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Sustainable waste management in Northern rural areas: Local utilisation of bio-wastes

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Abstract
The Finnish Lapland is the most sparsely populated region in Europe and the population is decreasing all the time. The constantly growing tourist visits and overnight stays cause large amounts of wastes and erosion of local nature. Tightening waste regulations and increasing fossil energy prices provide motivation to improve local waste processing in order to reduce the amounts of bio-waste transported to landfills and use bio-waste as material in bioenergy production. In this study, the current status of waste management at two tourist centres in Finnish Lapland is mapped and proposal for a more sustainable waste management is given. The amount of bio-waste in area where no separate bio-waste collecting is organized is estimated based on the developed prediction model. The estimation of local bioenergy potential produced by anaerobic digestion process in these two case areas is calculated. Usage of liquid and solid end products of anaerobic digestion process as a fertilizer and soil improvement is also presented. It is found that the annual bioenergy potential is fair, but the bioenergy production is not economic profitable around the year using only bio-wastes due to the significant seasonal variation of the amount of wastes.

Keywords: Anaerobic digestion; Bioenergy; Cross-validation; Lapland; Revegetation; Waste-to-energy.

1. Introduction
The Finnish Lapland is the most sparsely populated region of Europe, with fewer than two residents per square kilometre, as compared with the 17/km^2 average in Finland and the 72.5/km^2 in Europe. With the area of about 100 000 km^2, it represents 30% of the landmass of Finland, but hosts only 3.4 % of its population. At the same time, Lapland is a popular tourist destination where 2.2 M overnight stays are registered yearly. Overall tourist visits have been estimated to be more than 6 M per year [1, 2].
The municipality of Kolari is located in the western part of Lapland near the Swedish border. Saariselkä, on the other hand, is located in Inari, Northeast part of Lapland (Figure 1). As typical for Lapland, the population in Kolari and Inari have been slowly decreasing. The present population in Kolari is about 3800 and the population density is 1.5/km^2, whereas the population of Inari is about 6800 and the

population density is only 0.45/km^2. On the other hand, the Ylläs tourist centre in Kolari is the third most visited tourist centre in Lapland, where tourist visits and overnight stays in area hotels have been constantly growing. The number of domestic overnight stays has doubled and international stays have more than tripled since 2001 in Kolari. The ski centre in Saariselkä with about 13500 bed places is also one of the most visited tourist centres in Lapland. Over half of the overnight visits are during the spring ski-season, from February to the end of April. The Christmas holidays and the autumn foliage period are the next most popular visiting times. Most of the domestic tourist visits are done in the spring and foreign tourist visits during the Christmas time [3-5].

While increasing numbers of tourists boost the local economy, they also increase the amount of waste substantially and strain the local nature. During the tourist season, the Ylläs tourist centre is the largest contributor to waste amounts in the Kolari area. The seasonal variation of wastes over a year in the tourist centres is significant and reflects the tourist seasons: the highest amounts of wastes are collected during spring ski-season and the Christmas season when waste amounts are twice as much as during the summer time [6]. From the households of Kolari municipality and Saariselkä area only mixed waste is collected, but the Ylläs tourist centre is one of the few locations in Lapland where bio-waste has been collected separately during the tourist season. However, the bio-waste is not collected at the summer time when amounts are low [1].

Due to the greenhouse gas (GHG) emission potential of bio-waste disposal, it is important to enhance separate collection of different waste fractions, and find innovative methods for the utilization of biodegradable wastes locally in Lapland. Reducing the amount of bio-waste going to landfill is required by European and Finnish waste regulations. The Landfill Directive 1999/31/EC sets targets for progressively reducing the amount of biodegradable municipal waste landfilled by 2016. The Finnish bio-waste strategy also prescribes that, in 2016, no more than 25 % of all biodegradable waste generated can go to landfill [7]. Due to tightened legislative, requirements the number of operating landfills in Lapland has decreased from nearly 100 landfills to three. The wastes collected from Kolari and Saariselkä are nowadays transported to Tornio landfill, which is approximately 200 kilometres from Kolari and 400 kilometres from Saariselkä (Figure 1). Currently, there are no Waste-to-Energy plants in Lapland which utilise municipal combustible wastes as fuel. The nearest Waste-to-Energy plant is located in Oulu, almost 150 km south from Tornio. There is only one biogas plant in Lapland. At the end of 2011, a biogas plant started operating in the educational farm of Kemi-Tornionlaakso Municipal Education and Training Consortium Lappia. The anaerobic digestion (AD) process is a potential treatment method of bio-waste to produce biogas locally and decrease the release of GHG from landfills. The biogas can be used locally in combined heat and power (CHP) plants, which reduces the need for fossil fuels. Reducing the amount of wastes transported to landfill will also decrease transportation costs. In addition to economic and ecological benefits, efficient waste management and producing renewable energy will also improve the image of the area. It has been estimated that the total bio-waste amount produced in Lapland is over 10 000 tons per year [1, 3].

