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Illustration case for Finland

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Abstract

The illustration case of Finland aimed at estimating technical potential of primary forest residues for energy by using an advanced spatially explicit method. The procedure combined national forest inventory (NFI) plot data, thematic biomass maps, satellite images, constraints for biomass mobilization, location of energy plants, road network, and felling statistics. A major advantage provided by the method is the possibility to apply spatially explicit constraints (i.e. constraints for which geographic location can be defined) on the potentials.

The results of the illustration case provide estimates of technical potential for Central Finland. The illustration case also demonstrates the use of tools and methods for state-of-art bioenergy potential estimation for other regions.

Two types of primary forest residue potential were calculated: Residues from Business As Usual Cuttings (BAU) and Residues from Maximum Cuttings corresponding to regional sustainability (MAX). The regional and municipality level potentials were calculated separately for logging residues and stumps for pine, spruce and broadleaved tree biomass. Regional sustainable harvesting level of Central Finland were downscaled for each municipality. Total annual bioenergy potentials from final fellings from the region of Central Finland were 9.5 PJ for BAU and 11.4 PJ for MAX.

1. Introduction

The illustration case for Finland differs from the other illustration cases due to intensive use of National Forest Inventory (NFI) data and satellite images. The availability of NFI plot data and related up-scaling techniques (Tuominen et al. 2010) provide data and methods for spatially explicit analysis of bioenergy potentials.

The study aimed to provide estimates of technical potential of forest chips for bioenergy by using a harmonised estimation method. The advanced spatially explicit method for stemwood and primary forest residues was applied (chapter 3.4.2 in Vis et al. 2010). The sources of chips considered here were logging residues and stumps from final fellings. In Finland, logging residues and stumps consist mostly of Norway spruce.

The study was a pilot study and focused on the region Central Finland (Fig. 1). The region represents area where the utilization of bioenergy is already at high level. The total land area of the region is 1.7 mill. ha, of which 1.4 mill. ha is forest land. The region of Central Finland consumes a lot of bioenergy due to abundant forest resources and the large number of heat and power plants.

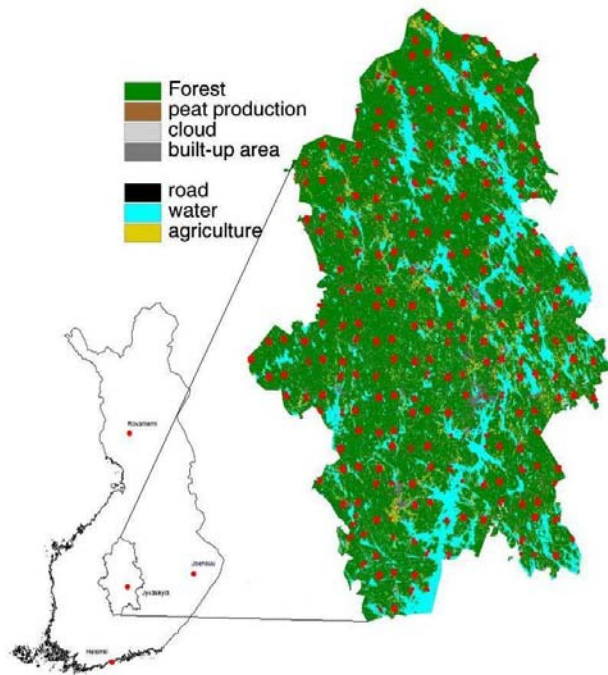


Figure 1. Location of the study area and a classification of land cover and use. Sample plot clusters of the National Forest Inventory are illustrated in red.

Potential of forest chips for energy in Central Finland has been earlier estimated by Laitila et al. (2009). They estimated that the total potential would be 1.3 mill. m³, which constitutes of logging residues from spruce-dominated final-felling stands (542,000 m³), logging residues from pine-dominated final-felling stands (130,000 m³), stumps from spruce-dominated final felling stands (304,000 m³) and small trees from precommercial thinnings (354,000 m³).

2. Methodology

The methods of the Finnish illustration case combine spatially explicit biomass maps, segmentation of EO data, polygons for protected areas, and forests characteristics for each segment. For more details see Methods Handbook, chapter 3.4.2 (Vis et al. 2010).

