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GIS-based Approach to Identifying Potential Heat Sources for Heat Pumps and Chillers Providing District Heating and Cooling

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ABSTRACT

Geographic information system (GIS) software has been essential for visualising and determining heating and cooling requirements, sources of industrial excess heat, natural bodies of water, and municipalities. Policymakers highly encourage the use of GIS software at all administrative levels. It is expected that the heating and cooling demand will continue to increase. For a reliable heat and cooling supply, we must identify heat sources that can be used to provide heat or for removing surplus heat. We propose a method for identifying possible heat sources for large heat pumps and chillers that combines geospatial data from administrative units, industrial facilities, and natural bodies of water. Temperatures, capacities, heat source availability, as well as their proximity to areas with high demand density for heating and cooling were considered. This method was used for Estonia, Latvia and Lithuania. Excess heat from heat generation plants and industries, sewage water treatment plants, and natural heat sources such as rivers, lakes and seawater were included. The study's findings provide an overview of possible industrial and natural heat sources, as well as their characteristics. The potential of the heat sources was analysed, quantified, and then compared to the areas of heating and cooling demand..

Keywords

District heating and cooling;
Energy planning;
ESPON;
Heat sources;
Large-scale heat pumps;

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1. Introduction

In the EU, heating and cooling are responsible for half of the final energy consumption, 75% of which was produced using fossil fuels in 2012 [1]. Even though district heating (DH) accounts for only 12% of the heat supplied to EU residents, the proportion is highly dependent on the country. Countries in the North have particularly high proportions of DH. The proportion of DH in Denmark, Sweden, Finland, Poland, and the Baltics was about 50% or more in 2012 [2]. The transformation of the DH sector is not only important for these regions, but it could also aid in achieving ambitious climate goals. Mathiesen et al. [3] highlighted that an increased DH and district cooling (DC) share will support reaching the EU climate objectives in a cost-effective manner.

Geographic information system (GIS) tools have often been used to visualise and determine heating and cooling needs [4,5], as well as visualise and identify industrial excess heat sources [6], municipalities [7], natural bodies of water [8], solar energy potential [9], and densely populated areas [10]. Policymakers and experts strongly recommend using GIS tools at various administrative levels. There is a wide variety of such tools available, for example, in the ESPON Toolbox Database [11], such as ESPON's SDGs benchmarking tool [12], which shows indicators that measure and

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Abbreviations

CHP	Combined heat and power plant
DC	District cooling
DH	District heating
GIS	Geographic information system
HPs	Heat pumps
PEC	Primary energy consumption
RES	Renewable energy sources

monitor the 17 Sustainable Development Goals of the United Nations across Europe at country or regional level. For example, it can be used to show the share of renewable energy in heating and cooling of buildings as an indicator for Goal 7: Affordable and clean energy. Furthermore, this tool can be used to identify the benchmark for certain indicators or regions that are at the same level as the own in terms of the indicator under investigation or other similarities like similar rural/urban areas.

For the energy sector, energy need densities, resource availabilities and resource potentials have been visualised for various projects. Within the *Hotmaps* project [4], an online tool has been developed, which displays among others building related content such as heat and cooling demand densities, gross floor areas, and building volumes among the EU28 member states. Furthermore, industrial sites, emissions, sectors, and potential excess heat are displayed, as well as other parts related to the potential of renewable energy sources (RES), such as sewage water treatment plants or the potential of solar thermal and wind power. The information is complemented by climate data like average temperatures, wind speed and solar radiation.

With the *Heat Roadmap Europe* project, an online tool has been developed called Pan-European Thermal Atlas (Peta), version 4.3 [13]. A newer version, called Peta 5.1, is based on the *sEEnergies* project [14]. In Peta 4.1 [13], a GIS map with similar information as in the *Hotmaps* project [4] is provided for 14 countries of the EU. Information is also available for the quantities of annual available excess heat from metro stations, power plants and sewage water treatment plants, biomass resources, DH distribution costs, and others. In Peta 5.1 [14], information is provided for all EU member states and a new features were included to show e.g. the area of existing DH infrastructure.

