FOREST-BASED BIOENERGY IN THE EURASIAN CONTEXT

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This study analyses the Russian forest biomass-based bioenergy sector. It is shown that presently – although given abundant resources – the share of heat and electricity from biomass is very minor. With the help of 2 IIASA model, future green-field bioenergy plants are identified in a geographically explicit way. Results indicate that by only using 3.3% of the total wood removals, twice as much heat and electricity than presently available from biomass could be generated. Furthermore, there is a multitude of additional co-benefits quantified for the socio-economic sector such as green jobs linked to bioenergy.

One of the major opportunities to reduce fossil CO2 emissions is the transition to alternative sources for energy production, including the sustainable use of biomass. Biomass can be used for heating, cooling, producing electricity and transport biofuels. Use of biomass significantly reduces GHG[1] emissions since the emissions from biomass are considered carbon-neutral. Bioenergy can hence make an important contribution to various policies e.g. in the energy and climate sector [e.g. 1]. International statistics indicate for 2008 that biomass is presently the largest global contributor of renewable energy, showing a total share of about 10% (51.3 EJ = 1,225,000 ktoe[2]) of the global annual primary energy consumption (513.8 EJ = 12,271,000 ktoe), mostly as traditional biomass used for residential heating and cooking [2]. In addition to a significant potential to further expand in the production of heat, electricity, and fuels for transport, the deployment of bioenergy - if sustainably developed - could also provide significant improvements in energy security and trade balances by substituting fossil fuels with domestic biomass. Moreover, it bears substantial opportunities for environmental benefits as well as economic and social development in rural communities [e.g. 3].

Russia[3] is the country with the largest land mass, accounting for 1,638 million ha (hectares), and has also the largest forest area in the world totaling between 809 million ha [4] and 817 million ha [5]. According to [5], some 87% of Russia's forest area (710 million ha) form part of the global boreal forest biome with its unique characteristics, inter alia with respect to the abundance of ecosystems, its biomass growth (and –use), vast climate-driven natural disturbances such as wildland fires and insect calamities, as well as its special biodiversity. Overall, Russia and its (boreal) forest might be best known for its enormous natural resources. The growing stock of the Russian forest e.g. amounts to some 81,523 million m^3 [see e.g. 4] which form part of a total amount of living biomass estimated to reach dimensions ranging from 43.5 Pg carbon (including 37.5 Pg carbon in forests, equaling about 75 Pg biomass) [6] to a maximum estimation of 148 Pg biomass [see e.g. 7] in Russia. Estimations based on [8] indicate that the energy equivalent for the Russian forest biomass exceeds 1,400 EJ (33,440,000 ktoe), not including 8 Pg carbon (300 EJ = 7,170,000 ktoe) stored in above- and on-ground dead wood. The gross energy content of the annual NPP[4] of the country's forest ecosystems is estimated to be

[1] Greenhouse Gases (GHG)

[2] ktoe = thousand tons of oil equivalent

[3] The Russian Federation

[4] Net Primary Production (NPP)

about 85 EJ per year (2,030,000 ktoe). Losses of wood due to different reasons (inter alia natural and pathological dieback; stand-replacing disturbances; wastes due to logging and wood processing; etc.) exceed 1 billion m^3 per year, of which 50% occur on in territories of forest available for exploitation [8].