In general, the work builds on the paper by Tuominen et al. (2010), where NFI plot data was used to estimate biomass of individual NFI plots and those were further up-scaled with satellite images to the region of Central Finland. Thereafter the area of Central Finland was segmented into homogenous segments representing forest stands. Sustainable harvesting levels according to two definitions were estimated for each municipality. Next, the stands were sorted in descending order according to stand volume (m^3/ha) and selected for final felling. The biomass potential was obtained as a sum of crown and stump masses from the final felling stands after applying multiple environmental and technical constraints. The proportion of unmerchantable stem top was assumed to be 4% for pine, 5% for spruce and 17% for the broadleaved trees. The figures for pine and spruce are based on Hakkila (2004) and the figure for the broadleaved on unpublished NFI statistics in Southern Finland.

The applied harvesting level definitions were as follows:

Business As Usual (BAU). The definition is based on mean annual roundwood removals in 2000–2009. Roundwood removal land areas by harvesting type in Central Finland and total volumes harvested on municipality level divided in owner groups (private owners / organizations) were utilised (MetINFO 2010). Information on final felling roundwood removal percentage from total fellings in organizations' forests in Finland in 2008 (Mäki-Simola 2009) and the area data of final fellings were used to calculate the percentage of volume in final fellings in private forests. These regional percentages were then applied on municipality level.

Maximum Sustainable Cuttings (MAX). The definition aims at maximum harvesting level that can be maintained sustainably during 2007–2016 in Central Finland (MetINFO 2010). The maximum possible harvesting levels according to the law for the next five years (measured in 2004–2008) by municipality and the whole region are based on NFI information. Maximum sustainable cuttings on municipality level were calculated using the ratio of maximum possible cuttings and maximum sustainable cuttings in the whole region of Central Finland.

The constraints applied in the study are listed in table 1. The constraints for economic accessibility are gathered from the instructions found from the Internet sites of Finnish companies.

Table 1. The constraints applied in the study.

Constraint	Value or measure
Net annual increment	Harvesting levels in the definitions are below NAI
Recovery rate	70% for logging residues (Äijälä et al. 2010), 95% stumps (Laitila et al. 2008)
Maximum forwarding distance	500 m
Protection of biodiversity	Conservation areas and Natura2000 area were removed from the analysis
Economic accessibility	Minimum recovery volume for logging residues 20 m^3/ha and 40 m^3/stand and for stumps 100 m^3/stand . In addition, the minimum area of a stand for stump harvesting 2 ha.
Protection of soil	Recovery of stumps and logging residues only from fertile stands (Äijälä et al. 2010)
Protection of water and remaining trees	A buffer zone of 10 m on stump harvesting sites

All biomasses were initially calculated in dry tonnes. In order to obtain the potentials in volume and energy units (m^3 and GJ, respectively), the conversion factors in table 2 were used. For logging residues and stumps the moisture as received was assumed to be 50% and 35% (wet basis), respectively.

Table 2. Basic densities ($r_{0,g}$) and lower heating values of dry matter ($Q_{\text{net},d}$) for the different biomass types.

Biomass type	$r_{0,g}$ (kg/m^3)	$Q_{\text{net},d}$ (MJ/kg)
Logging residues, pine	395 ¹	20.5 ³
Logging residues, spruce	465 ¹	19.7 ³
Logging residues, broadleaved	500 ¹	17.7 ³
Stumps, pine	475 ¹	19.5 ³
Stumps, spruce	435 ¹	19.1 ³
Stumps, broadleaved	450 ²	18.5 ³

Sources: ¹ Hakkila et al. (1978); ² estimated based on Kärkkäinen (2007), p. 156; ³ Alakangas (2000)

3. Potential for biomass

Technical potential for biomass in Central Finland was calculated for primary forest residues from final fellings. Potential was calculated separately for pine, spruce and broadleaved tree biomass and further divided into logging residues and stumps. Calculations for potential were made for each municipality in the region and then combined to obtain results for total area. The results for the total area are shown in Table 3 and the municipal-level results in Appendix 1.

Table 3. Forest biomass potentials in Central Finland from final fellings (GJ/year) and corresponding land areas (1000 ha).

