ИССЛЕДОВАТЕЛЬСКИЕ СТАТЬИ

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SUSTAINABLE FOREST-BASED BIOENERGY IN EURASIA

F. Kraxner[1], S. Leduc[1], S. Fuss[1, 2], D. Schepaschenko[1, 3], A. Shvidenko[1, 4]

[1] *International Institute for Applied Systems Analysis (IIASA)*
Schlossplatz, 1, Laxenburg, 2361 Austria

[2] *Mercator Research Institute on Global Commons and Climate Change (MCC)*
Torgauer Str. 12-15, Berlin, 10829 Germany

[3] *Mytischinski Branch of N. E. Bauman Moscow State Technical University*
Pervaya Institutskaya str., 1, Mytischi, Moscow Oblast, 141005 Russian Federation

[4] *Federal Research Center Krasnoyarsk Scientific Center, Russian Academy of Sciences, Siberian Branch*
V. N. Sukachev Institute of Forest, Russian Academy of Sciences, Siberian Branch
Akademgorodok, 50/28, Krasnoyarsk, 660036 Russian Federation

E-mail: kraxner@iiasa.ac.at, leduc@iiasa.ac.at, fuss@mcc-berlin.net, schepd@iiasa.ac.at, shvidenk@iiasa.ac.at

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This study analyzes 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 two IIASA models (G4M and BeWhere), future green-field bioenergy plants are identified in a geographically explicit way. Results indicate that by using 3.78 Mt (or 6.16 M m^3), twice as much heat and electricity than is presently available from forest biomass could be generated. This amount corresponds to 3.3 % of the total annual wood removals or 12 % of the annually harvested firewood, or about 11 % of illegal logging. With this amount of wood, it is possible to provide an additional 444 thousand households with heat and 1.8 M households with electricity; and at the same time to replace 2.7 Mt of coal or 1.7 Mt of oil or 1.8 G m^3 of natural gas, reducing emissions of greenhouse gases from burning fossil fuels by 716 Mt of CO_2-equivalent per year. A multitude of co-benefits can be quantified for the socio-economic sector such as green jobs linked to bioenergy. The sustainable sourcing of woody biomass for bioenergy is possible as shown with the help of an online crowdsourcing tool Geo-Wiki.org for forest certification.

Keywords: *bioenergy, G4M, BeWhere, Geo-Wiki, Russian forest sector.*

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INTRODUCTION

One of the major opportunities to reduce fossil CO_2 emissions is the transition to alternative sources for energy generation, 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 to have significant lower GHG footprint than emissions from fossil fuels. Bioenergy can hence make an important contribution to various policies in the energy and climate sector (e. g. IEA, 2015). International statistics indicate

[1] Greenhouse Gases (GHG).

for 2012 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 (Survey…, 2010). 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 offers substantial opportunities for environmental benefits as well as economic and social development in rural communities (e. g. FAO, 2010).

Russia[3] is the country with the largest land mass, accounting for 1.638 million hectares (ha), and it also has the largest forest area in the world totaling between 809 million ha (Shvidenko, Apps, 2006) and 817 million ha (Shvidenko et al., 2007). According to Shvidenko et al. (2007), 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 for example amounts to some 81 523 million m^3 (see e. g. Shvidenko, Apps, 2006), 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 (Houghton et al., 2007), to a maximum estimation of 148 Pg biomass (see e. g. Shvidenko et al., 2004) in Russia. Estimations based on IEA (2008) 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 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 (IEA, 2008).

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 (FAO, 2008) 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). National estimate of the amount of woody biomass used for energy (basically by local consumption by population for heating and cooking that is not included in the official country reporting) is 32 M $m^3 \cdot yr^{-1}$; the State Program of development of forest management in the RF by 2030s plans to increase this number to 75 M $m^3 \cdot yr^{-1}$ (Gosudarstvennaya programma…, 2012).

