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Is Using Biomass for Power Generation a Good Solution? The Polish Case

Abstract. *It is argued that using solid biomass for power generation in Poland is a questionable way of using this renewable resource as means for abating CO_2 emissions, as it leads to significant technological, environmental and economic problems. It is shown that a better alternative is to use this resource for space heating, especially in rural areas, which should be supported by diverting a fraction of subsidies given to using biomass for power generation to help farmers install modern, efficient biomass heating boilers.*

Streszczenie: *W Polsce sposób wykorzystania biomasy stałej do produkcji energii elektrycznej jest wątpliwą metodą redukcji emisji CO_2, ponieważ prowadzi ona do znacznych problemów technologicznych, środowiskowych i ekonomicznych. Wykazano, iż lepszym rozwiązaniem jest wykorzystanie tego zasobu w celach grzewczych, zwłaszcza na obszarach wiejskich. Część dotacji promującej produkcję energii elektrycznej z biomasy należy przekazać rolnikom, do wsparcia zakupu nowoczesnych i efektywnych kotłów grzewczych na biomasę. (**Czy biomasa dla elektrowni to dobre rozwiązanie? Przypadek polski).***

Keywords: biomass, co-firing, electricity, heating.
Słowa kluczowe: biomasa, współspalanie, energia elektryczna, ogrzewanie.

Introduction

Contrary to what some decision-makers seem to assume, biomass is a limited resource when considered in a defined region. Its potential is determined by the available land area, soil quality, climate conditions, etc. On the other hand, biomass as a source of renewable energy, can be used for energy purposes in different ways: it can be converted to gas or liquid fuels or can be used in the solid form, either directly (e.g. log wood, or straw bales) or as densified matter (pellets, briquettes, etc.). As a converted fuel, biomass can cover a wide spectrum of final energy applications: it can be used for electricity generation; heating or as motor biofuels (as opposed e.g. to wind or hydro energy). It is usually not possible to satisfy simultaneously all energy needs (electricity, heat, transportation) using the available biomass resource alone, the more that we need it also for food and fodder production or for industrial purposes. One has to make an informed choice, the best possible one, given the assumed criteria. This means that we face a typical optimization problem of finding a maximum (or minimum) of a defined goal function, under given constraints. To achieve that, an appropriate tool (mathematical model) is needed to support the decision-making process. Such a tool should be sufficiently universal and usable at each decision-making level, including the local level, i.e. it should be sufficiently user-friendly. The task is not simple as it involves optimization in a multidimensional space of parameters characterising different agricultural and technological processes as visualised in Figure 1. The goal function(s) can obviously be different, depending on the specific interest or concern of the particular decision-makers. For example:

- A reduction of GHG emissions (global concern),
- fossil fuel substitution such as motor fuels or gas (typically, the national concern),
- revenue from investment (company, private or public investor, such as a farmer or a local authority).

Such a model, which still remains to be elaborated, would be of great value in the decision making process.

This paper is based on the lecture under the same title, delivered at the seminar on "SMART GRIDS Technology Platform" at the AGH-University of Science and Technology, Krakow, 2011 (http://www.smartgrid.agh.edu.pl/).

Otherwise, decisions are likely to be suboptimal or plainly wrong from the point of view of the goals they are supposed to serve.

Poland provides an example of such suboptimal choices. The example is using biomass for power generation, while a huge potential of CO_2 emission reduction exists in another area. As presented later, model calculations show that more CO_2 emissions could be avoided by converting only a small fraction of subsidies given to electricity production from biomass to help farmers invest in modern, dedicated and efficient biomass boilers. In this case, even simple, "back-of-the-envelope" calculations provide sufficient qualitative justification.

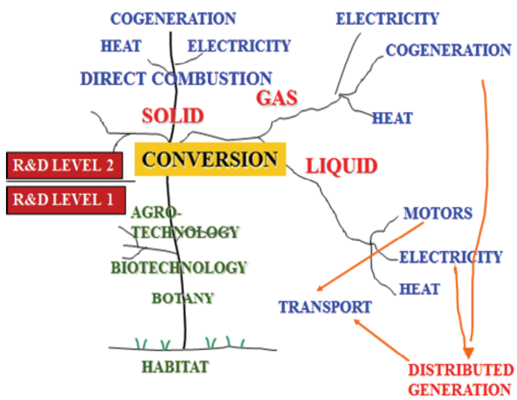

Fig.1 Optimisation tree

The following sections address: (i) the technological problems of co-firing biomass with coal, (ii) logistical problems related to transportation of large volumes of biomass, (iii) economic aspects of support given to biomass-based power generation, and (iv) alternative use of biomass, which is using it locally for heating, particularly in rural areas. In the concluding section the considerations are placed in a broader context of defining ways of a possibly optimal use of solid biomass for energy purposes and several policy suggestions are made.