General Characteristics		BAU	MAX
	Definition		
	Type of potential	Technical	Technical
	Method applied	advanced spatially explicit method	advanced spatially explicit method
	Year	2000–2009	2007–2016
Land category	Detailed Land Category		
Total (1000 ha)		15	18
	Forest & other wooded land	15	18
Biomass category	Detailed Biomass Category		
Primary forest residues (GJ)			
	Total logging residues	9,478,141	11,408,605
	Residues, pine	1,174,054	1,481,023
	Residues, spruce	4,377,410	5,190,415
	Residues, broadleaved	681,020	841,350
	Stumps, pine	809,668	1,003,679
	Stumps, spruce	2,155,602	2,546,890
	Stumps, broadleaved	280,387	345,247

The following sustainability criteria were applied:

- All conservation areas and areas of the Natura2000 network were removed from the analysis.
- A buffer zone of 10 m was applied on stump harvesting sites.
- The region of Central Finland is PEFC certified and the calculation of potentials was made accordingly.

4. Analysis and discussion

4.1. Data gaps and methodological challenges

Methodological challenges of the spatially explicit approach are mainly related to demanding spatial analysis and also to data availability. The approach presented here requests NFI data (or similar forest inventory data) that is sufficient for the satellite image analysis and for up-scaling. Satellite images for the procedure presented here are freely available, but unfortunately the spatially explicit forest inventory data of larger areas is often difficult to access. The GIS analysis of biomass maps requires expertise and knowledge about methods and software. However, the method was applicable in Central Finland, because all the needed data and expertise were available.

Another methodological challenge is the estimation of potential from thinnings. Estimation of this potential calls for reliable classification of stands to development classes in order to find the stands where thinning should take place. Use of development classes was tried in this study, but the classification proved to be unreliable for this purpose.

4.2. Current status of biomass utilisation in Finland

In Finland about one quarter of energy is produced of renewable sources, and about 80% of this is biomass (Statistics Finland 2010). Of biomass, almost all is wood-based. The total energy consumption in Finland in 2008 was 1,414 PJ and the consumption of wood-based fuels 302 PJ.

In 2008 the consumption of forest chips in heat and power plants in Central Finland was 588,000 solid m³ (Ylitalo 2009), corresponding to c. 4 PJ. Additional 10-20% of chips are also used in small-sized dwellings. The comparison between consumption and calculated potentials is shown in Figure 2.

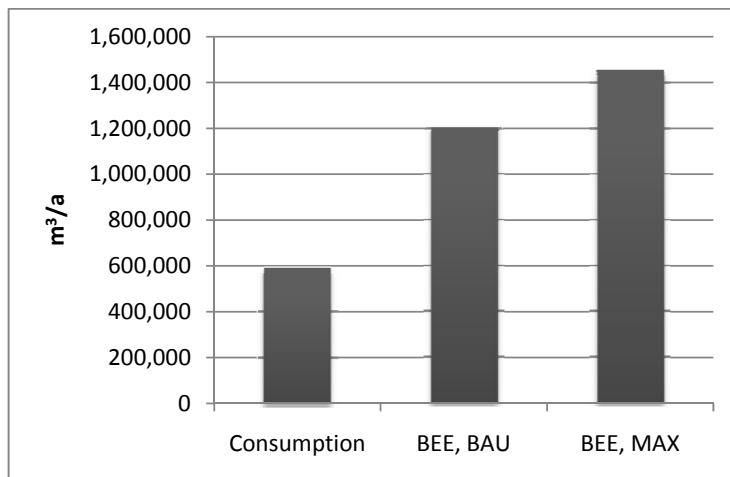


Figure 2. Consumption of forest chips in 2008 and forest energy potentials from final fellings in Central Finland.

4.3. Implementation issues in Finland

For heat and power plants logging residues are the cheapest source of forest chips. Stumps and thinning material require extraction which is an extra cost compared to procurement of logging residues. The use of forest chips in Central Finland is already intensive and increasing the use will raise supply cost. This is firstly because of the utilisation rate of logging residues is high, which will direct the increase to more expensive sources. Secondly, with increasing competition and higher

supply amounts, the transport distances will get longer. New economical incentives have been planned to boost the use.

5. Conclusion and recommendation

Despite the already high level of forest energy use in Central Finland the calculations show that there is still room for increasing the use. However, one must bear in mind that the calculated potentials are technical in nature. This means that e.g. supply costs and the willingness of forest owners to sell residues and stumps further restrict the potential. Thus, the real availability of forest chips is lower than estimated here. Furthermore; due to the age structure of forests, the amount of final felling and, consequently, the technical potential for forest residues, is expected to decrease after the year 2017 in Finland (see Kärkkäinen et al. 2008), including Central Finland (The Finnish... 2010).

