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Article

Assessment of Gasification Potential of Agricultural and Woody Biomass Resources in Iran

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Abstract: Nowadays, gasification is one of the progressive methods of energy production (heat and power) from biomass resources. This method is more efficient than direct combustion of the biomass, because the produced gas (syngas) can be combusted at higher temperature or maybe used in other processes to generate further energy carriers. In this study, the feasibility of syngas utilization for power generation is considered. The distribution of biomass resources plays a significant role on locating proper places for establishment of gasification power plants. The key parameters which have a great influence on selecting a specific gasification technology in any region are the amount and type of biomass resources. Here, the area under cultivation of various agricultural and orchard products, and wood farming have been estimated from the official database of the agricultural ministry of Iran through which, the amounts of agricultural residues, orchard pruning and short rotation coppices were calculated around 33.4 million tons in 2009. Proximate and ultimate analyses of the most common biomass resources in Iran including ash, moisture, volatile matter content, components and the heating value were carried out in this research. So, by means of the obtained information on heating values, it was capable to approximate the total potential of the biomass energy around 167 TWh. And finally by picking a proper coefficient for usage of biomass residues and a moderate performance for regular gasification plants, the applicable and feasible potential of biomass resources was derived for whole the country around 51 TWh.

Keywords: agricultural residues; orchard pruning and residues; wood forestry; heating value; biomass; Iran.

1. Introduction

Iran is one of the countries which have different climate zones due to the diverse weather conditions:

- Moderate temperature, high humidity and high amount of annual precipitation in north regions (the coastal plains of the Caspian Sea);
- Low temperature and severe winters in west regions;
- High temperature, low precipitation in east and central regions;
- High temperature, high humidity and very hot summer in south regions (the coastal plains of the Persian Gulf and Gulf of Oman).

Mentioned diversity in the climate of a country makes each district capable and suitable for cultivation of distinct plant species. Some of the most common species cultivated in Iran are as follows (Azizaddini et al., 2010):

- Agricultural crops such as wheat, barley, corn, cotton, sugarcane and rice;
- Orchard plants such as apple, orange, pistachio, grapes, date palm, almond and walnut;
- Short rotation forests such as poplar and eucalyptus.

Despite the fact that Iran has great reservoirs of natural gas, coal and petroleum, utilizing these fuels leads to environmental problems such as greenhouse gas (GHG) emissions. According to the reports of the U.S. Energy Information Administration (2009), Iran produces around 528 million tons of CO_2 equivalents annually. Direct combustion of fossil fuels contributes to increase the amount of GHGs which contribute to global warming. New policies are legislated since 15 years ago, to bind the industries particularly power generation sector to reduce the amount of consumed fossil fuels (SUNA, 2012). The renewable energies such as solar, wind, geothermal and biomass were studied with more emphasis during recent years and found to be of great potentials in Iran.

Some researches and studies have addressed the estimation of biomass resources in Iran for various usages of different feedstock. Typically, the production of bioethanol from agricultural residues was studied by Najafi et al. (2009). They approximated that 17.86 million tons of residues could be obtained after harvesting and processing the crops. Hamzeh et al. (2011) categorized the Iranian biomass resources into three categories; agricultural residues, animal wastes and municipal wastes. These biomass resources were assessed 8.8, 7.7 and 3 million tons per year, respectively.

In this study, as mentioned before, agricultural residues, orchard pruning and short rotation forestry are considered as main resources for biomass gasification for the purpose of either thermal usages or power generation.

2. Potential of Biomass Resources

The biomass resources potential in any region was studied regarding the area under cultivation and in some cases the amount of harvested crops for (i) agricultural crops (ii) orchard crops and (iii) short rotation forestry. The relevant information about cultivation area and crop production was gathered from the official reports of the Ministry of Agriculture of Iran. The reports were categorized by the types of crops and comprise the area of irrigated and rain fed farmlands and total weight of harvested crops in provincial resolution.

2.1. Agricultural Crops

One of the basic subdivision parts of the country which plays a significant role in rural development and economic progress is summarized in agriculture sector. However, due to lack of adequate water and poor soil quality in most areas of Iran, only one third of total lands are arable at the sufficient water availability. In reality, just 12 percent of the whole country was under cultivation in the form of either irrigated or rain fed lands (Najafi, 2009).