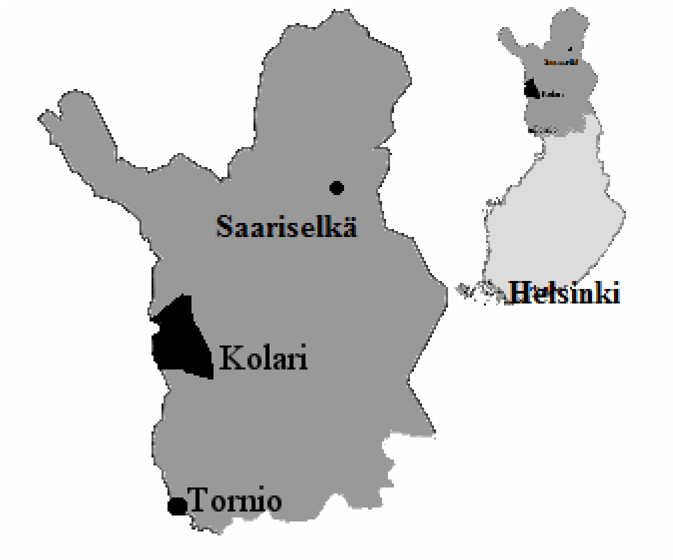

Figure 1. Locations of Kolari municipality, Saariselkä and Tornio landfill in Finnish Lapland.

In this study, the status of waste management of two tourist centres in Finnish Lapland is presented. The waste data from Kolari is used in developing a model for estimating the amount of bio-waste in Saariselkä, where bio-waste is not currently collected separately. Based on the model estimation, the annual bioenergy potential in Saariselkä and in Kolari is also calculated assuming that the bio-waste is collected during the summer. The calculations will indicate whether local bioenergy production in anaerobic digestion process using bio-waste is economically efficient. The model based bioenergy estimation is easily generalised and can be done for any other tourist centre or area in Lapland, as well. End-use suggestions for liquid and solid by-products of anaerobic digestion are also made.

2. Material and methods

2.1 Waste management in Lapland

Waste amounts (kg/cap) are higher in Kolari and Lapland than the Finnish average (Table 1). The amount of mixed waste per capita is comparable to the Lapland average but the collection of bio-waste in Kolari is more efficient than in Lapland on average. The higher amounts of mixed and total waste in Lapland can be explained by higher relative amounts of tourists and the less evolved infrastructure for separate waste recovery [6].

There is no data on exact amounts, but it is assumed that nearly 70 % of mixed waste is biodegradable and two third of biodegradable wastes are transported to landfills in Finnish Lapland [1]. Depending on the source, 25-70 % of landfilled waste in Finland is estimated to be biodegradable, such as bio-waste, paper and cardboard [8-11].

Table 1. Waste generation in Kolari and Lapland compared with the Finnish average (kg/cap), in 2010 [1, 6].