Another source estimated production of major wood energy products in the country in 2010 –

Table 1. Electricity and heat production and their primary energy sources in Russia in ktoe.
Source: own compilation and FAO (2008)

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	1385	42 538	14 023	14 335	40	2	217	89 457
% of total electricity	19	2	48	16	16	0	0	0	
Heat	29 556	7984	93 138	328		7803	837	1907	141 553
% of total heat	21	6	66	0		6	1	1	
Total	46 473	9369	135 676	14 351	14 335	7843	839	2124	231 010

[2] ktoe = thousand tons of oil equivalent.
[3] The Russian Federation.
[4] Net Primary Production (NPP).

charcoal 44 thousand tons, briquettes and pellets 800 thousand tons and wood-based liquid fuel at the zero level, and the respective numbers projected by 2030, at 120, 8500 and 405 thousand tons (FAO, 2012). Current pellet production capacity is two million tons per year, but about half is actually used. Pellet exports are growing and have a good prospect. Eurostat reports exports to EU 28 as 0.7 and 0.8 million tons in 2013 and 2014 respectively.

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 being derived from bioenergy (Smeets et al., 2007). 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 hydropower. 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 (Offermann et al., 2011), who indicate a bioenergy potential for Russia of annually 50–205 EJ (1 200 000–4 900 000 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 CIS[6] and non-OECD[7] Europe (Rakitova, 2010).

Further work (e. g. Martinot, 1998) 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, it can be said that there is vast potential for bioenergy from forest in Russia, even though this remains poorly specified with respect to realistic mobilization and access potential or more detailed spatial indications.

OBJECTIVE AND METHODS

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 sustainable bioenergy development with the help of two 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 Paris agreement, as well as by that contribute to the efforts in mitigating climate change. Russia could also generate multiple co-benefits by diversifying 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 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 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. World bank, 2010; IEA, 2011). Consequently, direct savings and indirect value added effects with respect to, for example green jobs, would be created. Another linked effect with positive national and international impact could be achieved by efficiency-improvements (or substitution) of coal-run power plants: according to the International Energy Agency (Kindermann et al., 2008) more efficient energy production from coal

[5] Combined heat and power (CHP).

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

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

could in turn take over from natural gas as the major source for Russia's primary energy supply. Then, 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. In modern coal-fired power plants, co-firing with biomass is converted with a substantially higher net efficiency. By replacing a portion of coal with biomass, co-firing seems to be the most economic near-term solution for employing biopower at large. In general, modern coal power plants can accept up to 15 % biomass without modifying the steam boiler system. 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 has been developed in order to predict wood increment and stocking biomass in forests (Kindermann et al., 2013). As an 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 (Leduc et al., 2009) 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 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 (Gridded population…, 2004). 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 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 G4M, as well as harvesting costs (as a function of tree size depending on site quality and rotation time) and slope steepness.

RESULTS AND DISCUSSION

For the modeling part of our study we assume the following. 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 Fig. 1.

We furthermore assume that all larger cities in Russia possess extensive DH[8] grids. Although also these DH grids – similar 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 Fig. 2, as an important driver for the entire optimization process of BeWhere (i. e. as a demand proxy when facing suboptimal 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).

[8] District heating (DH).

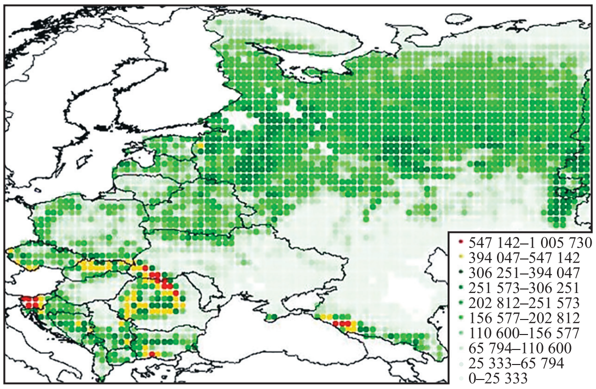

Fig. 1. Forest biomass intensity for Central-East Europe and European Russia in tons per grid and year ($t \cdot grid^{-1} \cdot yr^{-1}$). Grid size: 0.5 degree. Source: own compilation from G4M output data.