Another relevant online GIS and planning tool for the energy sector is based on the Thermal Energy Resource Modelling and Optimisation System (THERMOS) project [15]. It can be used to plan and map the expansion of existing DH and DC infrastructure, to identify synergies and an optimal network path between local demands and known energy sources, to perform an assessment of potential DH and DC networks.

It should be mentioned that many of the mapped results of the above-mentioned projects are based on a top-down approach and several assumptions and general basic calculations in order to achieve approximate values for each country and to use the same approach for each country. Furthermore, a variety of RES were identified and mapped, while other sources are still missing that can become particularly relevant for large-scale heat pumps (HPs) and chillers, such as rivers and lakes [16,17]. Large-scale HPs and chillers are seen as a very efficient technology to utilize RES, to integrate the power and thermal energy sector and thereby help balancing the power generation from fluctuating RES. HPs allow the use of heat at ambient temperature from e.g. seawater, rivers, lakes, or sewage water for DH, which would reduce the proportion of fossil fuel-based heat [18,19]. Similarly, these sources can be used by chillers as a heat sink to supply DC. Connolly et al. [20] show the relevance of large-scale HPs for European DH systems, which are expected to produce 520TWh/a in the EU by 2050, thus providing 25% to 30% of the total DH production.

Therefore, the aim of this study is to perform a geospatial analysis and to develop a GIS map with the focus on providing detailed information about available sources that can be used particularly for large-scale HPs and/or chillers. Thereby, the potential of implementing large-scale HPs and chillers for DH and DC can be identified and barriers be lowered, if geospatial analysis based on advanced GIS software is used to provide detailed information and an overview of suitable locations of heat sources and sinks near DH and/or DC regions. This would be an added value to GIS maps by focusing (and adding) heat sources particularly relevant for large-scale HPs and to quantify their potential usage. So far identified heat sources in GIS were not considered for this purpose.

Estonia, Latvia and Lithuania were used to apply the methodology of a geospatial analysis of heat sources for large-scale HPs. The results of the ESPON *COMPASS* project [21] show how well spatial planning is integrated in sectoral policy. In terms of the Baltic states, it is noted that the influence of spatial planning on energy policy is very strong in Estonia and Lithuania, and less significant in Latvia. Therefore, the Baltic was considered as very suitable for such analysis, also in terms of a potential implementation of obtained results.

2. Method

According to the ESPON *FUTURES* project [22], the energy needs (space heating, domestic hot water, and cooling) of residential buildings in the Baltics are among the highest in Europe. In order to identify sustainable ways of supplying these large energy needs, the following methodology was applied:

- Geospatial analysis was used to locate possible high- and low-temperature heat sources for large-scale HPs and chillers in the Baltic countries.
- DH areas were visualised using geospatial data from settlement units or densely populated areas by filtering these general data sets according to information about the DH supply in cities.
- Heat source potential was calculated based on the data gathered and the proximity to established DH areas.
- The GIS data used to visualise the DH areas was compared to the data on the heat demand density areas from the *Hotmaps* project [4]. Likewise, potential DC areas were compared to the cooling demand density areas from the same project.

Industrial excess heat and flue gas from heat generation plants can be used as high-temperature heat sources to supply DH via HPs. Industrial excess heat is heat discharged into the atmosphere as a result of an industrial process. The exhaust gas that is discharged into the atmosphere as a result of the combustion process (e.g. at a DH plant) is flue gas. A heat exchanger and extra pipes can be used to deliver excess heat beyond the supply temperature of DH (for example, 90°C) straight into the DH network. Excess heat below the DH supply temperature necessitates the use of an electric boiler or HP in order to get the excess heat temperature up to the DH supply temperature. We considered the following high-temperature heat sources: boilers, combined heat and power plants (CHPs) (flue gas), and industrial processes like wood, dairy, cement, and food processing (industrial excess heat).

Low-temperature heat sources were only considered in the case of utilising HPs to provide DH when the temperature of the heat source is near the ambient temperature. These sources are mostly based on natural sources. Seawater, lake and river water, and treated sewage water from cleaning facilities were among the considered low-temperature heat sources. The low-temperature heat sources mentioned above can also be utilised as heat sinks to discharge excess heat from DC consumers.