The major cultivated agricultural crops are wheat, barley, rice, sugarcane, corn, oil seeds and cotton. In all provinces, all crops except sugarcane are grown with various shares. Wheat as the most cultivated crop in Iran has a cultivated area around 6.6 million hectares and total harvested product reached ca. 13.5 million tons (Ministry of Agriculture, 2009a).

The second cultivated crop which is harvested around 5.7 million tons annually out of 68,000 ha cultivation area is sugarcane (Ministry of Agriculture, 2009a). Barley, rice, corn and cotton which stand on the next ranks, are harvested 3.4, 2.3, 1.6 and 0.2 million tons per year and their cultivation area occupies 1.7, 0.5, 0.25 and 0.1 million hectares, respectively (Ministry of Agriculture, 2009a).

Due to shortage of formal domestic data for estimation of agricultural residues which is a key stage in this study, the similar studies and reference codes were employed in order to approximate the coefficient of residues to crop ratio (RCR). For instance, the RCR of wheat straw is around 1.5 and for rice straw is around 1.15 (Koopmans, 1997). Detailed information on provincial distribution of agricultural crops and residues is reported in Table 1 by the alphabetical sorting of the provinces (Azizaddini et al., 2010).

With attention to Table 1, the total amount of agricultural residues is appraised around 28.6 million tons in Iran. The amount of wheat, barley, corn, sugarcane, cotton and rice residues reach to around 20.4, 2.3, 1.8, 0.9, 0.6 and 2.6 million tons in 2009. Khuzestan and Fars have the most prolific and productive lands in Iran which empower the agro-industries. These two provinces also produce the highest shares of agricultural residues which are followed by Golestan and Razavi Khurasan provinces.

Wheat, as the most common and widespread crop in the country, represents a great potential for energy production from biomass resources. Moreover rice, barley, corn, sugarcane stand at the next

priorities. Even though cotton residues have the least share, it could be taken into account for combined heat and power generation, regarding the high heating value of dried cotton stalks (Azizaddini et al., 2012).

For more consideration and understanding of the Table 1 along with above mentioned information, the provincial distribution of agricultural wastes in Iran is represented in Fig. 1 (Azizaddini et al., 2010). The abbreviation of the provinces has been indicated in the right column of Table 1.

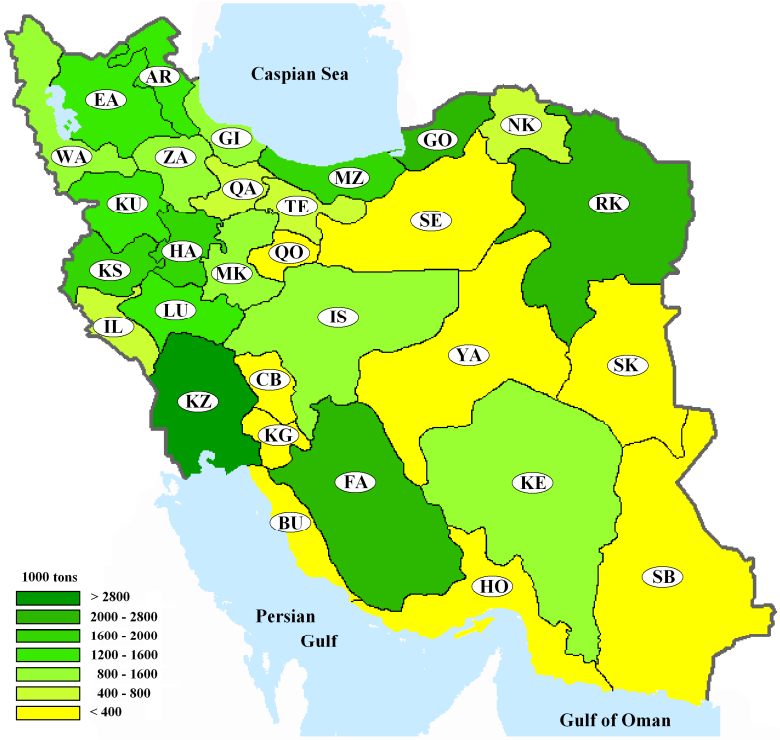

Figure 1. Provincial distribution of annual crop residues.

2.2. Orchard Crops

Citrus, apple, grape, pistachio, walnut, almond and date palm have been extended in large areas of Iran. Huge amount of pruned branches or cut trunks are annually abandoned from orchard lands. Moreover, large quantities of walnut and almond shell remain unused.