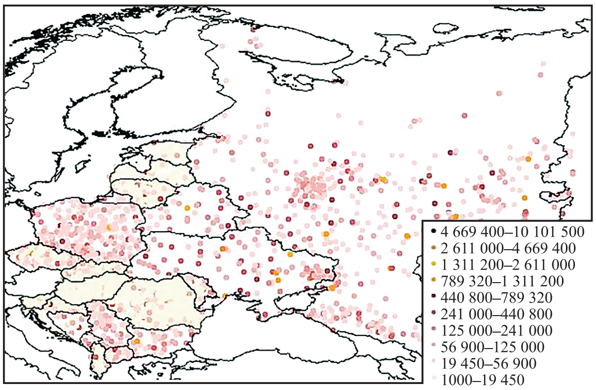

Fig. 2. Population distribution for Central-East Europe and European Russia. Source: own compilation from G4M output data based on (FAFMR, 2011).

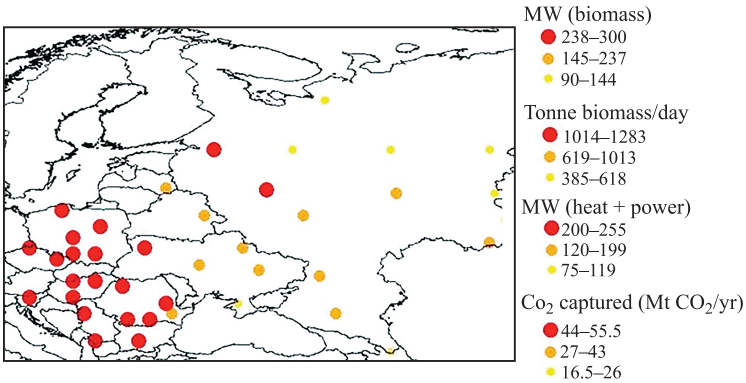

Fig. 3. Major clusters of forest-based green field biomass plants projected for Central-East Europe and European Russia. Different scales indicated by primary energy demand (MW), biomass demand (tons/day), combined heat and electricity supply (MW), and GHG emission savings (Mt CO_2/yr). Source: own compilation from BeWhere output data (Gridded population…, 2004).

