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14. POTENTIAL UTILIZATION OF RENEWABLE ENERGY SOURCES AND THE RELATED PROBLEMS

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Introduction

In 1994, the amount of electricity produced in Estonia was 9.1 TWh (32.8 PJ). 28.22 TWh (101.6 PJ) of fuel energy was used og which 99% of the fuel was oil shale. In 1994, the share of oil shale was 60 % in the balance of primary energy, totalling 180 PJ (Statistical ..., 1995). Because oil shale is a domestic fuel, Estonia's national energy economy is based on it. However, oil shale resources are limited (according to expert estimates they can cover the main share of electricity demand approximately to the year 2025). The future vision of Estonia's energy economy is foreseen to be based on nuclear energy, and on a smaller scale, on the use of different renewable energy sources (Estonian ..., 1994). While the introduction of nuclear requires major investment, the long-term preliminary design, work and efforts for forming public opinion, promotion and development of different renewable energy potentials, as a rule, are affected by economic and ecological factors only. Among Estonia's most significant renewable energy sources are bioenergy, hydropower, solar and wind energy. Furthermore, peat is given a priority in the national fuel balance, but usually not considered a renewable energy source due to its prolonged rotation period.

Biomass energy

Biomass can be divided mainly into three subgroups depending on origin: natural, man-made and animal biomass. Estonia's natural biomass resources include wood and residues of agricultural crops. The total area of forest land in Estonia is approximately 2.02 Mha, which accounts for about 48 % of the total area. The total volume of growing wood stock in Estonia's forests is about 350 Mm^3, while in the recent years, the annual cut was about 3-3.5 Mm^3. In addition to productive forest land, bushland on the former fields cover 200-300 thousand ha, where 1-1.5 Mm^3 of firewood could be supplied. About one third of the harvested wood is used as firewood, the remaining two thirds is processed in the woodworking industry (Estonian Energy,1992, 1994). Table 1 (Fig. 1) shows the use of wood and waste wood in 1980-1994 (Estonian Statistical Office (ESO)).