Even though being a biomass-superpower, when looking at the energy sector, forest biomass and the associated bioenergy production - at industrial scale - definitely plays a rather minor role in Russia to date. Table 1 provides an overview of the heat and electricity share of Russia's present energy sector: latest data by the International Energy Agency [9] indicate for 2008, that only 0.6% (840 ktoe) of the total heat production in Russia (142,000 ktoe) is derived from biomass. Moreover, it is indicated that the share of biomass as a primary energy resource contributing to the total electricity production (90,000 ktoe) is even closer to zero (0.0023% = 2 ktoe). Compared to these figures, Canada, another large country with a 74% -boreal share of its total forest area, shows some 4.5% of its total primary energy supply deriving from bioenergy [10]. The total primary energy production in Russia is some 1,254,000 ktoe, of which about 45% (i.e. gas, oil and coal products) are exported. Some 53% (230,831 ktoe) of the country's remaining total final energy consumption of 435,516 ktoe is used in the form of electricity and heat. Table 1 further indicates that the primary energy for electricity generation in Russia is dominated by fossil sources such as gas (48%) and coal/peat (19%). Additionally, some 16% of electricity is produced from nuclear power and about the same share from hydro power. Also, heat production is dominated by the fossil sources gas (66%) and coal/peat (21%). Smaller contributions come from oil (6%) and other renewable sources than biomass (6%, i.e. geothermal and solar). The largest share (61%) of the produced electricity and heat comes from CHP[5] plants, whereas only 22% of these energy forms are produced from pure heat plants and 17 % from pure electricity plants.

Given the very low share of forest-based bioenergy use in Russia, relatively little and only rather vague information on that issue can be found in recent peer-reviewed literature on that topic. There are authors such as [11], who indicate a bioenergy potential for Russia of annually 50 - 205 EJ (1,200,000 – 4,900,00 ktoe) by 2050. Other global bioenergy potentials meta-studies list shares of 10 – 76 EJ (239,000 – 1,800,000 ktoe) annually over the next couple of decades for for CIS[6] and non-OECD[7] Europe [12].

Table 1. Electricity and heat production and their primary energy sources in Russia in ktoe. Source: [own compilation and 9]

Source / Product	**Coal and Peat**	**Crude Oil and Oil Products**	**Gas**	**Nuclear**	**Hydro**	**Geothermal, Solar, etc.**	**Combustable Renewables**		**Total output**
							Biomass	**Waste**	
Electricity	16,917	1,385	42,538	14,023	14,335	40.41	*2*	217	89,456
% of total Electricity	19	2	48	16	16	0	*0*	0	
Heat	29,556	7,984	93,138	328		7,803	*837*	1,907	141,553
% of total Heat	21	6	66	0	-	6	*1*	1	
Total	**46,514**	**9,376**	**135,790**	**14,367**	**14,351**	**7,849**	***839***	**2,125**	**231,009**

Further work [e.g. 13] is more regionally focused, and concludes that in the 11 regions of North-West Russia the present bioenergy use is some 3%, but by just efficient use of the wood waste of present felling in the region, some 5% could be covered easily. Compared to boreal Finland, there is a 7.5 times higher growing stock in North-Western Russia, but harvest is only 2/3 and the share of the harvested wood dedicated to bioenergy is lower than in Finland by a factor of 10. Overall can be said that there is vast potential for bioenergy from forest in Russia even though little specified with respect to realistic mobilization and access potential or more detailed spatial indications.

The objectives of this study are 3-fold. First, to better assess the present situation of forest-based bioenergy in Russia. Second, to provide technical options for an optimal bioenergy development with the help of 2 models developed at IIASA. And third, to contribute to identify possible policy tools and solutions for an increased bioenergy use in Russia.

By covering a higher share of the energy consumption from electricity and especially heat generated from forest-based bioenergy, Russia would not only contribute substantially to meet its climate targets agreed under the Kyoto Protocol and by that contribute to the efforts in mitigating climate change. Russia could also generate multiple co-benefits by increasing its energy portfolio and shifting from fossil-based to biomass-based energy production, especially in forest-rich and remote areas. There would be several economic benefits that could be achieved by increasing the generation of energy from forest-based biomass. For example, substantial amounts of

[5] combined heat and power (CHP)

[6] Member states of the Commonwealth of Independent States (CIS)