Biomass-based power generation

According to different estimates biomass is the dominating, non-stochastic renewable energy resource in Poland.

The estimates vary significantly[1], which is illustrated in Table 1, however, the dominant position of biomass is evident in short and medium term. This is confirmed by the structure of the use of renewable energies illustrated in Figure 2, which shows the actual energy production from renewable sources in 2010. As is seen, biomass contributed more than 85% of to the total RES in Poland, followed by biofuels (6,67%) and hydroenergy (3,67%).

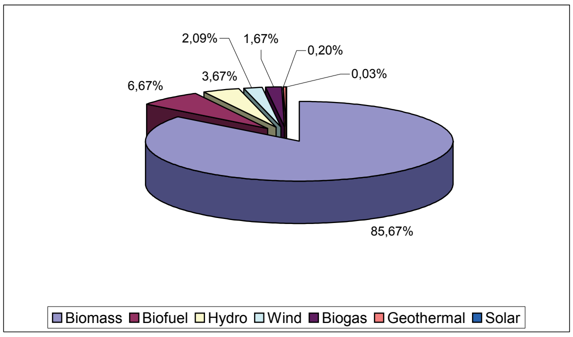

Fig. 2. Energy production from renewable sources in Poland [1]

Table 1. Technical potentials of renewable energy sources in Poland [2,3] in [PJ/year]

Energy source	EC BREC		GHG reduction Strategy [2]	Report for World Bank [2]
	2000 [2]	2007 [3]		
Biomass	895	927	128	810
Hydroenergy	43	18	50	30
Geothermal	200	12	100	200
Wind	36	2582	4	4-5
Solar	1340	19	55	370
Total	**2514**	**3552**	**337**	**1414**

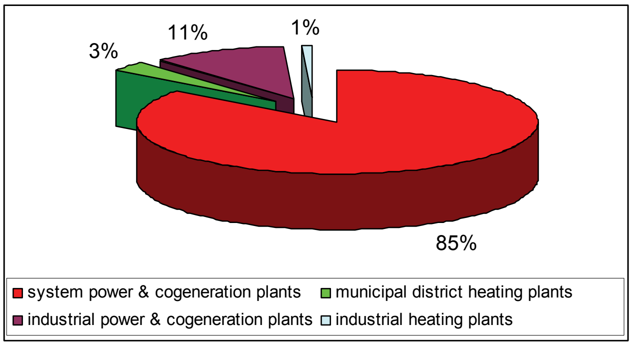

Fig. 3. The use of solid biomass in the energy sector in Poland [4]

Figure 3 shows the actual use of biomass for energy purposes in Poland. As it is seen, the lion's share (85%) of biomass is used for electricity generation and co-generation in system power plants, followed by industrial plants (11%), which gives together 96% of the total. Only a small fraction is used in dedicated district heat and industrial heat plants (4%). Biomass use in individual, small-scale heating boilers and stoves is difficult to assess and is not included in the pie diagram of Figure 3. At present, coal-fired boilers dominate as the source of heat in this capacity range. Consequently, the missing number of the biomass share consumed in the individual households is small compared to coal and is not influencing the general conclusions of this paper. Actually, those concern the question: what would be the effect of a support mechanism that would divert part of the 96% of the biomass resource used for electricity production to provide heating in rural areas?

The emphasis on electricity generation (co-generation) from biomass in Poland is driven by the directive 2001/77/EC [5]. Although this was replaced in 2009 by the new directive 2009/28/EC [6], the Polish legal regulations and financial support schemes based on the previous one are still in place.

Table 2 and Figure 4 present the targets, which have driven (are still driving) the rush to invest in biomass-based electricity in Poland [7]. Indeed, if the target of 20 TWh/year is to be achieved, biomass and waste will have to provide about 11,3 TWh/y. (For our "back-of-the-matchbox calculations" this number will be rounded to 10 TWh/y considering that waste contribution is still negligible).