The estimation method proved to be feasible for potential estimation from final fellings. Either other methods should be applied for estimation of potential from thinnings or better data on development classes should be available.

The presented method combines satellite images, forest inventory data, digital road data, location of power plants and biomass maps. This novel approach takes into account the spatial information of forest resources and provides therefore realistic estimates about transportation distances. The use of wood as bioenergy depends heavily on the transportation costs which can be obtained by this approach e.g. for each municipality.

The given approach can be applied if one has adequate forest inventory data, biomass maps or biomass models, satellite images (e.g. free Landsat images) and digital road maps. The natural level of application would be a geographical area roughly equal to one Landsat scene or larger.

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Appendix: Technical potentials from final fellings in Central Finland at municipal level

Column names in the result tables are in format x_y_z , where
 x = type of biomass; res = logging residues, stump = stump and root biomass
 y = species group; pine = *Pinus sylvestris*, spruce = *Picea abies*, bl = broadleaved species (mainly *Betula pendula*, *B. pubescens*, *Alnus incana*, *Populus tremula*, *Sorbus aucuparia* and *Salix* sp.)
 z = unit; t = metric ton (dry mass), m^3 = solid cubic metres (volume), GJ = gigajoule (lower heating value as received).

Table 1. Potentials according to Business As Usual cutting definition (BAU) in tonnes.

	res_pine_t	res_spruce_t	res_bl_t	stump_pine_t	stump_spruce_t	stump_bl_t
Aanekoski	3121	14645	2156	2174	7280	793
Hankasalmi	1478	12585	1500	996	5973	532
Jamsa	3902	18032	3347	2627	8284	1230
Jamsankoski	1524	7161	1363	839	2858	393
Joutsa	2158	13198	2256	1322	5832	792
Jyvaskyla	918	4721	813	668	2268	318
Jyvaskyla_mlk	1597	8383	1401	1228	4080	540
Kannonkoski	2144	6500	1471	1475	3236	609
Karstula	3304	9710	1857	2124	5261	715
Keuruu	7051	15075	2539	6546	8577	1088
Kinnula	1645	2758	860	883	1247	292
Kivijarvi	1643	5814	1088	1124	3452	443
Konnevesi	1400	10600	1476	885	4505	449
Korpilahti	2589	12513	2174	2127	6863	927
Kuhmoinen	2863	14427	2305	1973	6761	851
Kyyjarvi	1889	2691	844	789	873	235
Laukaa	1936	12719	1820	1341	6149	743
Leivonmaki	2357	3955	1262	1463	1549	398
Luhanka	585	3848	679	376	1803	236
Multia	2425	7231	1216	1772	3301	445
Muurame	423	2488	389	361	1398	171
Petajavesi	1683	7784	1204	1266	3750	436
Pihtipudas	4194	10918	2533	2523	4981	930
Pylkonmaki	1270	3827	681	852	1978	259
Saarijarvi	3170	12415	2157	2324	6198	829
Toivakka	1772	5683	1342	986	1899	351
Urainen	1316	5107	709	903	2378	263
Viitasaari	4654	18830	3187	2653	8054	1004

Table 2. Potentials according to business as usual cutting definition (BAU) in cubic metres.

	res_pine_m 3	res_spruce_ m3	res_bl_m 3	stump_pine_ m3	stump_spruce_ m3	stump_bl_m 3
Aanekoski	7901	31495	4313	4577	16736	1762
Hankasalmi	3742	27064	3000	2096	13732	1182
Jamsa	9878	38779	6694	5530	19045	2733
Jamsankoski	3858	15400	2726	1767	6570	874
Joutsa	5465	28384	4512	2783	13406	1760
Jyvaskyla	2323	10152	1626	1407	5215	707
Jyvaskyla_mlk	4042	18027	2802	2585	9378	1201