[7] Organisation for Economic Co-operation and Development (OECD), www.oecd.org

GHG emissions could be saved and sold under a future emissions trading scheme. Moreover, by modernizing or substituting old and inefficient coal-run power plants by e.g. biomass plants CHP plants of the latest technology, energy efficiencies could be generated that are similar to European standards (e.g. 2 - 3 times higher energy efficiency on the production site) [e.g. 14, 15]. Consequently, direct savings and indirect value added effects with respect to e.g. green jobs would be created. Another linked effect with positive national and international impact could be achieved by efficiency improving (or substituting) of coal – run power plants: According to the International Energy Agency [16] more efficient energy production from coal could in turn take over from natural gas as the major source for Russia's primary energy supply. Then, the natural gas that is no longer required for domestic supply could be exported. This would significantly increase the country's export revenues, as natural gas is more profitable for Russia than coal. By improving the efficiency of its coal-fired power plants, GHG emissions will be reduced within Russia. Carbon emissions could also be reduced beyond Russia's borders, if energy-consuming countries buy natural gas (lower carbon relative to other fossil fuels), as opposed to coal. According to the opinion of the authors of this study, ideally a substantial share of the old coal power plants would be replaced by bioenergy plants, which would even enhance the effect described above.

Two models are applied for the optimal design of bioenergy units in Russia. (1) the Global Forest Model G4M from IIASA is used to calculate the growing stock and the sustainable biomass extraction rate. G4M, as described by [17], has been developed in order to predict wood increment and stocking biomass in forests. As input parameter it uses yield power which is achieved through the NPP for a specific region. This NPP can be supplied by existing NPP-maps [18] or – for higher accuracy –estimated with the help of driver information of soil, temperature and precipitation. The model can be used like common yield tables to estimate the increment for a specific rotation time. It can further be used to estimate the increment– related optimal rotation time and to provide information on how much biomass can be harvested under a certain rotation time and how much biomass is stocking in the forest. G4M also supplies information on the harvesting losses like needles, leaves and branches which typically remain in the forests under sustainable management. Further, other economic parameters such as harvesting costs - depending on tree size and slope - can be calculated.

(2) the BeWhere Model - a spatially explicit optimization model, depicting the supply chain of bioenergy industries - is used for the optimal locations and capacities of green field bioenergy plants [19]. The model, developed at IIASA, considers industries competing for wood resources. On the supply side, forest wood harvests, sawmill co-products and wood imports serve as biomass resources for possible new bioenergy plants. Wood demand of pulp-and-paper mills, of existing bioenergy plants and of private households is considered on the demand side. The model assumes that the existing wood demand has to be fulfilled, allowing new plants to be built only if there is enough surplus of wood available. The model is spatially explicit and the transportation of wood from biomass supply to demand spots is considered either by truck, train or boat. The model selects optimal locations of green-field bioenergy plants by minimizing the costs of biomass supply, biomass transport and energy distribution. Full costs and emissions at the optimal locations are calculated such that we are able to indicate the bioenergy potential for the country under investigation. Spatial distribution of forestry yields was estimated and provided by the G4M, as well as the harvesting costs (as a function of tree size depending on site quality and rotation time) and the slope steepness were provided by the same model.

For the modeling part of our study we assume the following: 1) the G4M provides the forest biomass information data to the BeWhere model. The BeWhere model chooses – under the sustainable forest management assumption that in no case more biomass than the annual forest growth can be harvested and that protected areas are excluded – from all available biomass resources as indicated in Figure 1.

2) we furthermore assume that all larger cities in Russia possess extensive DH[8] grids. Although also these DH grids – similarly to most of the existing fossil fuel-based electricity, heat and CHP plants - might need investments for modernization and efficiency improvements, these grids are fully operational and a majority of the urban population is linked to the DH grids. The population density, indicated in Figure 2, as an important driver for the entire optimization process of BeWhere (i.e. as a demand proxy when facing sub-optimal information) is used for the identification of the optimal location of a green-field (new) plant with respect to demand (heat/electricity demand by the population) and supply (distance to forest biomass).