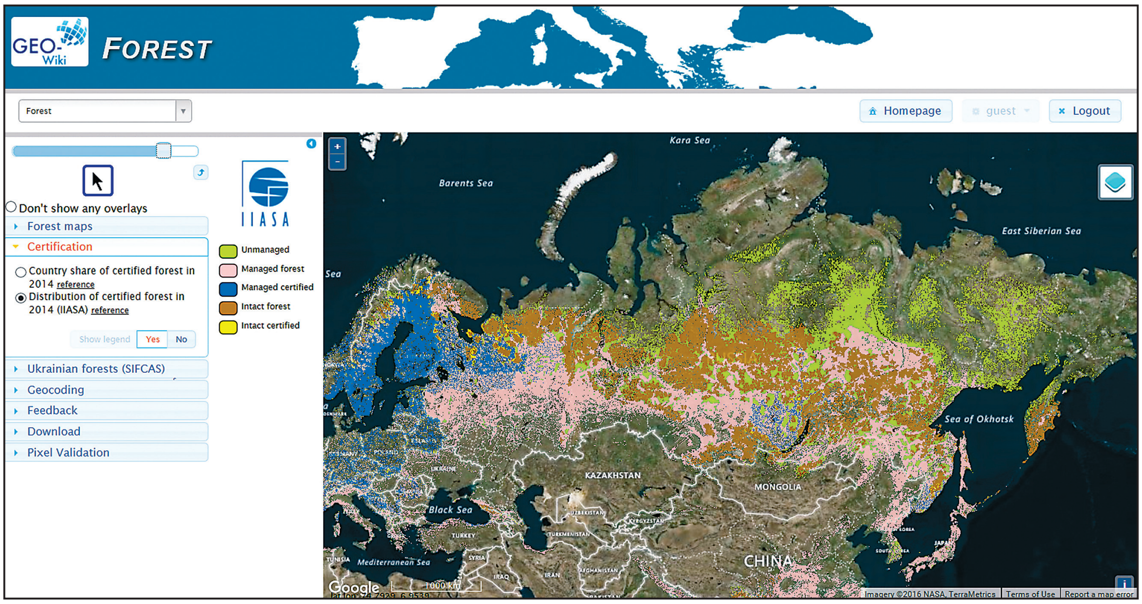

Fig. 4. Area with certified forest management in Russia and Europe (blue color). Furthermore indicating unmanaged forest area (green), managed (and not certified, pink), intact forest (brown) and intact and certified (yellow). Screenshot from the online crowdsourcing tool «Geo-Wiki» (cf. Fritz et al., 2009, 2012; Foody et al., 2014; See et al., 2015; Schepaschenko et al., 2015; Geo-Wiki, 2016). Source: modified after geo-wiki.org and Kraxner et al. (2016).

It is further assumed that – based on the information by IEA (Kindermann et al., 2008) – brownfield (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 constrained to the European part of Russia. Furthermore, the initial target for the model runs is to triple the energy production from forest-based biomass.

The first modeling results are displayed in Fig. 3.

For Russia, two larger bioenergy clusters with a capacity of up to 500 M W for heat and electricity are indicated in West Russia close to Moscow and in the vicinity of Novgorod and St. Petersburg. Five medium sized plants with a total output of some 1000 M W heat and electricity are placed in further urban areas with higher population density such as Volgograd or Samara. Another six de-central biomass plants are located further to the north-east of the discussed territory and at the border to Kazakhstan with a total capacity of some 720 M W. As explained in 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 2219 M W.

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 1500 ktoe (17520 GWh) which comes very close to the double amount of current bioenergy production of 839 ktoe (9700 GWh, see Table 1).

In order to produce energy equivalent to 1500 ktoe, some 3.78 million tons (6.16 million m^3) of dry matter biomass need to be supplied annually. The official statistics by (Shvidenko, Apps, 2006), 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 round wood, or 12 % of the total harvest of fuelwood. According to official Russian statistics by the Forest State Agency, there has been illegal logging of some 1.34 million m^3 in 2010 (FAFMR, 2011). However, other literature states illegal logging of additional up to 30 % to the existing legal harvest in 2005 (Sukhikh, 2005; Kant et al., 2014*b*). Consequently, some 11 % of the total illegal harvest in 2005 or 40.3 % of only the illegal harvest of fuelwood would suffice to double the energy generation from forest-based biomass in Russia. Some efforts to decrease the amount of illegal harvest are undertaken: The Russian Federation has adopted the Plan for the Prevention of Illegal Logging and Illegal Wood Trade, and the aerospace monitoring was introduced on major part of harvested areas; however, the effectiveness of these measures is not clear yet.

One measure to counteract illegal harvesting and trade might be forest certification by one of the large international schemes Forest Stewardship Council (FSC) or the Programme for the Endorsement of Forest Certification (PEFC) the area of which has reached above 30 M ha (2011). While this placed the country second in the world by certi-

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 three 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, M W	476	600	725	1185	540	864	1741	2649
Biomass input, tons/day	2028	2566	3095	5065	2310	3708	7433	11339
Output, M W	400	510	600	995	450	714	1450	2219
CO_2 saved, Mt CO_2/yr	88	111	135	215	99	156	322	482

fied forest area, it covers only 26 % of all forests leased for logging (FAO, 2012) and almost two-third of the certified area is the European part of the country, which accounts for about 25 % of all Russian forests.

The basic assumption for the application of forest certification as a safeguard is the fact that this market tool can also serve as a proxy for ensuring sustainable forest management (Confronting sustainability…, 2006; Klooster, 2010; Masters et al., 2010). Furthermore, the necessary monitoring for meeting the certification rules might at the same time help avoiding illegal timber harvest and trade. Based on a new online crowdsourcing tool for mapping global forest management certification, developed at IIASA (Kraxner et al., 2016) it can be shown that a) the demand for biomass in the European part of Russia can be covered from certified forest area, and b) that transport distance from the certified forest in southern Karelia and north of Moscow to the respective bioenergy plants is reasonable (Fig. 4).