	Kolari	Lapland	Finland
Mixed waste	364.9	362.7	282.6
Collected bio-waste	27.9	21.8	55.9
Total amount of waste		500.1	468.8

2.2 Anaerobic digestion and energy potential of biodegradable wastes

Anaerobic digestion is a viable technology to treat bio-waste, to generate bioenergy and reduce the formation of GHGs in landfills. In the AD process, biodegradable material is broken down by micro-organisms in the absence of oxygen. Carbohydrates, fats and proteins are digested into their component parts by different bacteria in four separate consecutive phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The final product biogas, which mainly consists of methane (CH_4) and carbon dioxide (CO_2), is produced in the methanogenesis phase. The methane and carbon dioxide content of biogas are usually 55-70 % and 30-45 %, respectively. Biogas also contains small amounts of nitrogen, hydrogen, hydrogen sulphide and oxygen. AD is a complex biochemical process where several components, such as the input substrate, pH, temperature (mesophilic or thermophilic process), nutrients, microbes, process configuration and residence time, affect the quality and quantity of biogas [12].

An anaerobic digestion process is called mesophilic or thermophilic depending on the operation temperature. Mesophilic bacteria operate optimally at the temperature approximately between 30°C and 40°C, thermophilic bacteria at the temperature between 50°C and 60°C. Generally, mesophilic systems are considered more stable and less energy consumptive than thermophilic systems but thermophilic digestion produces methane faster and with higher gas yield. Digestion time varies depending on the configuration of the process and type and amount of the feedstock. An AD process can be operated as a batch or continuous process and the solids content of input material can be high and dry (no water is added), high and wet (total suspended solids is over 20%) or low and wet. For example, a thermophilic single-stage process is faster than a multistage mesophilic process. Usually an anaerobic digestion process takes from two to four or five weeks. Even over 100 days processing time is possible in low temperature digestion [12].

In addition, the amount and quality of bio-waste are strongly varying season-by-season, and most AD plants do not have the ability to equalize these seasonal variations [13]. Due to the complexity of AD process, the exact amount and composition of produced biogas is very difficult to predict and only estimates for biogas production can be made beforehand. Biogas yield per one kilogram of bio-waste has been found to be 0.1-0.15 m^3 in [14], 0.3-1.0m^3 in [12], 0.37 m^3 in [15], and about 0.20 m^3 in [16]. The energy content of biogas depends on the total methane content. The energy content of pure methane is 9.97 kWh/Nm^3, so the energy content of biogas varies from 3 to 7.5 kWh/Nm^3 when the methane content is 30-70 %. Typically, the energy content of biogas is 6.0-6.5 kWh/m^3.

2.3 Use of digestate

Recreational tourist activities e.g. downhill skiing, cross-country skiing and hiking, cause increasing pressure on Northern Finland's nature and have considerable impact on local ecosystems [17, 18, 19]. Northern areas are especially sensitive to trampling. The impacts of recreational use depends on the type of the activity and vegetation type as trails caused by hiking are relatively deep whereas cross-country skiing has the lowest impact on trails because of the protecting snow cover. Especially ski slopes are causing environmental degradation as the vegetation layer and top soil layers are removed and the slopes are prone to the erosion. To prevent erosion, the slopes are often revegetated [17, 18]. According to the studies of Ruth-Balaganskaya and Myllynen-Malinen, the most disturbed ski slope areas in Ylläs that are machine-graded to the bare soil with hardly any nutrients and organic matter left, are not likely to recover unassisted [17]. The implementation of the growth substrate with enough organic material, preferably the upper layer from initial soils, is recommended for the revegetation purposes.

To reduce the harmful impacts of tourism (i.e. erosion, seasonal excessive production of wastes) the treated organic waste can be recycled back as nutrients to be used on land [20]. Whereas the end product of composted municipal solid waste could only be used in land remediation and restoration schemes [21], the liquid and solid by-product of biogas plants could be used as a fertilizer or soil improvement material for revegetation purposes. In Northern tourist areas, the possible use of digestate could be to revegetate eroded areas. As they are used for inserting the nutrients to the ground, they need to be mixed with additive, e.g. sand or peat [22]. Inserting digestate on land may improve soil quality and water retention of the soil, reduce the requirements for herbicide use, and reduce erosion [23, 24]. The properly treated by-products of the biogas plants are safe to use, as the digestate does not significantly increase the microbiological activity of soils and no significant phytotoxicity (i.e. toxic effect on plant growth) was detected in the studies of Marttinen et al. [22]. As the quality of digestate for fertilizing purposes has to be according to Finnish legislation, efficient pretreatment and optimization of the digestion process need to be carefully studied [20, 22]. Thermophilic process is preferable, since the higher temperature kills most of the pathogens and seeds of the non-native plant species in biomass [22, 25, 26]. In addition to direct benefits, there will be added environmental benefits as the production and use of commercial fertilizer will be lower [27].

