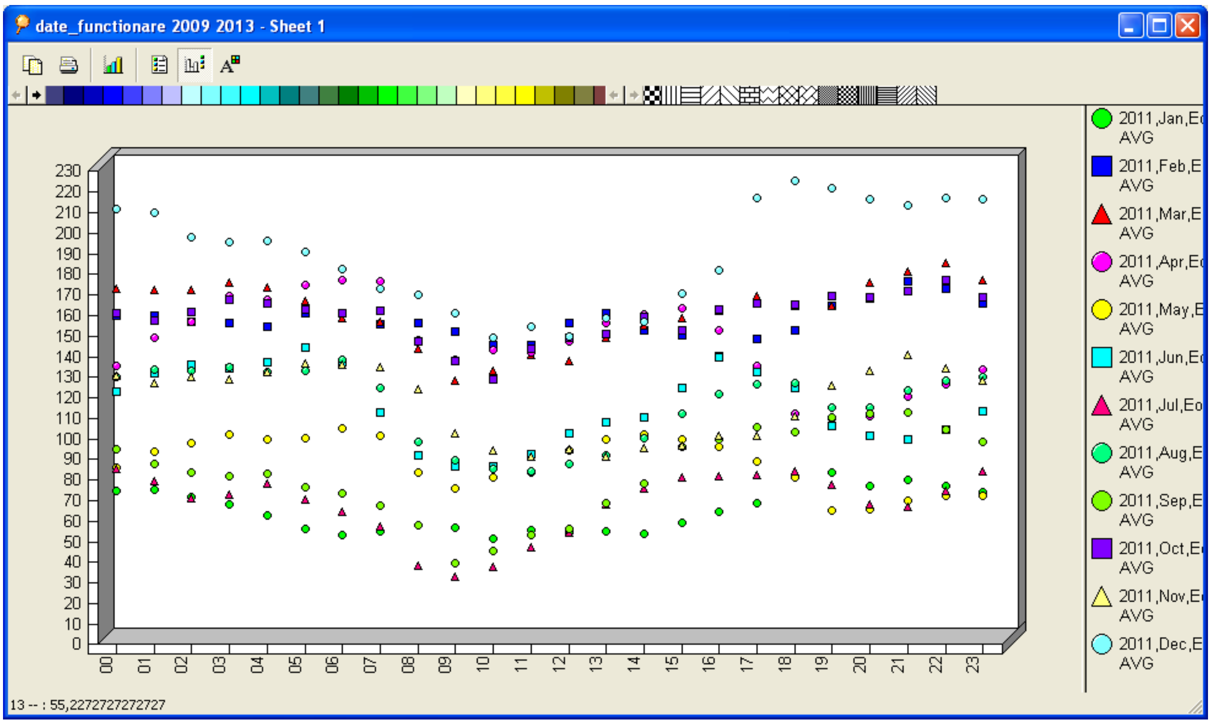

Fig. 19. Hourly average WPP output each month in 2011

In winter time the level of WPP output is higher than WPP output in summer time. The lowest level is about 30 MW recorded in July and the highest level is about 220 MW recorded in December [9].

4 Conclusions

Starting from 2010, installed power increased from 13 MW to about 400 MW by the end of the year. In 2011, the installed power was almost double (700 MW) compared with the previous year. The maximum installed power was recorded in 2012 (800 MW), then in 2013 it decreased up to 500 MW and in 2014 as forecast it will decrease even more (270 MW). This evolution is well-related to the specific legislation that incentives RES development.

Taking into account the large available recorded data set that describes the global operation of WPP between 2010 and 2013 (over 200000 records), business intelligence solutions developed by Oracle will be used. No business intelligence technique has been applied for wind power plants operation until now. Out of data set some interesting results are found such as hourly average WPP output grouped by studied years, comparison among curves that describe hourly average WPP output, relation between WPP output and installed power in WPP in terms of maximum and average values and seasonal analyses on each studied year.

The main conclusions regarding WPP operation in Romania are:

- wind blows more at night that is not helpful for system operation;
- summer months were less windy;
- if we compare WPP output in the same month in two consecutive years, the difference could be significant;
- average WPP output could be considered no more than 30% and maximum WPP output could be considered around 80%.

Although in this paper several analysis regarding WPP operation are presented for different consecutive years, it is obvious that more data is required in order to obtain better correlations and more significant conclusion that could be useful in power systems operation.

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