Table 2. Structure of RES power generation in Poland (forecasts according to [7])

Electricity production	**2005**	**2010**	**2015**
		[TWh/y]	
Fossil fuels:	**144,1**	**155,1**	**175,0**
RES, from which:	**4,6**	**12,0**	**20,0**
Hydro energy	2,1	2,1	2,2
Wind energy	0,1	3,9	6,5
Solar energy (PV)	0,000	0,003	0,022
Biomass and waste	2,3	6,0	11,3
Total	**148,6**	**167,1**	**195,1**

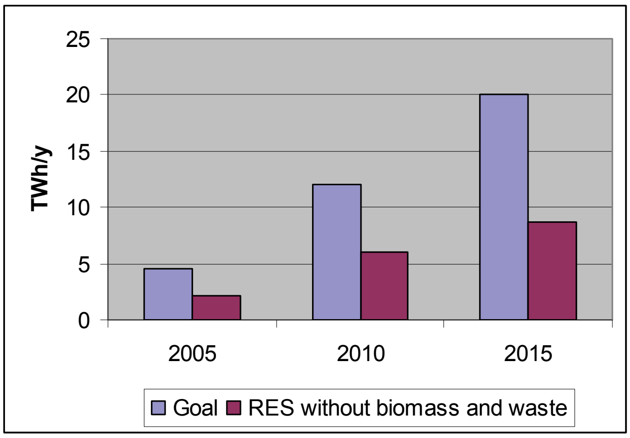

Fig. 4. Structure of RES power generation in Poland [7]

In Poland, most of this biomass-based electricity is produced in pulverised coal boilers in the existing power plants. This leads to serious technological problems. The main ones are described below.

Technological problems

Compared to coal, biomass is characterised by:
1) about 50% lower heating value,
2) higher humidity,
3) high content of potassium, calcium and phosphorus (the content of sulphur is lower),
4) high content of chlorine (mostly in straw, bark and leaves),
5) high volatile fraction, which influences the ignition and combustion processes changing the conditions of coal combustion,
6) low energy density per unit volume.

The first two factors directly affect the boiler efficiency. Table 3 shows the results of the measurements performed by the team of the Institute for Chemical Processing of Coal (IChPW) from Zabrze in several Polish power plants [8] equipped with pulverised coal boilers.

[1] The authors are aware that there exist much higher expectations regarding the geothermal and wind energy. However, the high estimates are disputed, so that the numbers in Table 1 are used as reference values.

Table 3. Change of efficiency of pulverised coal boilers due to adding biomass [8]

Unit	Total efficiency of boiler without co-firing [%]	Total efficiency of boiler with co-firing [%]	Mass of biomass fraction [%]	"Green electricity" generation [MWh/y]	Reduced CO_2 emission [MWh/y]
A	93,3	91	20	350 000	320 381
B	92,17	92,07	8	203 000	185 821
C	90,20	89,61	5	18 630	17 053,4
D	92,8	92,6	10	136 850	125 269
E	77,53	78,15	48,7	15 000	13 731
F	93	91,5	14	314 000	45 769

As it is seen, the efficiency of the pulverised boilers shown in the table decreases rather slightly (about 1%)[2], which still has to be compensated by burning correspondingly more fuel. Moreover, even such a small decrease in efficiency is quite significant in terms of financial losses. For instance, for a single 400 MW boiler those translate into about 7 mln PLN/year (ca. 1,75 mln EUR/y). However, the financial losses are much higher due to the damage done to the hardware as a result of presence of alkali and chlorine compounds in biomass [9].

Fig. 5. Biomass enhanced slugging [9]

Those are mainly: increased slugging and fouling, and chlorine corrosion in the hot parts of the boiler system.
Slugging and fouling hinder heat transfer in the smoke pipes and superheater. Moreover, the flow of hot exhaust gases heating the upper parts of the superheater is also hindered by a layer of the fouling material fallen on the lower parts. Additionally, electricity consumption of the fans forcing the airflow increases due to higher aerodynamic resistance. The enhanced slugging is illustrated in Figure 5, which shows a heat exchanger pipe of a co-firing boiler [9]. Furthermore, the detached pieces of the layer may clog the slug removal funnel (Fig. 6.), which requires more frequent and labour intensive maintenance.