3) it is further assumed that – based on the information by IEA [16] – brown-field (existing) plants are not only modernized but in most cases (depending on the specific demand and supply situation) transformed into forest-based bioenergy plants of the latest technology (CHP). Green-field forest-based bioenergy plants are mostly to be introduced in more remote areas or as new clusters in order to use the existing infrastructure of energy production units or industry. However, the initial model runs presented in this study are limited to green-field remote or clustered bioenergy plants and the area of biomass extraction and plant construction is limited to the European part of Russia. Furthermore, the initial target for the model runs is to triple the energy production from forest-based biomass.

[8] district heating (DH)

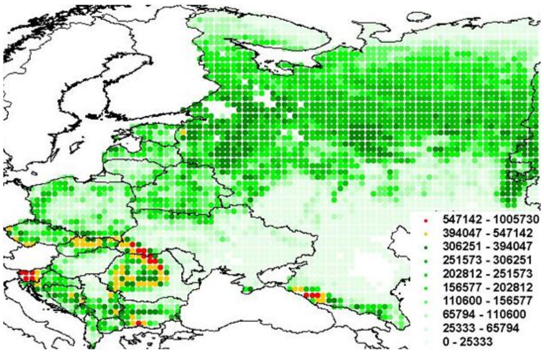

Fig. 1. Forest biomass intensity for Central-East Europe and European Russia in tons per grid and year (t/grid/y). Grid size: 0.5 degree (approx. 50 km grid length at the Equator). Source: own compilation from G4M output data [17].

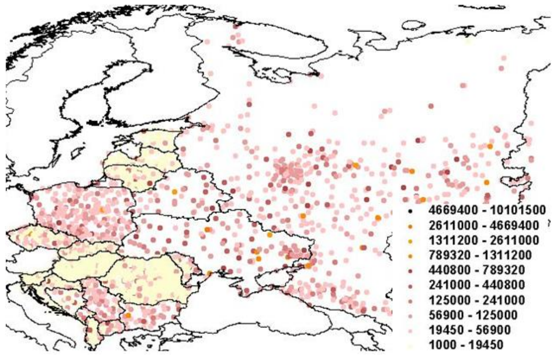

Fig. 2. Population distribution for Central-East Europe and European Russia. Source: own compilation from G4M output data [20].

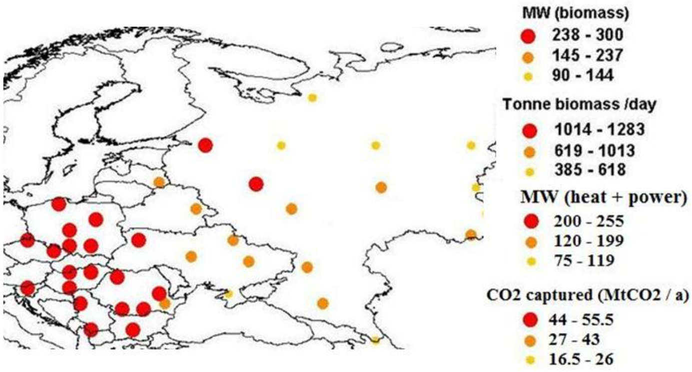

Fig. 3. Major clusters of forest-based green field biomass plants projected for Central-East Europe and European Russia. Different scales indicated by primary energy demand (MW), biomass demand (tons/day), combined heat and electricity supply (MW), and GHG emission savings ($MtCO_2$/y). Source: own compilation from BeWhere output data [19].