We used ArcGIS Pro [23] to evaluate the potential of heat sources based on the sources located within the specified DH areas and up to 1km away. The 1km cut-off criterion was selected because anything over 1km would result in overly expensive investments in pipelines. Based on the heat source, this may not be reasonable. The cut-off criterion proposed by Bühler [24] is based on the maximum cost of connection, which varies depending on the heat capacity and the heat source. He discovered that distances of over 200m lead to a rapid increase in connection costs, while distances of 1km or more are still viable for larger heat sources.

The *Hotmaps* project [4] has created heat and cooling demand density maps for all EU countries. In order to display heat and cooling demand density maps at NUTS 3 level, they used the approach presented in the *LOCATE* project [25]. Before, energy consumption data of different end use sectors was not available at NUTS 3 level. However, within the *LOCATE* project [25], they scaled the useful energy demand and final energy consumption from level NUTS 0, NUTS 1 or NUTS 2 to level NUTS 3 based on own developed regional conversion matrices, depending on the kind of energy used (heating, cooling) and data availability. For example, detailed final energy consumption data of heating and cooling distinguished by the system and building categories at level NUTS 0 was broken down to level NUTS 3 using building stock data at NUTS 3 level. More information about this method and data availability at which NUTS level can be found in the *LOCATE* project [25].

2.1. District heating areas

In the Baltics, the majority of the residents get their heat via DH (62% in EE, 65% in LV, and 58% in LT), which is significantly higher than the EU average (26%) [26,27]. In 2018, the Baltic states had a far higher share of RES in the heating and cooling sector (54% in EE, 56% in LV, and 46% in LT) than the EU average of 29% [28]. Data was gathered from 184 (EE), 111 (LV), and 56 (LT) DH areas.

Datasets created for other uses were taken and used to visualise the DH areas. These areas were then compared to the data on the existing DH areas obtained from a variety of reports and databases, including regional and national development plans, as well as DH competition authorities [29–36]. It must be noted that the data used was collected for other purposes, so it does not reflect the accurate location and/or boundaries of the DH networks.

GIS data [7] containing administrative and settlement units was used to visualise DH areas in Estonia by means of processing it using data obtained on the DH areas and comparing the results to a similar online map of these areas [37]. In Latvia, the dissemination of datasets concerning territorial units and their borders is currently prohibited [38]. As a result, a dataset of densely populated areas had to be used [10] and then filtered based on the DH area data. A dataset of settlements and population was used for Lithuania, and it was filtered to display only areas with more than 4000 residents [39].

2.2. District cooling areas

DC is not very common in the Baltics. In Estonia, there are only a handful DC networks that are in operation. The available information on the planned and existing DC areas in Tartu and Tallinn was compared with the cooling demand density areas from the *Hotmaps* project [4].

Tartu's DC network is the first of its kind in the Baltics, with a cooling capacity of 13MW and a length of 1.3km. Fortum constructed it in 2016 and further expanded it in 2017, adding an extra 1.3km of pipes and 5.4MW of cooling capacity. Chillers, DC HPs, free coolers that utilise river water, and a cooling tower make up the two DC plants' equipment [40]. Large shopping malls, office complexes, and municipal buildings are the primary customers.

Tallinn has master plans for three different DC areas [41]. The first DC network is currently being built. The cooling demand of existing buildings in the region is 7.3MW, and the heat demand is 8.1MW. In the future, it is anticipated that extra cooling (23.6MW) and heating (26.2MW) capacity will be needed [41].

In addition, each Baltic country is expected to construct several more DC networks. This means that DC is still in its early stages of development. More DC networks could be implemented in the future due to their higher efficiency compared to individual cooling systems. At the same time, cooling demand is expected to rise rapidly in the future due to changing customer needs and a rise in the annual Cooling Degree Day (CDD) Index affected by climate change.

2.3. High-temperature heat sources

2.3.1. Industrial excess heat

Industrial excess heat typically produces higher temperatures of up to several hundred degrees than other natural or artificial heat sources. Bühler et al. [6] used Denmark data to analyse it and provide a detailed description. They measured the potential for using excess heat in a variety of industrial sectors, as well as the amount of excess heat that could be generated, and the temperatures at which it is usually produced. It was discovered that industrial excess heat derived from thermal processes would cover 5% of the current heat demand. In comparison to other regions, it is more likely to be used in industrial areas where it can be incorporated into a local DH network. Industrial excess heat is expected to provide a total of 1.36TWh per year, with HPs being needed for 36% of that to increase the temperature to the required level. Agreements between DH companies and companies from the industry are needed to allow and distribute investments, as well as to ensure long-term planning [42]. Bühler [24] provides a lot more detail on the matter.