[2] The data in the table were collected in the first year of the operation of the boilers after adding biomass had been started. The decrease of efficiency has likely become larger with time, due to slagging and fouling processes.

Fig. 6. Clogged slug removal funnel [10]

Further damage is caused by chlorine corrosion illustrated in Figure 7 [11]. Figure 8 shows an example of high temperature corrosion in a boiler where biomass is co-fired with coal [12].

Fig. 7. Corrosion of a biomass boiler superheater tube after two years of service firing high chlorine fuels [11]

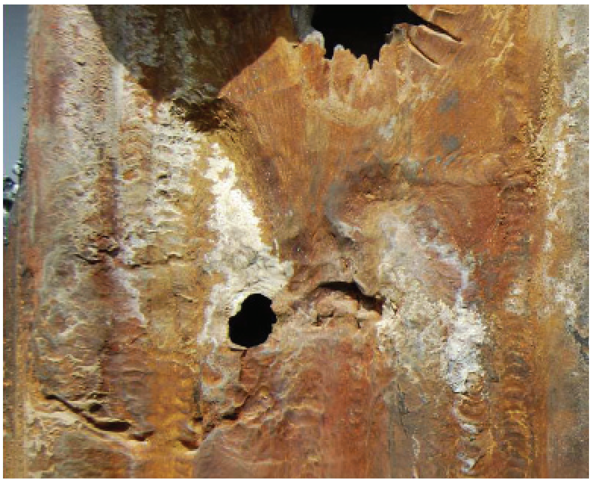

Fig. 8. Pipe perforation in a boiler co-firing biomass with coal [12]

An additional problem in pulverised boilers is the increase of electricity consumption in grinding biomass to be injected through the nozzle. This is due to the fact that biomass is ground into fibres, rather than particles and consequently settles on the sieves. As a result, biomass requires longer grinding time, which leads to the electricity losses, typically, of 10-15% [9].

Transportation problem

Biomass, compared with coal, has lower bulk density, roughly by 50%, as illustrated in Table 4 for several solid biofuels and coal.

Table 4. Bulk density of several biofuels and coal [13-15]

Biofuel	Bulk density [kg/m^3]
Hard coal [14]	800-1000
Willow wood chips (fresh) [13]	393,5
Willow pellet [13]	592,3
Sida pellet [13]	492,4
Pine sawdust pellet [13]	667,6
Beech sawdust pellet [13]	598,4
Sunflower waste pellet [13]	477,6
Briquette from mixed sawdust [13]	295,1
Straw bales (rice) [15]	110-200
Straw bales (wheat, rye) [15]	ca. 100

Taking into account that, typically, the lower heating values of solid biomass fuels range between 8-15 MJ/kg [16], while for coal between 20-30 MJ/kg one can accept, as a rule of the thumb, that energy density per unit volume of biomass fuels is four times lower compared to coal. This obviously translates into the consumption of liquid fossil fuels and corresponding emissions, as well as other related life cycle energy costs, such as attrition of vehicles, roads, etc.

For large capacity units (above, few tens of MW) the problem is even bigger, considering that in typical Polish (and European) conditions, the needed amounts of biomass have to be collected from large areas, in a radius often (far) exceeding 100 km. For illustration, let us consider an example of a hypothetical (still realistic) power plant of 400 MW located in south-eastern Poland, which plans to add 5% of biomass for co-firing. This would require deliveries of ca. 500 tons of biomass per day. Considering, the road structure in the area, one can assume that this biomass would be transported by trucks (10 tons load each) travelling on average 100 km per delivery. This makes in total 5000 km covered each day, one way. It is perhaps shocking to realise that this is a distance from Moscow to Lisbon via that plant.

It is sometimes argued that long distance deliveries by rail (or by sea) instead of trucks solve the problem. However, it is then forgotten that delivering biomass to the rail station or harbour must involve in practice transportation by roads, so even if the energy/emission costs of rail (sea) transportation are neglected the problem remains the same.

Obviously, all those factors increase the costs of delivering biomass to the plant. According to [17]: *"typically biomass thermal facilities spend nearly 50% of their operating budget to purchase and deliver biomass to the boiler".*

Poland: Biomass for electricity or heat?