In 2009, around 2.6 million hectares were under cultivation of orchard products from which 14% was marked as rain fed farmlands. Pistachio as the most cultivated fruit tree, reaches around 0.4 million hectares of orchard lands. Grapes, date palm, apple, walnut and citrus lands covered 0.3, 0.25, 0.23, 0.21 and 0.19 million hectares, respectively. As previously stated, estimation of residues were calculated on a combination of experimental and theoretical bases (Adl, 1999). For instance, the woody biomass residue which obtains from pruning of orchard trees is around 0.5 ton per hectare for grapes and 5.75 tons per hectare for apple.

Table 1. The provincial distribution of agricultural harvested crops and residues (Azizaddini et al., 2010)

Province	Wheat		Barley		Corn		Sugarcane		Cotton		Rice		Total Residue (10^3 t)
	Production (10^3 t)	Residue (10^3 t)	Production (10^3 t)	Residue (10^3 t)	Production (10^3 t)	Residue (10^3 t)	Production (10^3 t)	Residue (10^3 t)	Production (10^3 t)	Residue (10^3 t)	Production (10^3 t)	Residue (10^3 t)	
Ardabil (AR)	729.3	1104.8	132.9	87.7	54.8	60.2			7.3	18.3	5.3	6.1	1262.5
Bushehr (BU)	40.5	61.4	2.6	1.7	5.1	5.6							68.7
Ch. Bakhtiari (CB)	169.2	256.3	52.1	34.4	0.9	0.9					16.6	19.1	310.7
East Azerbaijan (EA)	485.2	735.1	108.7	71.8	0.3	0.3			5.0	12.5	6.9	8.0	817.7
Fars (FA)	1396.6	2115.9	138.2	91.2	423.0	465.3			24.9	62.3	105.0	120.8	2805.7
Gilan (GI)	11.6	17.6	10.4	6.8	0.2	0.2					661.3	760.5	785.1
Golestan (GO)	1101.6	1668.9	188.5	124.4	3.6	4.0			18.7	46.7	207.2	238.3	2044.8
Hamadan (HA)	767.3	1162.5	266.2	175.7	82.6	90.9							1429.0
Hormozgan (HO)	55.0	83.4	2.4	1.6	33.6	36.9			0.3	0.7			122.0
Ilam (IL)	198.6	300.8	34.9	23.1	24.8	27.3					7.9	9.1	360.3
Isfahan (IS)	300.4	455.1	193.7	127.8	14.5	16.0			9.3	23.2	39.1	44.9	648.5
Kerman (KE)	268.0	406.0	61.0	40.3	256.9	282.6			4.1	10.3			730.9
Kermanshah (KS)	824.1	1248.5	301.0	198.7	252.6	277.8					0.1	0.2	1725.2
Khuzestan (KZ)	1179.3	1786.7	38.4	25.3	296.6	326.2	2822.9	875.1			87.0	100.0	3113.3
Kuh Giluya (KG)	146.4	221.8	37.4	24.7	9.2	10.1					33.5	38.6	295.2
Kurdistan (KU)	671.1	1016.8	37.3	24.6	10.1	11.1							1052.5
Luristan (LU)	518.8	785.9	161.9	106.9	0.7	0.7					1.8	2.1	895.6
Markazi (MK)	517.6	784.1	98.9	65.3	4.1	4.5			6.9	16.2			857.4
Mazandaran (MZ)	166.9	252.9	92.9	61.3	4.1	4.5	0.2	0.1	0.3	0.7	1038.7	1194.5	1513.4
North Khurasan (NK)	381.2	577.6	105.9	69.9	1.5	1.7			12.9	32.3	4.8	5.5	661.1
Qazvin (QA)	293.5	444.7	138.8	91.6	85.8	94.4			0.5	1.2	10.3	11.8	642.8
Qom (QO)	41.6	63.0	121.4	80.1	1.7	1.9			8.4	21			149.2
Razavi Khurasan (RK)	1127.7	1708.4	574.9	379.5	2.4	2.7			100.5	251.2	8.0	9.2	2150.1
Semnan (SE)	129.8	196.6	84.3	55.6					11.9	29.8			258.2
Sistan and Baluchistan (SB)	116.9	177.1	22.7	15.0	26.0	28.6					10.9	12.5	233.2
South Khurasan (SK)	120.3	182.3	72.2	47.7					33.9	84.8			246.9
Tehran (TE)	352.5	534.0	183.4	121.1					8.1	20.2	1.4	1.6	660.7
West Azerbaijan (WA)	732.1	1109.1	91.5	60.4	18.2	20.0					0.2	0.2	1189.7
Yazd (YA)	90.5	137.1	19.3	12.8	29.6	32.5			0.6	1.5			182.7
Zanjan (ZA)	550.8	834.5	72.4	47.8							7.3	8.4	890.7
Total	**13,484.5**	**20,429**	**3,446.2**	**2,274**	**1,642.7**	**1,806**	**2,823.1**	**875.2**	**253.6**	**632.9**	**2,253.4**	**2,591**	**28,609.9**