Kannonkoski	5429	13978	2942	3106	7440	1354
Karstula	8364	20882	3715	4471	12093	1588
Keuruu	17850	32419	5077	13781	19717	2418
Kinnula	4164	5931	1720	1860	2868	649
Kivijarvi	4159	12503	2175	2367	7935	985
Konnevesi	3545	22796	2953	1864	10356	997
Korpilahti	6555	26909	4348	4479	15776	2060
Kuhmoinen	7248	31027	4609	4153	15542	1892
Kyyjarvi	4782	5787	1688	1661	2006	522
Laukaa	4900	27352	3641	2823	14136	1652
Leivonmaki	5967	8505	2524	3079	3561	885
Luhanka	1482	8276	1358	793	4145	524
Multia	6138	15550	2431	3731	7589	989
Muurame	1070	5351	778	759	3214	379
Petajavesi	4260	16740	2407	2665	8620	968
Pihtipudas	10617	23479	5065	5312	11451	2067
Pylkonmaki	3215	8230	1362	1793	4547	576
Saarijarvi	8025	26699	4315	4893	14249	1843
Toivakka	4485	12221	2683	2076	4366	781
Uurainen	3331	10983	1418	1902	5466	584
Viitasaari	11782	40495	6374	5586	18516	2231

Table 3. Potentials according to business as usual cutting definition (BAU) in gigajoules.

	res_pine_G J	res_spruce_G J	res_bl_G J	stump_pine_ GJ	stump_spruce_ GJ	stump_bl_G J
Aanekoski	56361	252774	32906	39467	129927	13663
Hankasalmi	26695	217216	22893	18073	106602	9163
Jamsa	70468	311234	51073	47684	147845	21191
Jamsankoski	27524	123599	20796	15233	51003	6773
Joutsa	38982	227805	34427	24002	104071	13644
Jyvaskyla	16574	81476	12409	12133	40481	5479
Jyvaskyla_ml k	28837	144685	21376	22287	72806	9309
Kannonkoski	38729	112185	22451	26781	57754	10498
Karstula	59666	167598	28345	38556	93882	12315
Keuruu	127334	260191	38741	118832	153065	18748
Kinnula	29702	47600	13124	16035	22262	5032
Kivijarvi	29669	100348	16596	20409	61601	7638
Konnevesi	25290	182956	22528	16074	80391	7733
Korpilahti	46760	215967	33172	38622	122472	15974
Kuhmoinen	51707	249018	35169	35810	120653	14667
Kyyjarvi	34113	46446	12881	14324	15571	4046
Laukaa	34957	219527	27780	24340	109738	12807
Leivonmaki	42568	68258	19255	26553	27643	6865
Luhanka	10573	66421	10360	6834	32178	4066
Multia	43790	124805	18549	32170	58913	7671
Muurame	7636	42945	5933	6548	24953	2941
Petajavesi	30386	134351	18366	22979	66921	7505
Pihtipudas	75738	188437	38648	45802	88894	16028
Pylkonmaki	22937	66050	10392	15462	35296	4462
Saarijarvi	57248	214285	32921	42194	110613	14286
Toivakka	31994	98083	20474	17899	33894	6056
Uurainen	23766	88145	10822	16399	42434	4530

Viitasaari	84051	325005	48630	48169	143739	17296
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Table 4. Potentials according to maximum sustainable cutting definition (MAX) in tonnes.

	res_pine_t	res_spruce_t	res_bl_t	stump_pine_t	stump_spruce_t	stump_bl_t
Aanekoski	4526	20034	3141	3167	9802	1164
Hankasalmi	1630	13617	1654	1133	6590	605
Jamsa	5350	23860	4540	3570	11040	1674
Jamsankoski	1748	8127	1574	974	3289	468
Joutsa	2010	12429	2102	1208	5539	743
Jyvaskyla	429	2453	390	256	1017	125
Jyvaskyla_mlk	2181	10898	1875	1679	5366	725
Kannonkoski	1661	5381	1184	1213	2730	509
Karstula	4313	11238	2335	2565	5779	840
Keuruu	8126	17144	2967	7485	9613	1272
Kinnula	3188	4135	1521	1724	1784	515
Kivijarvi	2054	6822	1340	1502	4191	590
Konnevesi	1780	13353	1917	1171	6056	627
Korpilahti	2856	13555	2390	2347	7451	1017
Kuhmoinen	2965	14831	2387	2025	6910	874
Kyyjarvi	2771	3316	1114	1198	1055	312
Laukaa	2372	14998	2202	1624	7250	897
Leivonmaki	3822	6229	2081	2376	2378	657
Luhanka	809	5192	962	571	2606	367
Multia	3460	10505	1791	2446	4955	633
Muurame	649	3634	589	513	1897	237
Petajavesi	2037	9119	1466	1436	4280	516
Pihtipudas	5425	13494	3184	3227	6099	1166
Pylkonmaki	1925	4986	1002	1077	2352	330
Saarijarvi	3512	13854	2396	2535	6810	901
Toivakka	2379	6926	1783	1433	2380	501
Uurainen	1858	7126	1061	1271	3355	393
Viitasaari	6171	23464	4185	3561	10141	1378