Electricity.

As mentioned earlier, one can assume that approximately 10 TWh/y of electricity needs to be produced from biomass to meet the assumed "green" electricity target. Following this obligation, Poland has witnessed a huge drive to invest in power generation from biomass. In 2008 it amounted to 3267 GWh, (2752 GWh in co-firing), which constituted about 49,7% of total electricity production from RES, compared to 43,5% in 2007. In 2010 the production of electricity from biomass reached 5784 GWh (5149 GWh in co-firing) [18], which apparently involved investments of order above billion Euro.

Having in mind the aforementioned problems, one may wonder "why?". The answer is that for each MWh of "green electricity" the power generating companies receive about three times more money than for the "traditional" (black, coal-based) MWh. On top of the price of a "black" MWh (ca. 35 EUR) they are rewarded by about 70 EUR/MWh in form of Green Certificates. Both numbers vary somewhat with time, but for our "back-of-the-envelope calculations" the above rounded numbers are of sufficient accuracy.

One should realise that the 70 EUR/MWh is a subsidy "hidden" in the price of electricity, which means that it is paid by all electricity consumers in Poland. For the assumed 10 TWh/y generated from biomass, the total of this "hidden" subsidy amounts to 700 mln EUR annually. In Polish reality this is a huge amount of money.

The way of addressing CO_2 emission reduction by resorting to "green electricity" is increasingly criticised (e.g. see [19-22]) and has recently begun to be reconsidered by policy makers. Following the proposal of the new RES energy law [23], subsidies to co-firing will be reduced by about 30% [23,24]. In the authors' opinion this is a move in a good direction, although far not sufficient.

Below, it is argued that a better alternative is to use the domestic biomass resources locally for heating purposes in small-medium size units (between a few tens of kW and a few MW).

Heat.

The answer to the question posed in the title of this section[3] is country specific. In many European countries, notably in Poland, there is a significant demand for space heating. This could be largely satisfied by biomass, primarily in rural areas, where biomass is locally available, mainly as agricultural residues. In Poland this is mainly straw, which is often burnt uselessly in the fields, although it may become an environment friendly fuel for heating the rural holdings, if burnt in dedicated biomass boilers. However, most farmers heat their holdings by coal, using old, inefficient equipment[4]. At the same time, good and efficient biomass boilers, produced in Poland, are available on the Polish market [25]. Unfortunately, farmers in Poland usually do not have enough financial resources to buy and install them (those are sold rather to Western Europe). There exists no financial support scheme that would help them to overcome this barrier (while "green electricity" is so heavily supported).

Let us note, that the 10 TWh translated into units used for heat is 36 PJ. According to [26] the average farmer's holding uses about 240 GJ/y of heat. This means that primary energy needed to produce the 10 TWh of "green" electricity would be sufficient to provide heat to roughly 150 thousands of farmers' holdings with the same CO_2 emission reduction effect (if the real average conversion efficiency of the Polish power plants is assumed, this number would be about three times higher).

The calculations made using the Invert model [27-29], developed in the EU Altener Programme, have shown that, if only a fraction of a few percent of the "hidden" subsidy to "green electricity" were transferred to farmers to help them cover 40% of the investment costs, the market for small-scale biomass boilers (in the range of 20-50 kW) would grow significantly [30-32]. This is illustrated in Figure 9, where zero of the horizontal axis is the starting point of the support scheme and the vertical axis presents the number of new installed biomass boilers. The 40% corresponds to ca. 2 000 EUR [33], which for 150 thousand installations would make 300 mln EUR in total. One should note that this is less than a half of the 700 mln EUR of the "hidden" subsidy paid to power plants in one year alone. Assuming that the lifetime of boilers under consideration is (at least) 10 years, the subsidy accumulated over that time would be 7 billion EUR. Hence, the

3 *"Biomass for electricity or heat?"*

4 Because coal is increasingly expensive, the practice is often to burn plastics, old tires and other highly polluting materials.

300 mln EUR paid once per boiler life-time (for 150 thousand units) constitutes merely ca. 4% of that sum. In other words, the same public money would give an environmental effect (at least) 25 times bigger. This should be a convincing argument for the decision-makers that support should be given first of all to using biomass for (local) heating, rather than for large scale "green electricity" generation.