Detailed information of the lands under cultivation and estimated obtained biomass residues of orchard crops is represented in Table 2 (Ministry of Agriculture, 2009b; Azizaddini et al., 2010). The provincial distribution of orchard biomass residues which were collected from pruning of trees and the shell of nuts is shown in Fig. 2 (Azizaddini et al., 2010).

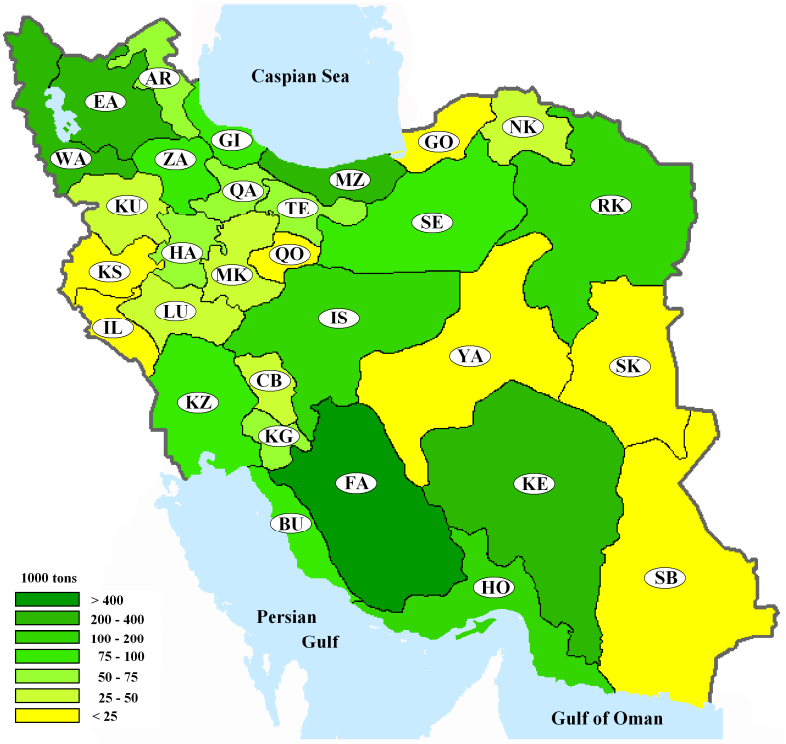

Figure 2. Provincial distribution of annual orchard residues.

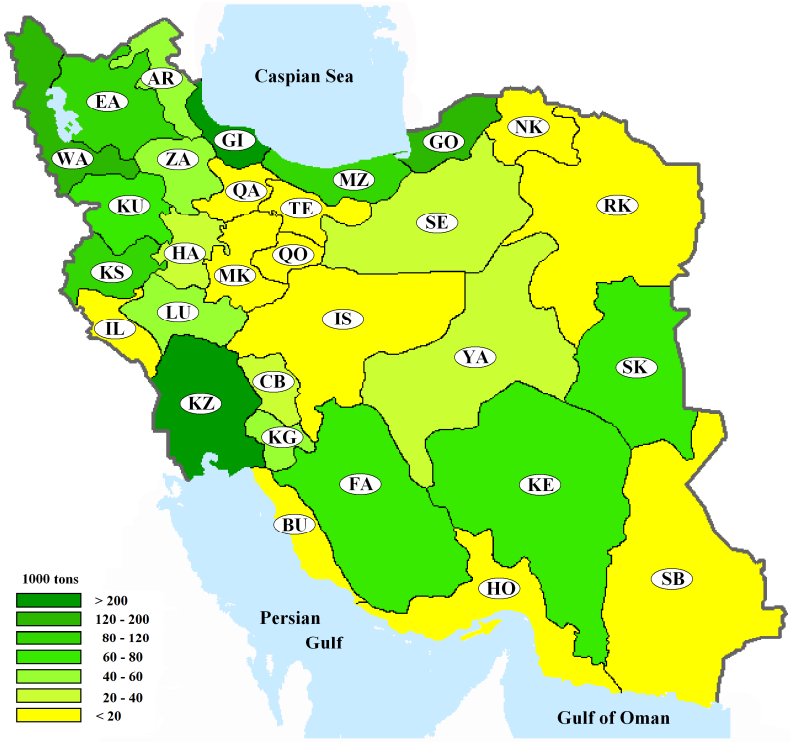

Figure 3. Provincial distribution of annual wood forestry.