The fist modeling results are displayed in Figure3. For Russia, 2 larger bioenergy clusters with a capacity with a total output of up to 500 MW for heat and electricity are indicated in West Russia close to Moscow and in the vicinity of Novgorod and St. Petersburg. 5 medium sized plants with a total output of some 1,000 MW heat and electricity are placed in further urban areas with higher population density such as Volgograd or Samara. Another 6 de-central biomass plants are located further to the north-east of the discussed territory and at the border to Kazakhstan with a total production of some 720 MW. As explained in the Figures 1 and 2, most of the urbanization area in Russia can be found outside the area showing the highest forest biomass productivity and availability. This supply-demand difference might lead to increased costs for transport in some cases. It is also shown in table 2, that these initial and limited model runs result in a maximum amount of 13 green-field bioenergy plants with a total consumption of max. 11,340 tons biomass per day. The maximum energy capacity totals 2,219 MW.

Table 2. BeWhere Model output table showing the input-output energy balance as well as the amount of saved annual fossil CO_2 emissions for all 3 plant types and minimum/maximum production capacities. Source: own compilations from BeWhere model runs.

Plant type	**Large**		**Medium**		**Small**		**Total**	
Number	**2**		**5**		**6**		**13**	
Capacity	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Input [MW]	476	600	725	1,185	540	864	**1,741**	**2,649**
Biomass input [tons/day]	2,028	2,566	3,095	5,065	2,310	3,708	**7,433**	**11,339**
Output [MW]	400	510	600	995	450	714	**1,450**	**2,219**
CO_2 saved [$MtCO_2$/year]	88	111	135	215	99	156	**322**	**716**

If we concentrate on the maximum capacity and assume in addition a workload of 90% for the power plants, which is common for the technology applied in CHP plants, the annual energy (electricity + heat) production would amount to some 1,500 ktoe (17,520 GWh) which comes very close to the double amount of current bioenergy production of 839 ktoe (9,700 GWh, see table 1).

In order to produce energy equivalent to 1,500 ktoe, some 3.78 million tons (6.16 million m^3) of dry matter biomass need to be supplied annually. The official statistics by [4], indicate for Russia annual removals of about 186 million m^3 in 2005, including 135 million m^3 industrial roundwood and 51 million m^3 fuelwood. The necessary amount for producing twice as much forest biomass-based energy in Russia, equals for example some

3.3% of the total removals, 4.6% of the removals of industrial roundwood, or 12% of the total harvest of woodfuel. According to official Russian statistics by the Forest State Agency, there has been illegal logging of some 1.34 million m^3 in 2010 [21]. However, other literature states illegal logging of additional 30% to the existing legal harvest in 2005 [22]. Consequently, some 11% of the total illegal harvest in 2005 or 40.3% of only the illegal harvest of woodfuel would suffice to double the energy generation from forest-based biomass in Russia. By additionally producing the double amount of the present bioenergy, another 444,000 households could be provided with heat and even 1.8 million Russian households could be provided with green electricity.

From a socio-economic point of view, investment in enhancing bioenergy production creates green jobs. In order to install this additional 2,219 MW, during 20 months of construction some 4,500 workers would find a job. Additionally, there would be permanent jobs created for some 2,000 people in the biomass supply and processing sector, as well as some 500 long-term jobs in the new power plants. A further benefit would be the substitution of some 2.7 million tons coal, 1.7 million tons oil or 1.8 billion m^3 of gas [23], resulting in avoiding fossil GHG emissions of 716 million tons CO_2 annually (table 2). The latter would contribute to the declared ambitious target to reduce GHG emissions by 15-25% below 1990 levels. Assuming the use of presently existing DH grid infrastructure as well as retrofitting existing fossil fuel based CHP plants for bioenergy use, on average some 1.5 million Euro might need to be invested per 1MW plant capacity [23].

Concluding it might be said that detailed economic analysis with respect to incentive building (e.g. feed-in tariffs, carbon tax, targeted subsidies or future international carbon trading schemes) need to be carried out in order to support the feasibility of studies like the present one. Further research needs are also identified with respect to the inclusion of detailed data of brown-field (to be modernized and substituted) energy systems, plants and the linked industry in Russia. Also moving towards higher value-added biorefinery products and negative emissions through BECCS[9] seem to be interesting future options for the energy sector in Russia.

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