As both the amounts of bio-waste and severity of erosion are real problems in Northern tourist areas, the use of digestate for revegetation needs to be considered carefully. Digestate should provide organic material for the eroded areas and should be used to replace commercial fertilizer. Major issue to consider when inserting digestate to the vulnerable Northern ecosystem is to ensure that the nutrient level of the ground will not become too high. Excessive amounts of nutrients may cause leaching and may have negative impact on the functioning of the organisms in the ecosystems. In addition, the possible problems, such as transporting and storing the product until the ground is not frozen, quality of digestate, local conditions affecting the use of digestate (soil type, rainfall, severity of erosion) and vulnerability of surrounding ecosystem including groundwater [20] need to be studied beforehand. If digestate is not suitable for revegetation purposes in eroded areas, it can be used for landscaping locally in less vulnerable environments such as in recreational areas, roadways and embankments. However, digestate will have to be stored during winter, because legislation prohibits using digestate when the ground is frozen.

2.4 Modelling

The quality of developed model depends highly on the quality and length of the dataset. Several modelling methods require separate subsets for efficient training and testing, which have to be long and representative enough [28]. Cross-validation is one way to predict the fit of a model for a validation set when dataset is small and an explicit validation set is not available. In *k*-fold cross-validation, the original dataset is randomly partitioned into *k* equal size subsets. One subset is used as a validation data for testing the model and the remaining *k*–1 subsamples are used as training data. The cross-validation process is repeated *k* times and each of the subsets is used only once as the validation data. A single estimation is then produced by combining (averaging) these *k* results of the folds. The advantage of the cross-validation method compared with for example the Multiple Linear Regression or Artificial Neural

Network method is that the entire dataset is used for both training and validation. Thus the largest possible test set can be used which is a great advantage especially with a small dataset. Optimal *k* is often reported to be between 5 and 10 folds because statistical performance does not increase a lot for larger values of *k*, and averaging over less than 10 splits is computationally feasible [29, 30].

Performance of the model can be evaluated for example by using Root Mean Square Error (RMSE) and coefficient of determination (R^2), which can be used to compare the relative performance of the models. The coefficient of determination value R^2 is defined as in Eq. (1) and RMSE is defined as in Eq. (2) [31].

$$R^2 = 1 - \frac{\sum (y_{meas} - y_{pred})^2}{\sum (y_{meas} - \frac{\sum y_{meas}}{k})^2} \tag{1}$$

where y_{meas} is a measured value, y_{pred} is a predicted value and k is the number of values.

$$RMSE = \sqrt{\frac{1}{k} \sum ((y_{meas} - y_{pred})^2)} \tag{2}$$

where y_{meas} is a measured value, y_{pred} is a predicted value and k is the number of values.

3. Results and discussion

Compared to waste amounts in Kolari [6], volumes in Saariselkä are larger but the seasonal variation is identical: the highest amounts of wastes are collected during the spring tourism season and the lowest in the summer time (Figure 2). Annual amounts of collected mixed waste in Kolari and Saariselkä are listed in Table 2.