Table 2. The provincial distribution of the cultivated areas of orchards and the amounts of residues (Azizaddini et al., 2010)

Province	Pistachio		Grapes		Date		Apple		Citrus		Walnut			Almond			Total Residue (10^3 t)
	Area (ha)	pruning (t)	Area (ha)	Pruning (t)	Area (ha)	Pruning (t)	Area (ha)	Pruning (t)	Area (ha)	Pruning (t)	Area (ha)	Pruning (t)	Shell (t)	Area (ha)	Pruning (t)	Shell (t)	
Ardabil (AR)			2,574	1,339			8,358	48,141			5,125	1,666	3,880	67	19	36	55.1
Bushehr (BU)			4	2	36,945	71,672			3,204	10,734				84	24	16	82.4
Ch. Bakhtiari (CB)			5,119	2,662			4,422	25,472			10,669	3,467	4,296	13,979	4,054	5,048	45
East Azerbaijan (EA)	139	14	16,807	8,740			38,679	222,788			14,233	4,626	14,684	7,979	2,314	4,763	257.9
Fars (FA)	14,743	1,474	61,757	32,114	24,770	48,054	28,110	161,913	66,852	223,954	12,133	3,943	9,526	32,328	9,375	11,336	501.7
Gilan (GI)			45	24			371	2,138	19,388	64,949	7,052	2,292	7,180				76.6
Golestan (GO)	23	2	41	21			234	1,347	5,212	17,460	3,275	1,064	959				20.9
Hamadan (HA)	126	13	18,727	9,738			4,729	27,236			17,284	5,617	14,722	6,302	1,828	2,517	61.7
Hormozgan (HO)	404	40	294	153	34,169	66,288			33,375	111,805				22	6	25	178.3
Ilam (IL)	3		519	270	224	435	57	328	392	1,313	1,581	514	757	39	11	2	3.6
Isfahan (IS)	4,313	431	6,249	3,250	244	473	21,395	123,237			12,885	4,188	5,369	6,589	1,911	2,957	141.8
Kerman (KE)	290,830	29,083	2,814	1,463	61,005	118,350	2,932	16,888	45,358	151,948	27,252	8,857	13,075	17,789	5,159	4,442	349.3
Kermanshah (KS)	22	2	8,623	4,484	481	933	3,183	18,336	319	1,068	13,185	4,285	14,600	3,285	953	416	45.1
Khuzestan (KZ)			1,849	962	37,492	72,735	66	381	5,801	19,434	445	145	1,520	65	19	29	95.2
Kuh Giluya (KG)			2,998	1,559	70	136	5,479	31,561	3,868	12,957	8,267	2,687	3,900	938	272	169	53.2
Kurdistan (KU)	2		13,313	6,923			2,304	13,273			4,815	1,565	7,230	1,336	388	313	29.7
Luristan (LU)	12	1	4,251	2,211			3,044	17,531	424	1,419	17,966	5,834	8,455	4,508	1,307	1,642	38.4
Markazi (MK)	5,309	531	11,764	6,117			2,212	12,742			3,313	1,077	1,882	5,539	1,606	1,466	25.4
Mazandaran (MZ)			9	5			2,374	13,676	103,211	345,758	6,277	2,040	967				362.4
North Khurasan (NK)	515	52	16,089	8,366			4,889	28,163			4,483	1,457	2,649	4,727	1,371	543	42.6
Qazvin (QA)	3,659	366	32,611	16,958			3,177	18,302			9,716	3,158	8,699	3,706	1,075	1,940	50.5
Qom (QO)	1,618	162	819	426			238	1,369			4,195	1,364	1,148	763	221	677	5.4
Razavi Khurasan (RK)	37,610	3,761	35,813	18,623			17,502	100,809			8,009	2,603	4,626	39,105	11,341	3,366	145.1
Semnan (SE)	11,821	1,182	4,130	2,148	28	55	1,716	9,886			2,143	696	2,278	1,519	441	610	17.3
Sistan and Baluchistan (SB)	6,378	639	1,583	823	44,855	87,018	150	866	3,063	10,262	61	20	72	116	34	47	99.8
South Khurasan (SK)	10,602	1,060	3,573	1,858	246	478	313	1,805			962	313	1,338	12,697	3,682	3,409	13.9
Tehran (TE)	2,712	271	2,522	1,311			6,322	36,416			9,364	3,043	22,391	547	159	765	64.4
West Azerbaijan (WA)	4		24,750	12,870			55,023	316,930			6,015	1,955	309	2,805	814	373	333.3
Yazd (YA)	40,252	4,025	2,013	1,047	3,901	7,568	394	2,269	110	368	1,761	572	571	10,839	3,143	742	20.3
Zanjan (ZA)	44	4	20,070	10,436			10,926	62,936			5,500	1,787	8,786	1,413	410	2,180	86.5
Total		**43.1**		**156.9**		**474.2**		**1,316.7**		**973.4**		**70.8**	**165.9**		**51.9**	**49.8**	**3,302.8**