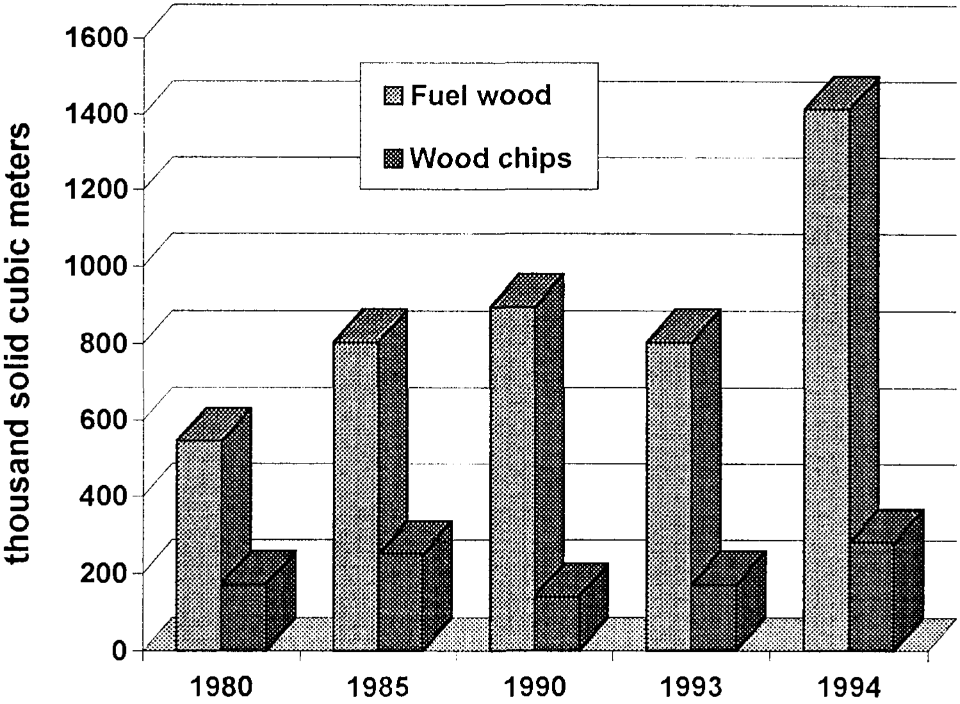

Fig. 1. Firewood consumption in Estonia 1980 – 1994, th m^3

Table 1. The used biomass resource

	1980	1985	1990	1993	1994
Firewood, th m^3s	544.7	804.2	894.9	804.2	1413.7
(PJ)	4.2	6.2	6.9	6.2	10.9
Wood chips, th m^3s	171.6	249.6	140.4	171.6	280.8
(PJ)	1.1	1.6	0.9	1.1	1.8

The total growing stock gives 66-75% of wood; branches, stumps and bark or the so-called logging residues form 25-33%. About 35-40% of timber becomes the residue of the wood industry (bark, saw dust, and shavings) (Kiipsaar, et. al., 1992). In 1994, the harvesting totalled 3.62 Mm^3 (Statistical..., 1995), including 1.4 Mm^3 of firewood, i.e., 39% of the total harvesting; and 0.28 Mm^3 for processing into wood chips, i.e., about 10% of the wood waste (Table 1).

Animal biomass

On January 1,1995 domestic animals in Estonia totalled (in the heads) cattle: 477.0, cows 280.7, sheep 139.9, horses 8.6, hogs 960.0, and poultry 6.536 t(Statistical Yearbook, 1995). Annually, 10-12 t of manure is produced per animal unit. One animal unit means, respectively: 1 milk cow, 1.8 heads of young cattle, 5 calves, 6.7 hogs, 250 hens, 1 horse or 8.5 sheep. Considering the amount of biogas that can be produced from one ton of manure (it differs for different animal species) and the methane content in the produced biogas, the resource of animal biomass for Estonia was 4.07 PJ in 1995 (Table 2).

Table 2. Resource of animal biomass in Estonia in 1995

Domestic animals	Number of animals, th heads	Production of manure, animal/yr	Biogas from the manure, m^3/t	Bioenergy resource, PJ
Cattle	215.8	5.6 - 6.7	20.8	1.53
Cows	218.9	10 - 12	20.8	1.56
Hogs	466.7	1.6 - 2.0	2.4	0.5
Poultry	3400.0	0.04 - 0.048	57.7	0.48
			Total	4.07

Table 2 shows the results calculated for the biomass with a methane content of 65% and a conversion factor 15 MJ/m^3 (Pachel, 1993).

The obtained total bioenergy resource is less than the real one, since horses, and sheep have not been included because there is no data on the amount of biogas that could be produced from one ton of horse or sheep manure.

In Estonia manure-based biogas is processed in two enterprises:, the Pärnu Seavabrik Ltd Pärnu County and, Linnamäe Peekon Ltd Lääne County. Both firms use hog manure, and the obtained biogas is used in the local boiler house for heat production. The designed capacity of the biogas plant of the Pärnu Seavabrik Ltd is 6,210 m^3 with the meanly biogas content of 60%. At present, the capacity of the hog farm is 60%; the number of hogs is 17,000 and the daily output of biogas amounts to 3,500 m^3. The thermal energy produced on the basis of this amount of biogas was about 6 TWh in 1994.

Waste

Currently, most of the organic waste is stored in landfills, with the total quantity is estimated at 250-300. Each year, 400 to 500 thousand tons of organic waste are delivered there. Municipal waste is not incinerated in Estonia, and only small amounts of oil product residues are burnt. A treatment system for hazardous waste is under construction, where oil and solvent residues will be incinerated.

Table 3. Origination, utilization and storage of organic waste, th t

	Generation		Utilization		Deposition	
	1993	1994	1993	1994	1993	1994
Waste of animal and vegetable origin	574.6	628.9	551.8	609.9	41.9	36.2
Domestic waste*	308.9	694.1	122.2	113.4	344.6	579.9
Total:	**883.5**	**1323.0**	**674.0**	**723.3**	**386.5**	**616.1**

* Domestic waste is a mixed waste generated by households, enterprises and hospitals, as well as by water purification waste and sewage.