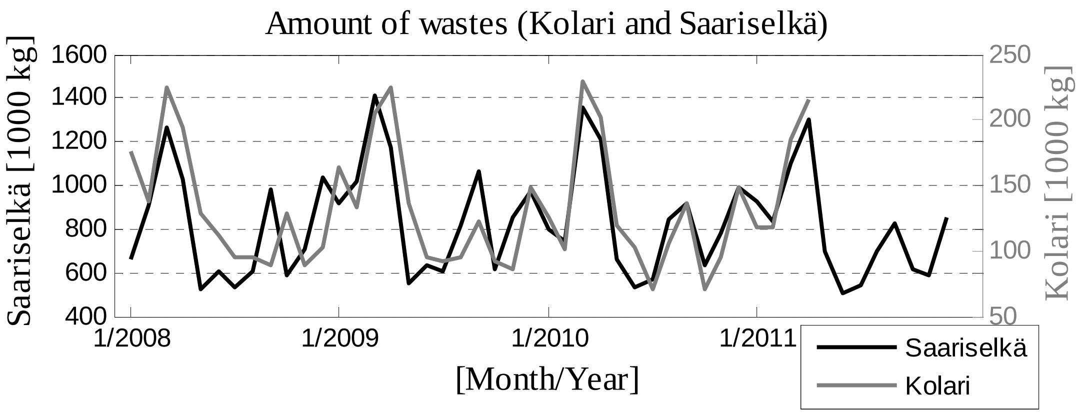

Figure 2. Collected mixed waste in Kolari [6] and Saariselkä, 2008-2011.

Table 2. Amount of mixed waste (1000 kg) in Kolari [6] and Saariselkä.

	Kolari			Saariselkä		
Year	Total in year (1000 kg)	Min Month	Max Month	Total in year (1000 kg)	Min Month	Max Month
2008	1574	88	225	9442	526	1264
2009	1467	80	203	10636	555	1411
2010	1401	69	212	10026	532	1361
2011	576(Jan-Apr)	108	199	9499	505	1303

Although the seasonal variation is identical year after year, the exact amount of waste in a specific month is difficult to predict. Waste amounts correlate with tourist visits, which are dependent on weather, economic situation and even the date of Easter holidays. In this study, the time of the year (months) and the amounts of mixed waste are used as inputs in modelling the amount of bio-waste. The developed model is used for estimating the quantity and the energy potential of bio-wastes in Saariselkä and Kolari.
The size of the waste dataset used in creating the model was rather small: 40 consecutive months, of which bio-waste was collected only in 22 months. Therefore, modelling was done using 5-fold cross-validation, although, efficient training and validation could not be done using separate subsets. Results of the modelling can be seen in Figure 3. The calculated R^2 value of the model was 0.54 and RMSE was 4.57. The model is accurate and efficient with small dataset, even though there must be some nonlinearity in the amount of bio-waste. The cross-validation model estimates that some bio-waste is also produced during the summer time which is similar to the reality.
The model was used for estimating the amounts of bio-waste in Saariselkä based on the time of the year (month) and the amount of collected mixed waste. The result of the estimation is shown in Figure 4. The estimation can be considered reliable, as the proportion of bio-waste to total amount of waste collected in Kolari was ~8 % during the years 2009-2011 (registered data) and, in the model based estimation, the proportion was around 11 %.

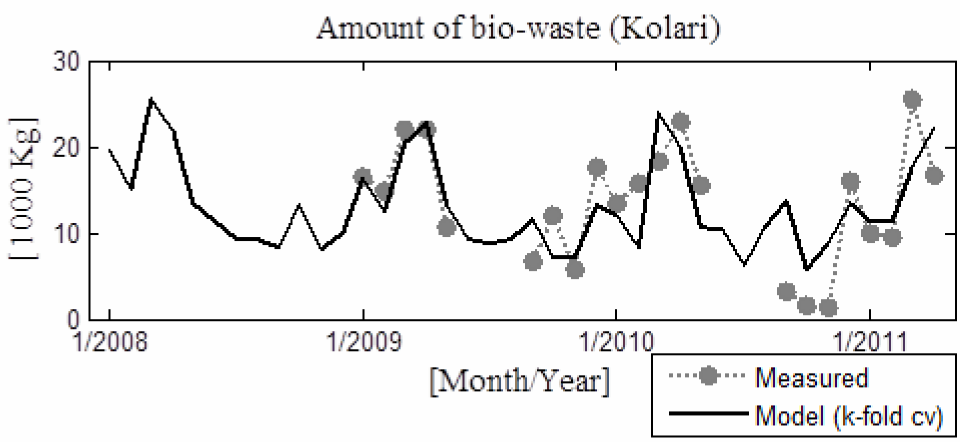

Figure 3. The 5-fold cross-validation model for the amount of bio-waste in Kolari.