Table 3. The provincial distribution of the woody forestry (Azizaddini et al., 2010)

Province	Poplar		Eucalyptus		Total Production (t)
	Area (ha)	Production (t)	Area (ha)	Production (t)	
Ardabil (AR)	5,150	46,260			46,260
Bushehr (BU)			534	7,796	7,796
Ch. Bakhtiari (CB)	3,500	23,400			23,400
East Azerbaijan (EA)	14,300	110,070			110,070
Fars (FA)	4,500	36,450	1,964	28,674	65,124
Gilan (GI)	45,000	506,250			506,250
Golestan (GO)	2,000	18,900	8,407	122,742	141,642
Hamadan (HA)	4,000	26,100			26,100
Hormozgan (HO)			666	9,724	9,724
Ilam (IL)	300	2,970	625	9,125	12,095
Isfahan (IS)	2,500	18,000			18,000
Kerman (KE)	1,350	8,865	4,553	66,474	75,339
Kermanshah (KS)	10,000	99,000	300	4,380	103,380
Khuzestan (KZ)	3,600	35,640	9,742	177,792	213,432
Kuh Giluya (KG)	3,200	31,680	1,104	16,118	47,798
Kurdistan (KU)	11,900	77,310			77,310
Luristan (LU)	5,800	43,920	976	14,250	58,170
Markazi (MK)	1,600	10,890			10,890
Mazandaran (MZ)	7,000	74,250	434	6,336	80,586
North Khurasan (NK)					0
Qazvin (QA)	500	3,150			3,150
Qom (QO)			200	2,920	2,920
Razavi Khurasan (RK)	1,850	13,140			13,140
Semnan (SE)	300	2,970	4,350	63,510	66,480
Sistan & Baluchistan (SB)			2,561	37,391	37,391
South Khurasan (SK)					0
Tehran (TE)	650	4,635	130	1,898	6,533
West Azerbaijan (WA)	14,700	148,725			148,725
Yazd (YA)			1,500	21,900	21,900
Zanjan (ZA)	5,800	58,500			58,500
Total (t)		**1,401,075**		**591,030**	**1,992,105**

2.3. Short Rotation Plantations

Short rotation forestry contributes the reduction of greenhouse gases in two ways. Afforestation of arid areas or marginal lands captures CO_2 while raises the organic content of the soil and significantly provides feedstock for biofuels which could be a substitution of fossil fuels (Stjernquist, 1994). Eucalyptus and poplar species are extensively cultivated in Iran; however, willow, alder, acacia and pine are grown in discrete regions as well. The last recent report on estimation of the area under cultivation of short rotation forestry shows that around 150 thousands of hectares are dedicated to poplar plantations and 38,000 hectares of eucalyptus were cultivated in Iran (Ministry of Agriculture, 2009c).

The research institute of forests and rangelands (R.I.F.R.) of Iran reported that the increasing growth rate of short forestry reaches 15 to 20 thousands hectares annually (Ministry of Agriculture, 2009c). Area under cultivation of poplar and eucalyptus and available wood products are represented in Table 3. Provincial distribution of woody biomass from short rotation forestry is shown in Fig. 3 (Azizaddini et al. 2010).

3. Results and Discussion

3.1. Experimental Results

The inter-laboratory experimental studies were conducted in order to investigate the characteristics and specifications of the most common lignocellulosic residues in Iran. Under the supervision of Niroo Research Institute, the certified laboratory of R.I.F.R performed the analyses of moisture content, ash content, volatile matter, lower and higher heating value (LHV and HHV), and the elemental components (CHNOS) of selected biomass resources of Iran.