As Table 3 shows, in 1994, 1.32 Mt of organic waste was produced: 0.72 Mt was utilized, and 0.62 Mt was stored in landfills. If we could incinerate the combustible part of total domestic and industrial waste, then, according to Swedish experience, we could produce about 1.2 TWh of thermal energy per year. In Sweden, where waste incineration technology is used extensively, in 1994, about 3 TWh of heat energy were produced from 1.4 Mt of waste. (Statistical ...,1995).

An alternative is to collect landfill gas and its combustion. By depositing waste in the natural environment-storage and burials-their organic decomposition will occur over time, resulting in the emergence of carbon dioxide and water, nitrous oxide and sulphur oxide and other gaseous compounds. With regard to environmental pollution, the anaerobic decomposition of waste by the limited access of oxygen, where one of the predominant released components is gaseous methane, is most unfavourable. In landfills, the self-ignition of methane may occur, resulting in fires and releasing toxic gases, such as dioxines and chlororganic compounds. On the other hand, methane has high greenhouse effect potential.

At the end of 1994, at the Pääsküla refuse dump in Tallinn, the largest dump in Estonia (2.5 Mm^3), an environmentally sound project for collecting biogas and generating thermal energy from it was launched. This methane-based gas (with a methane content of about 50-60%), which earlier volatilized simply in the atmosphere, is now collected by special collector-pipes installed in the landfill at different levels. The compressors suck the gas out of the system and compress it. Further, the compressed hot gas is cooled and directed along pipelines to boiler plants for combustion. The designed productivity of this facility is 1,000 nm^3/h, which corresponds to 5 MWh of energy. Biogas is an excellent fuel, and the flue gases from its burning are not as hazardous as the biogas itself. If it were possible to collect all the biogas from the decomposition of organic waste (0.6 Mt of organic waste was deposited in the landfill each year), we could produce about 40 GWh of energy per year on this basis.

Hydropower

Estonia has 7,378 rivers and streams, but most of them are short and low-discharged. Only 420 rivers are longer than 10 km and 10 rivers are longer than 100 km (Pachel, 1993) (Table 4). Most of the rivers have a low-medium slope, and thus no large hydropower plants can be built on them. But several rivers can be harnessed for building mini- or micro-hydropower plants (MHPP). The total hydropower potential of Estonia's rivers is about 200 MW, accounting for only 1-2% of the total capacity of Estonian power plants. But, still, the implementation of this capacity would facilitate generation of 0.2-0.7 TWh of electrical energy (Raesaar, 1994).

Table 4. Major rivers in Estonia

River	Length, km	F, km^2	Profile, m	Q_{max}, m^3/s	Q_{min}, m^3/s	Mq, l/s km^2
1. The catchment area of Lake Peipsi						
Narva	77	56200	30	399	114	7.1
Piusa	109	796	208	5.8	1.85	7.3
Võhandu	162	1420	98	10.3	2.44	7.3
Suur-Emajõgi	100	9740	4	70.1	17.9	7.2
Pedja	122	2710	67	25.4	3.04	9.3
Põltsamaa	135	1310	71	13.4	2.35	10.2
Ahja	95	1070	87	7.1	2.35	6.6
Amme	59	501	53	3.8	0.12	7.6
Väike-Emajõgi	83	1380	81	11.5	1.9	8.3
Õhne	94	573	63	4.5	0.6	7.9
2. The catchment area of the Gulf of Finland						
Purtse	51	810	77	6.6	0.48	8.1
Kunda	64	530	90	6	1	11.3
Loobu	62	308	93	2.9	0.39	9.4
Valgejõgi	85	453	107	3.9	0.7	12.8
Jägala	97	1570	82	12.2	1.34	7.8
Soodla	46	236	62	2.3	0.32	9.7
Jõelähtme	46	321	54	2.4	0.06	7.6
Pirita	105	799	75	7.8	0.51	9.8
Vääna	64	316	50	2.6	0.35	8.3
Keila	116	682	75	6.3	0.62	9.2
3. The catchment of the Väinameri and Livonian Gulf						
Kasari	112	3210	62	29.9	1.45	9.3
Vigala	95	1580	63	14.7	0.64	9.3
Velise	72	852	66	7.3	0.061	8.6
Pämu	144	6920	78	64.4	4.8	9.3
Navesti	100	3000	57	27.9	2.15	9.3
Halliste	86	1900	76	17.3	1.23	9.1
Sauga	77	570	60	5.1	0.045	9.0
Mustjõgi	84	1820	30	14.4	2.82	7.9

In 1995, six mini-hydropower plants (with a capacity below 25 MW) with the installed total capacity of 925 kW and several private micro-hydropower plants with the capacity of some kW were operated in Estonia. Table 5 gives a survey of the working hydropower plants.