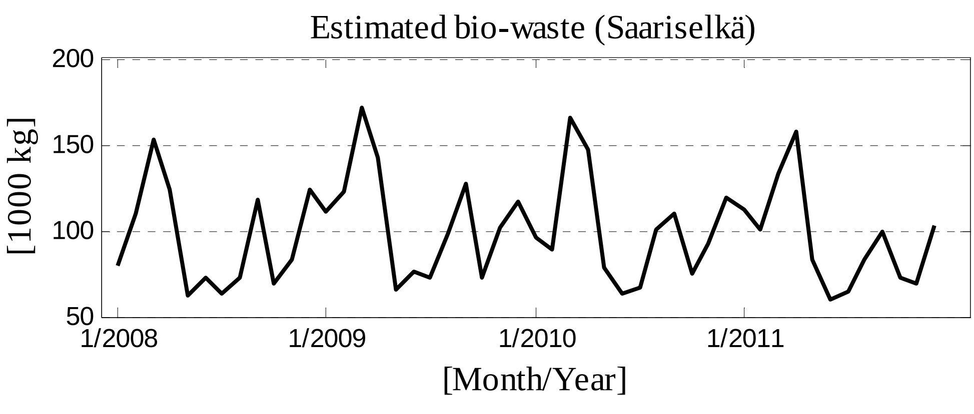

Figure 4. The estimated amount of bio-waste in Saariselkä.

In [6] biogas and energy potential of bio-waste in Kolari was calculated using assumptions that biogas yield is 0.35 m^3/kg of bio-waste and the energy content of biogas is 6.25 kWh/m^3. The estimated amount of energy produced using bio-waste collected from Kolari was 280 MWh and 235 MWh in the year 2009 and 2010, respectively. Assuming that 25 % of collected mixed waste was biodegradable and could be used in anaerobic digestion process due to more efficient waste separation, the total estimated amount of energy in the year 2009 would have been 1082 MWh and 1001 MWh in the year 2010. The total energy consumption per capita in Finland in 2009 and 2010 was 69.1 MWh and 75.6 MWh, respectively [32]. Based on the calculation, the total annual energy consumption of over 10 people could have been covered using the energy produced from biodegradable waste collected from Kolari.

Using the same assumptions as above, the calculated amount of energy produced from the bio-waste in Saariselkä (estimated amount) would have been from 2500 to 2800 MWh during the years 2008-2011. If 25 % of mixed waste was biodegradable and could be used in energy production, the estimated energy potential would have been from 7000 to 8000 MWh per year at Saariselkä area. This is about ten times more than in Kolari municipality and covers the annual energy consumption of circa 100 people. Variations of the energy potential of waste collected at Saariselkä are shown in Figure 5 and the total annual energy potentials during the years 2008-2011 is listed in Table 3. The proportion of the estimated energy potential of bio-waste and biodegradable wastes varied from 20 % to 30 % in Kolari during the years 2009-2011. In Saariselkä, the proportion of model based estimation was circa 35 %. Table 3 also lists the energy potential of the modelled amount of bio-waste and biodegradable waste in Kolari from January 2008 to April 2011. Estimation was done using the developed cross-validation model which assumes that some bio-waste is produced also during the summer time. Now, the estimated annual energy potential is slightly higher than calculated in [6]. Based on these estimations the bioenergy production in AD process cannot be considered economic efficient around the year using only local bio-waste. One possibility to improve the economic efficiency is co-digestion with wastewater sewage sludge and agricultural wastes in seasons when the amount of collected bio-waste is low. However, it is important to take into account that the above mentioned assumptions are just rough estimates, which are selected on the low side, in order to avoid the overestimation of calculated energy potentials. As mentioned earlier due to the complexity of AD process, the exact amount and composition of produced biogas is very difficult to predict. The estimations also do not include the efficiency of energy production methods.