Following, the empirical lower and higher heating values of selected biomass samples are summarized in Table 4 (Azizaddini et al., 2012).

Table 4. The low and high heating values

Species	LHV (MJ/kg)	HHV (MJ/kg)
Willow	17.69	19.48
Kiwi	17.72	19.42
Orange	17.29	19.12
Poplar – P. Nigra	18.39	20.05
Poplar Deltoides 55.69	19.00	20.57
Poplar Deltoides 51.67	19.00	19.47
Poplar - Euromerican	17.71	20.84
Pine	17.93	19.68
Eucalyptus	17.00	18.79
Apple	15.78	17.68
Rice straw	15.17	16.68
Cotton stalk	14.34	15.85
Corn cub	17.58	19.47
Corn cub and leave	16.63	18.40
Sugarcane bagasse	15.04	16.90
Wheat straw	16.21	18.08

3.2. Total potential of Biomass Resources

The total potential of agricultural residues, orchard pruning and short rotation coppices in Iran is calculated regarding the data of Table 4 and considering the total amounts of biomass resources. Its provincial distribution is shown in Fig. 4.

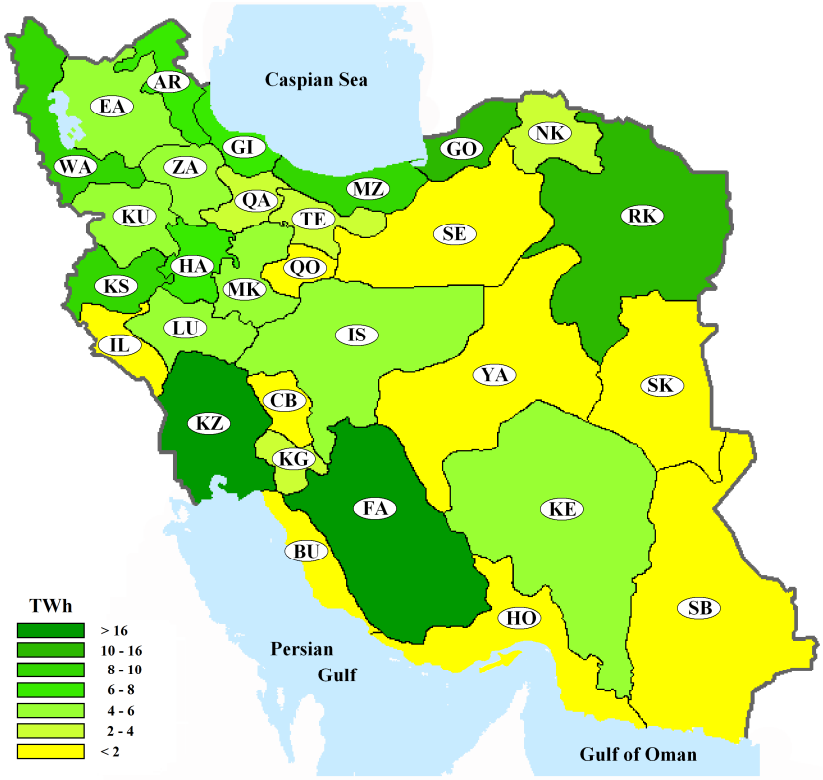

Figure 4. Provincial distribution of bioenergy potentials regarding lignocellulosic resources in Iran.

The gross energy potential of lignocellulosic biomass resources in Iran is approximated to 6.01×10^2 PJ, equals to 167 TWh. As represented in Fig. 4, the provinces of Khuzestan and Fars comprise the highest potential of biomass resources among Iranian provinces in which the gross amount reaches 17.07 and 16.98 TWh respectively that means each province represents around 10% of national potential. The subsequent provinces are Razavi Khurasan, Golestan and Kermanshah with the potential of 11.51, 11.01 and 9.51 TWh respectively.

The available biomass energy from the aforementioned resources in Iran shows that totally 9.85 million tons, equal to 51 TWh of biomass residues are actually available. This sustainable source of energy with much lower environmental impacts than fossil fuels, worthwhile to be utilized or partially substituted instead of the traditional diesel or natural gas-fired boilers for power generation.