Another source of supply of additional wood is the current wood waste which makes up to 30–50 % of the initial volume of logged growing stock at different stages of harvest and processing (Kant et al., 2014*a*), as well as substantial part of unlogged trees in clearcut areas where low quality and small size stems, often deciduous species etc., as a rule remain unused. Dominance of small enterprises and undeveloped infrastructure are among major reasons that hinder rational utilization of all wood allowed for harvest.

By additionally producing double the 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. Calculations based on (Wienenergie…, 2016) specify that in order to install additional 2219 M W, during 20 months of construction for example, some 4500 workers would find a job. Additionally, there would be permanent jobs created for some 2000 people in the biomass supply and processing sector, as well as some 500 long-term jobs in operating 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 (Wienenergie…, 2016), resulting in avoiding fossil GHG emissions of 716 million tons CO_2 annually (see 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 (Wienenergie…, 2016).

CONCLUSION

Concluding, detailed economic analysis with respect to incentive building (e. g. feed-in tariffs, carbon tax, targeted subsidies or future international carbon trading schemes) needs 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 within future strategies of transition of the Russian forestry and forest sector at large to sustainable development.

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ПОДХОДЫ К РАЗВИТИЮ УСТОЙЧИВОЙ БИОЭНЕРГЕТИКИ НА ОСНОВЕ ЛЕСНЫХ РЕСУРСОВ СЕВЕРНОЙ ЕВРАЗИИ

Ф. Кракснер[1], С. Ледук[1], С. Фусс[1, 2], Д. Г. Щепащенко[1, 3], А. З. Швиденко[1, 4]

[1] *Международный институт прикладного системного анализа (IIASA)*
Австрия, 2361, Лаксенбург, Шлосплатц, 1

[2] *Научно-исследовательский институт глобальных проблем и изменения климата им. Г. Меркатора*
Германия, 10829, Берлин, ул. Торгауэр, 12–15

[3] *Мытищинский филиал Московского государственного технического университета им. Н. Э. Баумана*
141005, Московская обл., Мытищи, ул. 1-я Институтская, 1

[4] *Институт леса им. В. Н. Сукачева СО РАН – обособленное подразделение ФИЦ КНЦ СО РАН*
660036, Красноярск, Академгородок, 50/28

E-mail: kraxner@iiasa.ac.at, leduc@iiasa.ac.at, fuss@mcc-berlin.net, schepd@iiasa.ac.at, shvidenk@iiasa.ac.at

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Проанализированы перспективы развития российского биоэнергетического сектора экономики, основанного на использовании лесной биомассы. Показано, что в настоящее время, несмотря на огромный ресурсный потенциал, доля тепла и электроэнергии, вырабатываемой из биомассы, остается еще очень незначительной. С помощью двух моделей, разрабатываемых в IIASA (G4M и BeWhere), предложено оптимальное географическое размещение тепловых электростанций, которые будут потреблять лесную биомассу. Результаты моделирования показывают, что удвоить текущие объемы производства тепла и электроэнергии из лесной биомассы возможно при использовании 3.78 млн т (6.16 млн $м^3$) древесины. Это количество соответствует 3.3 % от общего объема лесозаготовок, или 12 % от ежегодно заготавливаемой дровяной древесины (около 11 % незаконных заготовок). Это позволит обеспечить 444 тыс. домашних хозяйств теплом и 1.8 млн семей электричеством. Данное количество древесины способно заместить 2.7 млн т угля, или 1.7 млн т нефти, или 1.8 млрд $м^3$ природного газа, уменьшая эмиссии парниковых газов от сжигания ископаемого топлива на 716 млн т CO_2-эквивалента ежегодно. Помимо производства энергии развитие биоэнергетики положительно влияет на социально-экономическое положение, создавая «зеленые» рабочие места. Около 2000 рабочих мест потребуется для обеспечения поставок древесины и около 500 – для обслуживания тепловых электростанций. Обоснование устойчивых поставок древесной биомассы для производства энергии подтверждено картой сертифицированных лесов, которая создана с помощью онлайн инструмента Geo-Wiki.org, использующего возможности краудсорсинга.

Ключевые слова: *биоэнергетика, BeWhere, G4M, Geo-Wiki, российский лесной сектор.*