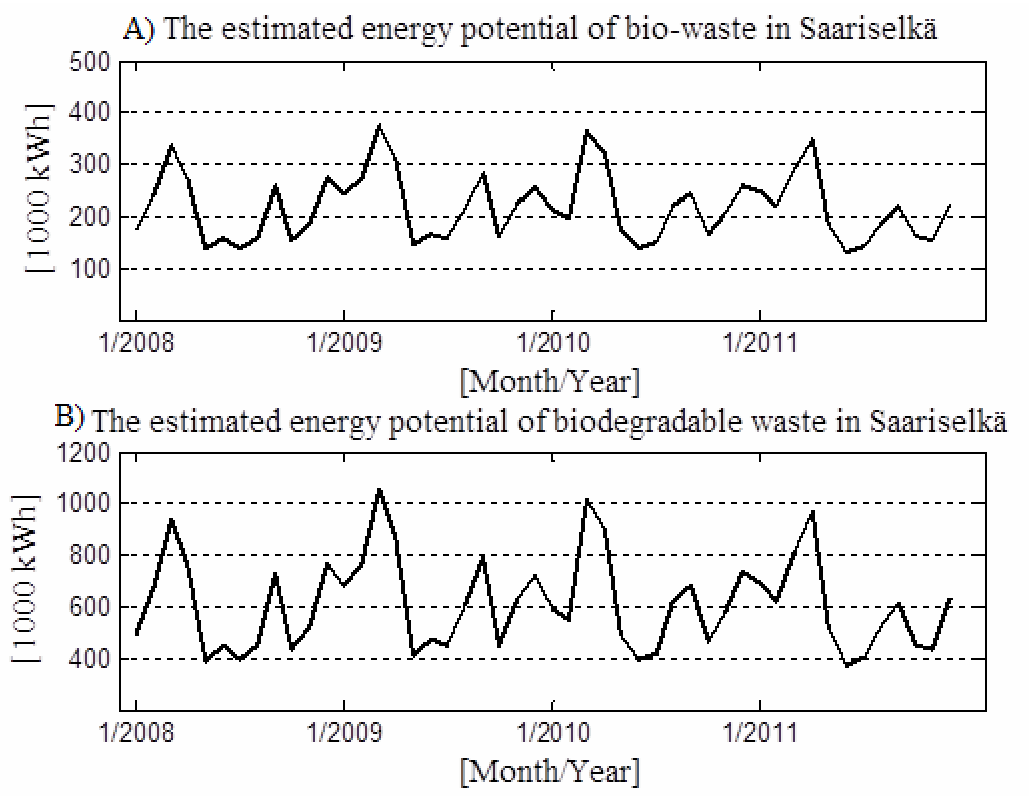

Figure 5. (A) The estimated energy potential of bio-waste, and (B) the estimated energy potential of biodegradable waste collected at Saariselkä.

Table 3. The estimated energy potential of modeled bio-wastes and biodegradable wastes.

	Kolari Estimated energy potential (MWh)		Saariselkä Estimated energy potential (MWh)	
Year	Bio-waste	Biodegradable waste	Bio-waste	Biodegradable waste
2008	357	1217	2476	7021
2009	332	1134	2797	7915
2010	316	1082	2633	7478
2011	144	459 (Jan-Apr)	2491	7063

4. Conclusion

In this paper, waste data of Kolari municipality were used to develop a prediction model for the amount of bio-waste. The selected modelling method was 5-fold cross-validation which is more suitable for small data set than traditional modelling methods. The amount of collected mixed waste and month were used as model inputs. The accuracy of model was good and the cross-validation model also gave an estimate for the amount of bio-waste at summer time. The model was used for estimating the bioenergy potential in Saariselkä and Kolari.

The seasonal variation of collected wastes is significant both in Kolari and Saariselkä, and it is reasonable to assume the same also in other tourist centres in Lapland. Waste amounts correlate to the intensity of tourist visits, with the highest amounts of wastes collected during the spring tourist season. The bioenergy potential varies during the year as well: fortunately, the highest potential is during the winter when the demand for energy is also higher. The energy potential of bio-wastes is fair, the total annual energy consumption of about 100 people in Finland could be covered producing energy from the biodegradable waste collected in Saariselkä. This is 10 times more than in Kolari. Using only locally collected bio-waste, bioenergy production by AD is economically not efficient around the year. Economic efficiency could be improved by co-digestion with sewage sludge or agricultural wastes. In addition, the use of digestate as fertilizer for revegetation purposes or material for landscaping in local tourist areas could provide environmental and economic benefits. Around the year bioenergy production will also require storage facilities, both for the excess bio-waste during peak-seasons and for the digestate during winter. In conclusion, optimizing waste collection, separation and treatment is essential to a profitable waste-to-energy solution in Lapland.

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