Moreover, these biomass residues are suitable feedstock for gasifiers to be used as cogeneration facilities. For instance, by assuming the overall efficiency of small-scale gasifiers for rural electrification, between 0.15 and 0.25, total power generation potential reaches to around 800 to 1400 MW. The moderate performance of the large-scale gasification plants is assumed around 0.4 and power generation potential could be as high as 2300 MW (NETL, 2003).

The available potential of biomass resources of Iran which was estimated on the base of assumptions in Table 5 is shown in Fig. 5. The most capable provinces are Khuzestan, Fars, Gilan,

Mazandaran, West Azerbaijan and Kerman which include 5.78, 5.66, 3.45, 3.22, 3.16 and 3.05 TWh, respectively.

Table 5. Share of availability of biomass residues

Residues	Share (%)	Available biomass (10^6 tons)	Available biomass (TWh)
Wheat	15	3.06	15.39
Barley	15	0.34	1.66
Corn	50	0.90	4.74
Sugarcane	50	0.43	2.05
Cotton	80	0.10	0.45
Rice	15	0.38	1.80
Pistachio	90	0.04	0.19
Grapes	90	0.14	0.75
Date palm	90	0.36	2.04
Apple	90	1.14	5.83
Citrus	90	0.87	4.68
Walnut	90	0.21	1.18
Almond	90	0.09	0.50
Poplar	90	1.26	7.01
Eucalyptus	90	0.53	2.78
Total	30.48	9.85	51.07

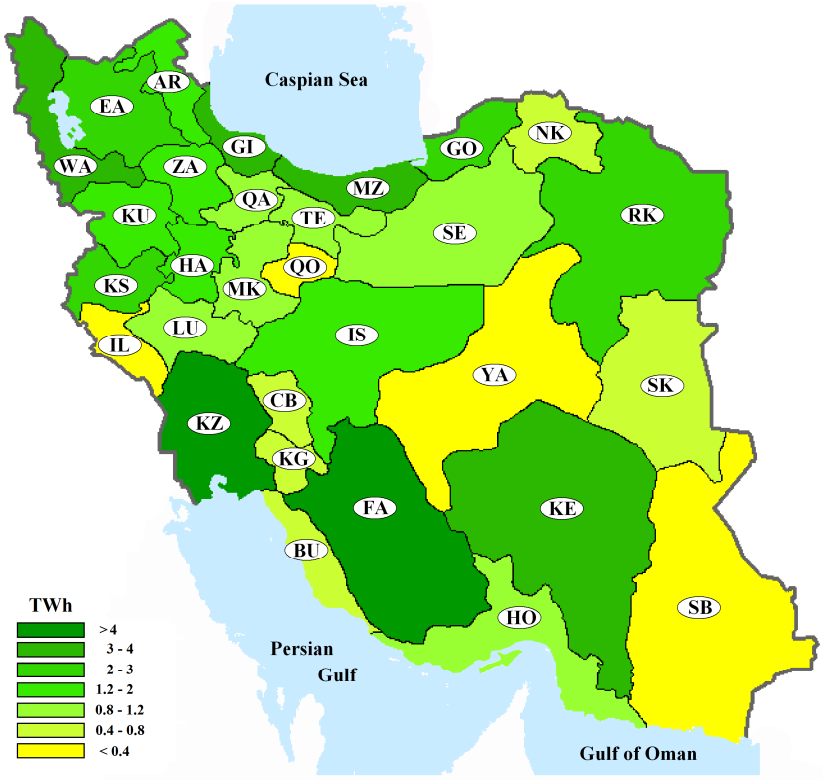

Figure 5. Available potential of biomass energy in Iran.

4. Conclusions

Total and accessible potential of biomass resources of Iran were estimated employing the official statistics of agriculture and artificial forestry in Iran. The total potential was assessed considering the total amounts of agricultural residues, orchard pruning and wood farming; however, a big share of agricultural residues is utilized for animal feeds or industrial purposes. Therefore, the accessible potential was calculated by taking to the account of the unused share of each product. The provinces of Khuzestan, Fars, Gilan, Mazandaran, West Azerbaijan and Kerman are the most potent places for biomass-based project specially gasification process. The amount of accessible potential of biomass resources of Iran which was assessed regarding the share of availability of resources was derived around 51 TWh. And this potential could be applied for around 1400 MW rural gasification power stations to 2300 MW advanced gasification power plants. The data which was used in this study for the assessment of biomass resources was based on provincial resolution. For further works on this issue, it is recommended that researchers in this field and related governmental organizations to gather and report the information for higher resolution to be able for site selection in any district and choose the proper capacity for construction of biomass power plants.

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