Table 5. Potentials according to maximum sustainable cutting definition (MAX) in cubic metres.

	res_pine_ m3	res_spruce_ m3	res_bl_ m3	stump_pine_ m3	stump_spruce_ m3	stump_bl_ m3
Aanekoski	11458	43083	6283	6667	22534	2586
Hankasalmi	4127	29284	3308	2384	15150	1346
Jamsa	13545	51311	9080	7515	25378	3719
Jamsankoski	4426	17478	3148	2050	7560	1041
Joutsa	5088	26730	4204	2544	12734	1651
Jyvaskyla	1085	5275	781	540	2337	279
Jyvaskyla_mlk	5522	23437	3749	3534	12336	1612
Kannonkoski	4206	11572	2367	2553	6277	1131
Karstula	10919	24169	4670	5400	13285	1867
Keuruu	20572	36869	5933	15757	22100	2826
Kinnula	8070	8893	3042	3630	4102	1145
Kivijarvi	5199	14671	2680	3163	9634	1311
Konnevesi	4507	28716	3834	2466	13921	1392
Korpilahti	7230	29150	4780	4941	17128	2260

Kuhmoinen	7507	31894	4773	4264	15885	1942
Kyyjarvi	7016	7131	2227	2521	2425	694
Laukaa	6004	32253	4403	3420	16666	1994
Leivonmaki	9677	13395	4163	5002	5468	1459
Luhanka	2049	11166	1924	1202	5990	815
Multia	8758	22591	3582	5150	11390	1406
Muurame	1642	7815	1179	1081	4360	526
Petajavesi	5157	19610	2932	3023	9839	1148
Pihtipudas	13734	29019	6368	6793	14021	2592
Pylkonmaki	4873	10723	2003	2268	5408	734
Saarijarvi	8891	29793	4793	5338	15654	2003
Toivakka	6022	14896	3566	3016	5471	1114
Uurainen	4703	15325	2123	2676	7712	874
Viitasaari	15624	50461	8370	7498	23314	3061

Table 6. Potentials according to maximum sustainable cutting definition (MAX) in gigajoules.

	res_pine_G J	res_spruce_G J	res_bl_G J	stump_pine_ GJ	stump_spruce_ GJ	stump_bl_G J
Aanekoski	81735	345780	47938	57488	174933	20051
Hankasalmi	29441	235027	25239	20560	117607	10433
Jamsa	96624	411816	69280	64802	197014	28839
Jamsankoski	31572	140278	24022	17678	58687	8072
Joutsa	36295	214531	32078	21934	98856	12800
Jyvaskyla	7740	42337	5958	4653	18143	2161
Jyvaskyla_ml k	39392	188100	28607	30477	95762	12499
Kannonkoski	30002	92878	18063	22016	48726	8766
Karstula	77891	193975	35633	46562	103130	14476
Keuruu	146755	295904	45272	135875	171563	21912
Kinnula	57567	71373	23208	31298	31843	8877
Kivijarvi	37091	117746	20451	27275	74793	10162
Konnevesi	32152	230475	29254	21267	108070	10796
Korpilahti	51577	233959	36472	42611	132964	17523
Kuhmoinen	53555	255980	36420	36765	123319	15061
Kyyjarvi	50050	57234	16996	21740	18823	5382
Laukaa	42830	258861	33596	29490	129376	15458
Leivonmaki	69034	107506	31762	43133	42446	11316
Luhanka	14618	89618	14683	10361	46503	6323
Multia	62479	181312	27331	44412	88420	10902
Muurame	11714	62719	8995	9318	33851	4075
Petajavesi	36785	157387	22374	26068	76384	8898
Pihtipudas	97975	232902	48589	58576	108842	20095
Pylkonmaki	34760	86061	15286	19557	41983	5693
Saarijarvi	63426	239113	36567	46027	121526	15529
Toivakka	42959	119551	27212	26010	42471	8637
Uurainen	33548	122999	16197	23073	59869	6774
Viitasaari	111456	404995	63866	64652	180986	23736

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