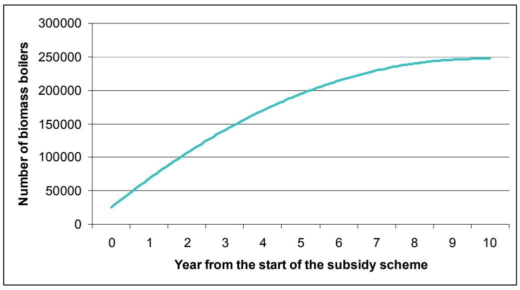

Fig. 9. Forecasted number of installed individual heating boilers [32]

The above observation is supported by the results of a recent study [34] made in the EU 4Biomass Project [35]. An opinion survey was performed on a sample of 1221 biomass experts/stakeholders from 8 countries (AT, CZ, DE, HU, IT, PL, SI, SK). Figure 10 presents the weighted numbers of answers to the question: "which use of biomass for energy purposes is most important for achieving the targets of your national Biomass Action Plan?".

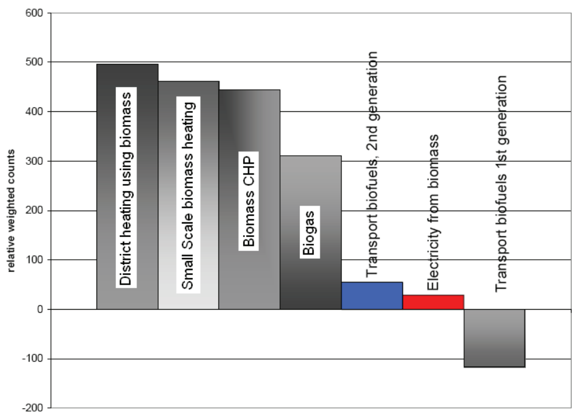

Fig. 10. Results of the 4Biomass study [34]

As can be seen, the majority of responses (the first three columns) point for heat production from biomass as the most important. Notably, individual biomass boilers (in practical terms those are mostly in rural areas) are ranked very high.

Conclusions

In conclusion let us formulate a few policy suggestions:

1) Part of the funds supporting biomass-derived electricity should be converted to support individual farmers to buy and install modern, efficient biomass boilers.

2) For larger installations (typical small-to-medium district heat units) Green Heat Certificates, should be issued, which would be valued 3 times more per 1 MW than the Green Electricity ones. This concrete suggestion follows from the fact that in Poland almost 100% electricity is produced in thermal power plants with a conversion efficiency around 33%.

3) The paradigm governing the use of biomass for energy purposes should be environmental protection, rather than market. Rules to guarantee that should be developed rather urgently to avoid further distortions. Currently, the damage labelled as success grows quickly. At present, market driven rush to co-fire biomass with coal leads to practices, the net effect of which is largely sub-optimal emission reduction compared with other possible ways of using the available biomass resource.

4) Rewarding the "green" energy producer must be based on avoided emissions corrected for the total life-cycle embedded emissions from all related process chains. Only such avoided emissions should be eligible for granting bonuses. To achieve that in practice and in a possibly short time, a comprehensive and EU-harmonised set of default values should be determined and a control mechanism established possibly quickly.

5) Smaller installations, especially in rural areas, can satisfy their fuel/energy needs by using supplies from an area of a smaller radius, i.e. their "embedded" transportation emissions are smaller. Additionally, energy used for densification of biomass which is needed to lower the transportation costs, can be avoided. Therefore, such installations should be favoured when granting investment subsidies. One should note here that in the exploitation phase no subsidies are needed, because local (often own) biomass fuel is cheaper than coal, oil or gas.

6) The over-riding principle in using biomass for energy purposes should be: "first satisfy the local needs; trade only the surplus" (possibly with nearby recipients). The local use of biomass is more efficient than transporting it to remote destinations (both for a final use or reprocessing).

7) The specific feature of biomass as a renewable energy resource is the variety of possibilities of how it can be processed and used. At the same time, biomass is a limited resource. Decision making should be supported by model calculations that would define the optimum way of using biomass to achieve the assumed goals (environmental, supply security, etc). Research in this area should be given higher priority.

The above conclusions are based on the Polish contribution to the Transnational Action Plan, which have been reflected in the final document of the 4BIOMASS Project [36] after thorough discussions with the Project Partners.

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