2.3.2. Flue gas

Flue gas, which is generated as a result of fuel combustion at the plant for the production of heat or power, can reach temperatures ranging from 120°C to 180°C [43]. Therefore, flue gas can be condensed to heat the DH return line to temperatures of 40-60°C before it even reaches the plant. With the aid of HPs, the temperature of the flue gas can be decreased even more until it reaches an ambient temperature of 20°C or so. As a result, the DH network's return temperature rises even higher, increasing the plant's efficiency. The small temperature difference between the heat source and heat supply must be compensated for by HPs that use flue gas as a heat source. HPs that use flue gas need a separate plant to burn fuel, limiting their cost-cutting capacity [42].

2.3.3. Assumptions and data gathering

The data from A and B air pollution permits was gathered for a variety of high-temperature heat sources available in Estonia [44], [31], Latvia [45], [33] and Lithuania [46]. Since the investments necessary for a smaller heat source would likely not be economically, only units with an installed capacity over 10MW were considered. Data on the industrial sector, installed capacity, fuel consumption, and fuel type was gathered for 174 (EE), 106 (LV), and 99 (LT) possible high-temperature heat sources (industrial excess heat and flue gas from heat generation plants). Primary energy consumption (PEC) for each heat source was calculated using the obtained information. Then, based on the data from Bühler [24], sector-specific excess heat factors were applied, ranging from 0.08 for paper to 0.37 for metal production.

Since the temperature of the excess heat from industrial processes is often higher than the DH supply temperature, a heat exchanger could be used to integrate significant quantities of the available excess heat before introducing HPs. The proportion of used heat by the heat exchanger on the one hand and by the HP on the other hand depends on the excess heat temperature. This ratio changes for larger excess heat temperatures, since more heat can be used by a direct heat exchange, while the amount of heat used by the HP would remain constant according to the DH temperatures. Based on the measured PEC, shares of 67% for direct supply of heat and 33% for heat supplied via HPs were assumed based on excess heat temperatures of 150°C to estimate the excess heat potential for each part.

With an efficiency of 0.85 for biomass-fired plants, a flue gas factor of 0.05 was assumed for boilers, suggesting that a flue gas condenser should be installed first, which decreases the temperature of the flue gas from about 150°C to about 50°C (67% of the excess heat), and HPs should then cool the flue gas to around 20°C (33%). The same calculation method was used for CHP plants. Because not all excess heat is discharged as flue gas to the atmosphere, the excess heat factor has been reduced to 0.04. Water from the condenser accounts for up to 2/5 of excess heat discharged into the atmosphere [43].

2.4. Low-temperature heat sources

Possible heat sources and sinks include rivers, lakes, seawater, and treated sewage water. Groundwater, ambient air, and low-temperature excess heat generated as a result of cooling processes (e.g. supermarkets, DC networks) are among the other heat sources.

2.4.1. Seawater

Changes in environmental conditions, especially surface water, affect seawater. The less the environmental conditions affect the point of seawater extraction, the deeper it is located. Surface water can already begin to freeze in winter. As a result, extracting water from deeper points could be more lucrative. Big HPs in Oslo, Norway [47] and Stockholm, Sweden work in this manner [48]. Saltwater, minerals, and algae have a negative effect on the equipment, which requires special materials or coatings. The equipment must also be cleaned on a regular basis.

Because of the large volume of water, seawater is an ideal heat source for large-scale HPs. Seawater has also been used for cooling via free cooling and refrigeration plants, from which practical experience and knowledge can be gained. Seawater must be easily accessible and in close proximity.

2.4.2. River and lake water

The temperature properties of rivers and lakes are identical to those of seawater. Larger cities are often located near major rivers and lakes. Water from rivers and lakes usually has a lower capacity than seawater. In the case of lakes, the capacity is constraint by the water volume, and in the case of rivers, by the flow rate. Furthermore, the depth can be lower, compared to seawater. Debris, such as grass, algae, and other organic matter, can impair efficiency, so the equipment must be cleaned on a regular basis.