Table 5. Hydropower plants in Estonia in 1995

Plant	Installed capacity, kW	Year of construction
1. Saesaare on the Ahja R.	240	1991
2. Leevaku on the Võhandu R.	195	1994
3. Kotka on the Valgejõgi R.	180	1994
4. Põltsamaa on the Põltsamaa R.	60	1945 -1950
5. Joaveski. on the Loobu R.	50	1945 - 1950
6. Keila-Joa on the Keila R.	200	1977
Total capacity:	**925**	

The real capacity of the hydropower plants is somewhat lower, and, according to the Estonian Statistical Office, the total power generated by hydropower plants was 500 kW in 1994 (Energy Balance, 1995).The restoration of six more hydropower plants with a total expected capacity of 3.7 MW is planned.

Wind power

Among Estonia's resources of renewable energy, wind power is most significant. However, several questions must be answered when assessing the possible use of this power. Among others, the most important are: are the wind resources sufficient, and is it economically justified to use wind energy? Will there be compatible local consumers in the locations where the wind energy presumably will be used? How can energy be stored or used in hybrid power systems for the changing wind speed? Can domestic industry and researchers be involved in the production of the necessary equipment? How expensive will the introduction of this type of energy be, and what will the production cost of wind energy be after its introduction? In order to make a valid assessment, all direct and indirect costs must be included by comparing different types of energy. Very often the problems are interrelated and need to be studied. It is evident that to introduce any new type of energy, supplementary expenses are required, and therefore thorough preparation and study of the influence of active processes and exterior factors are crucial. This assumes a national energy program, whereas at the initial period with the planning and funding of the studies should be supported from the state budget or respective foundations. Efficient legal procedures of the acts and regulations promoting the introduction of a new type of energy is also essential. For example, the projects of wind power, one of the most promising renewable energy sources in Estonia, have been successful when the manufacturers of the equipment and the energy producers have been provided with subsidies and exempted from the sales tax by the state during early operation. This was the practice in the USA, Denmark, Germany and in other countries which developed wind power technology.

Taking into account the natural conditions and the economic expediency, in the first years it pays to develop the capturing of wind power or wind power technology in those regions where the average annual wind speed at 10 m above the surface is 5 m/s, although the foreign experience shows that wind energy can be used efficiently in the areas with an average wind speed of 3.5 m/s or even lower (Wind...,1995). In the latter case the site of wind turbines must be carefully selected, and the height of the tower must be at least 40 to 50 m. For several years, the average wind speed at the Estonian western and northern coast and in particular on the islands has been over 5 m/s. The processing of meteorological data (SU Climate ..., 1966) shows that the highest wind speeds are at the western coast of Saaremaa and Hiiumaa, on Muhumaa, Vormsi and Kihnu islands and on thesmaller islands not-connected to the interconnected electrical network – Osmussaar, Ruhnu, Naissaar, Prangli. (Figure 2).

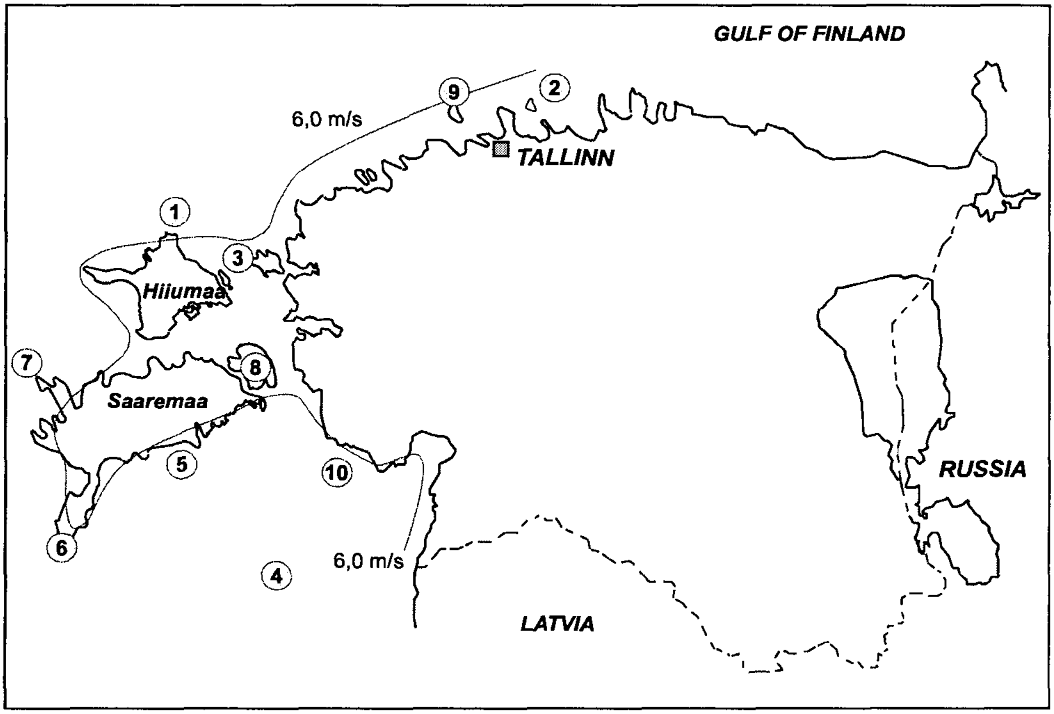

Fig. 2. Perspective areas for wind energy use.

1 - Tahkuna, **2** - Prangli, **3** - Vormsi, **4** - Ruhnu, **5** - Vätta, **6** - Sõrve, **7** - Undva, **8** - Muhu, **9** - Naissaar, **10** - Kihnu

Wind speeds at the Estonian meteorological stations

Considering the presumably high wind resources, in particular, on the islands and at the coast, detailed investigations should be carried out concerning the average wind speeds and the frequency of their occurrence. As a result, the best sites for installing wind turbines could be selected, and sufficient objective data on Estonia's potentials of wind power could be collected. In addition to the conventional wind speed measurements at 10 to 13 m above the surface taken at the meteorological stations, the wind speed, direction and frequency of occurrence according to wind classes at different heights should be measured in the special measuring towers at the sites of future wind plants. Such measurements are presently made on the island of Hiiumaa at Cape Kootsaare, on the islands of

Vormsi and Prangli, and on the Harilaid.The wind speed measurements taken earlier at the Estonian meteorological stations are not as reliable as those taken by modern equipment.

In the past, low-precision equipment was common, the measurements were made infrequently, and self-recording facilities were not available. However, the results of the earlier long-term observations permit to state that on Estonia's islands, in particular, the wind conditions are good and suitable for the installment of wind power plants. Table 6 shows the wind speeds of energy-producing value recorded at the meteorological stations on the Estonian islands and the results of data processing.

Table 6. Annual average wind speeds at the meteorological stations

Meteorological station	Height of the vane H_0 ,m	Average wind speed V_0 ,m/s	Calculated wind speed $V_{H=10}$, m/s	Calculated wind speed $V_{VH=30}$, m/s
Tahkuna	13	6.4	6.1	7.3
Vormsi	11	5.6	5.5	6.6
Pakri	13	5.6	5.4	6.4
Naissaar	13	5.8	5.6	6.6
Kihnu	13	6.2	5.9	7.1
Ruhnu	12	5.8	5.6	6.7
Sõru (Hiiumaa)	13	5.8	5.6	6.6
Kuressaare	13	5.9	5,7	6,7
Sõrve säär	12	6.2	6.0	7.2
Raugi (Muhu)	13	5.3	5.1	6.1
Osmussaar	13	6.8	6.5	7.8
Vilsandi	13	6.5	6.2	7.4

Table 6 shows the average readings of the annual average wind speeds V_0 for the vane height H_0 (SU Climate ...,1966) and the corrected annual average wind speeds $V_{H=10}$ and $V_{H=30}$, at the respective height from the ground of 10 and 30 m from 1945 to 1963. The first height (10 m) is generally recognized as the standard height for comparing wind speeds, the other (30 m) is the height of a usual middle class 100 to 250 kW rotor center. The correction of wind speeds was necessary in order to equalize the conditions by comparing the sites. It was calculated according to the formula

$$V_{H=10}= V_0 \times (10/H_0)^{0.16} \text{ or } V_{H=30}=V_0 \times (30/H_0)^{0.16}.$$

The exponent 0.16 (Kleemann, . 1988) corresponds to a landscape with low obstacles (single trees or bushes), flat islands and coastal areas, which are the traditional sites of wind power plants and meteorological stations.

Assessment of production and resources

The annual average wind speed alone cannot give a complete survey of the energy available. Our estimation of the resources of wind power was based on the frequency of wind speed occurrence at different observation stations in Estonia and on the dependence of the capacity of the modern Danish wind plant *Vestas V27* rated at 225 kW on the wind speed (Technical..., 1989). The blade diameter of the wind turbine controlled by changing the adjustment angle of the blade was 27 meters. This facilitates operation at the wind speeds of 3 to 25 m/s. For resource estimates, wind speeds of 3.5 to 24 m/s were considered. Table 7 shows the amount of electricity produced by a wind mill and the resource of wind power per square kilometre. The latter is obtained by adding the output of 16 turbines and reducing the sum by 10%, which shows the stand-by of the equipment for maintenance. The resources have been assessed conservatively, since the wind speed has not been corrected for heights – the measurements were made at the height of 10 to 30 m, but the axis of the rotor is at the height of 30 m in the area of higher winds. In addition, 25 windmills can be installed on a square kilometre for normal separation (7 diameters of a blade), or 200 m from each other. The data is given separately for winter (October -March), summer (April-December) and the whole year.

Fig. 3. The first wind turbine GENVIND CV – 150 kW in Estonia, Hiiumaa, Cape Tahkuna.

Table 7 includes no data on the site of the first Estonian pilot wind plant at Cape Tahkuna, Hiiumaa (Fig. 3). The reason is the lack of data on the frequency of the occurrence of respective wind speeds (no initial data for calculations) in the initial source (SU Climate ..., 1966). But it included data on the average wind speeds, and according to this data, Tahkuna is one of the windiest places in Estonia (see Table 6). The calculated outputs show that the wind resources on the Estonian islands (coastal regions) are sufficiently high to wind power production.

Table 7. Estimated wind resources

Meteorological Station	Output of Vestas V27, MWh			Wind Resource, GWh/km^2		
	Winter	Summer	Yearly	Winter	Summer	Yearly
Kuressaare	277.7	209.6	487.2	3.998	3.018	7.016
Vilsandi	364.1	255.9	620.0	5.243	3.685	8.928
Sõrve	329.8	215.9	545.7	4.749	3.109	7.858
Ruhnu	317.9	169.4	487.3	4.578	2.439	7.018
Ristna	254.3	140.1	394.4	3.662	2.018	5.680
Sõru	267.4	189.8	457.2	3.850	2.733	6.583
Raugi	244.8	179.5	424.4	3.526	2.585	6.111
Osmussaar	422.8	249.8	672.6	6.089	3.597	9.686
Pakri	266.9	180.9	447.8	3.843	2.605	6.448
Naissaar	311.2	195.1	506.3	4.481	2.810	7.291

How and what type of wind turbines can be used in Estonia

In terms of wind energy, small- and large-scale power engineering are distinguished. Large-scale power engineering covers wind power equipment rated at 100 kW and higher, used to produce electricity for the public electrical grid or independently (also in hybrid power systems), with a diesel generator to produce electricity and heat. Small power engineering covers low capacity equipment, mainly independent machines for the production of electricity or heat. However, in most cases, this differentiation is not significant. Four different approaches can be considered for the use of wind turbines:

* wind plants with a unit power of 200 to 600 kW or more, consisting of several wind turbines could be operated as a single source of power for producing electricity to the public grid with the equipment owned by a shareholders' company, a municipal enterprise or a power network. The distribution network would pay an agreed price for the generated power, which should not be lower than 80-90% of the average sales tariff to provide normal conditions.

* A private or a cooperative owner of a 75 to 250 kW wind turbine could supply electricity to the public grid throughout a year in the amount that satisfies the owner or exceeds his demand by using electrical heating in winter. The electricity distribution network would purchase the produced electricity at the price agreed (85-90% of the tariff of a small consumer is recommended) and would sell the demanded amount of electricity to the owner at a 100% tariff.

* A 30-150 kW wind turbine could be used in a hybrid system with a diesel generator as a power plant for a local electrical network. The system would include a rectifier, a storage battery, an inverter for converting the direct current into the 50 kW alternating current and some additional components for the use of the generated alternating or direct current under high wind conditions. No special constraints limit the type of the wind turbine, since a direct current interface would be used. According to this circuit, the diesel power plants on the Estonian islands of Prangli and Ruhnu are planned for reconstruction. This system is suitable for the island of Naissaar too.

* An autonomous 3-30 kW small- or medium- size wind turbine could cover the heat load for electrical heating and, if necessary, for charging storage batteries or for any other purpose, such as sawing wood. Such use of wind energy would be typical of self-built windmills, but here the controllability and wind harnessing would not very efficient.

The above options show the principal approaches to the implementation of wind energy in the near future. But the main interest of scientific investigations will be focused on the possible loading autonomous system, which facilitates the use of hydrogen as a fuel for diesel generators readjusted for this purpose. In principle, hydrogen could be added to the existing main of natural gas thus increasing the content of hydrogen in the gas. As a result of this application, the wind turbines installed at the north coast would operate in parallel with the electric network while producing hydrogen for the gas pipelines. Gas is fired in the power plants of major towns for starting gas turbines which combined cycles, primarily to cover the peak loads in Tallinn. To seek the possible implementations of such wind energy strategy, additional investigations are needed.

Solar energy

In practice, solar energy is not used in Estonia. However, this does not imply that this resource could not be used in the future. The average actinometrical resource in Estonia is estimated at about 977 kWh/m^2, which is sufficient as regards Estonia's geographical location. For example, in Denmark the corresponding figure is ca 1018 kWh/m^2, but as compared to Denmark, the lowest average outdoor temperature essentially limits Estonia's use of solar energy. Considering the large-scale private house projects in Estonia, it seems reasonable to develop solar energy-based household hot water production. The so-called "passive" or architectural trends in the use of solar energy (for instance, closing balconies to make them weatherproof) could also be feasible under Estonia's conditions.

Conclusions

Estonia's most promising resource of renewable energy is the natural biomass. In 1994 the use of wood and waste wood formed about 4.9% of the primary energy supply, the available resource will provide for a much higher share of biomass in the future primary energy supply, reaching 9 – 14%.Along with the biomass, wind energy can be considered the largest resource. On the western and northern coast of Estonia, in particular, on the islands, over several years, the average wind speed has been 5 m/s. Based on the assumption that the wind speed exceeds 6m/s in the area that forms ca 1.5% of the Estonian territory (the total area of Estonia is about 45,000 km^2) and is 5 – 6 m/s on about 15% of the total area, using 0.5 MW/km^2 for the installation density, very approximate estimates permit to state that the maximum hypothetical installed capacity could be 3750 MW. It might be useful to make use of the current maximum 50 MW, which could enable the generation of approximately 70 – 100 GWh of energy per year.Although the solar energy currently has no practical use in Estonia and the resource of hydropower is also insignificant (only ca 1% of the electricity consumption), these two resources of renewable energy hold future promise in view of the use of local resources and that of environmental protection. It is not reasonable to regard renewable energy sources as a substitute for the traditional oil shale-based power engineering in Estonia. But, to some extent, local energy demand can be covered by renewable energy sources. Thus, they can contribute to the reduction of the greenhouse gases emissions in Estonia.

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