The source capacity can be assessed based on the river's volume flow rate and the lake's water volume. This data, combined with current regulatory requirements for return flow temperature, can aid in the identification of capacity constraints. Large lake-based HPs have been constructed in Lausanne, Switzerland, and several locations in Sweden [18]. Lake and river water can be used for cooling alongside seawater.

2.4.3. Sewage water

The sewage water temperature is usually higher than that of the surrounding air, and the volume flow rates are high. This means that sewage water is a suitable heat source. Since biological sewage water treatment is susceptible to temperature changes and should not be disrupted, treated sewage water is usually considered [49]. Moreover, using untreated water may demand extra care when passing through the HP evaporator, as it necessitates the use of cleaning equipment and heat exchanger design alterations. However, also cleaned sewage water contains a number of nutrients that encourage the growth of bacteria [50]. To ensure smooth operation, clean-in-place (CIP) equipment and filters may be necessary [51].

Sweden has implemented several large HPs that use sewage water, including one in Malmo that has a thermal capacity of 40MW [52]. Sewage treatment plant operators can provide data on sewage water temperatures and volume flow rates.

2.4.4. Measurement and geospatial data

As can be seen in Table 1, geospatial data and measurements of seawater, rivers, lakes, and sewage water treatment plants were collected from a variety of sources. Seawater, river, and lake temperatures were measured at 12, 17, and 7 different locations in Estonia, Latvia and Lithuania, respectively. In the case of rivers, the volume flow rate was also determined. One sewage water treatment plant provided temperature and flow measurements of sewage water.

3. Results

First, we present the overall results of the collected GIS data for all Baltic countries. Then the comparison of the considered data for the DH and DC areas with the heat and cooling demand density map from the *Hotmaps* project is provided [4]. Below are the results of the geospatial analysis, including information on high-temperature and low-temperature excess heat sources.

3.1. Overall GIS results

Figure 1 depicts an overview of all gathered data's geospatial information. The following elements are depicted: DH regions (in pink), sewage water treatment plants (red squares), high-temperature heat sources (green circles), rivers (black lines), lakes (blue areas), and seawater (light blue coastal areas). A link to an interactive online map can be found here.

Many of the high-temperature heat sources are localised inside or in close proximity to DH regions, as shown in the figure. Sewage water treatment plants are spread all over the Baltics. Most cities are situated near rivers, and a few are by the sea (especially in Estonia).

3.2. DH areas: comparison of GIS data and Hotmaps data

Figure 2 shows an example of current DH areas and accessible low- and high-temperature heat sources in the Pärnu region of Estonia. National GIS data is compared to the *Hotmaps* project's heat demand density map [4]. This demonstrates what GIS data was used, the data's consistency, how to use the GIS map, as well as how the data can be used further. The settlements of Pärnu, Sauga (North), Sindi (Northeast), and Paikuse (East) are encircled in blue, and the heat demand density is depicted as a colourmap, where the highest demand is shown in red, and the lowest in grey. The sewage water treatment plant is depicted as a red circle, while the nine high-temperature heat sources are shown as green circles, rivers in black, and seawater in light blue.

The annual heat demand of these settlements has been estimated at around 250GWh, the largest share of which belongs to Pärnu. It can be seen that settlements occupy a larger area than the heat demand density map. Depending on the settlement unit, this can have a significant impact, as is the case for Paikuse. Most of the settlement area is occupied by agricultural and forest land, while the residents of Paikuse are concentrated in only two places. The settlement units of Pärnu, Sauga, and Sindi are somewhat similar to the heat demand density maps. From this point of view, they can be used to pinpoint the approximate location of existing DH areas. It should be noted that the heat demand density map does not show the location of DH areas. However, since the existing DH areas are located in very densely populated areas, it can be assumed that this is the case.

Out of the nine high-temperature heat sources, one is located further away (pellet factory up North with 15.5GWh of potential excess heat). Despite the distance, constructing a pipeline to the DH network for excess heat sources of this scale could prove to be cost-effective. Paikuse also has a high-temperature heat source in

Table 1: Sources of GIS data and measurements (lakes, rivers, seawater, and sewage treatment plants)

Estonia	Latvia	Lithuania
Estonian Land Board: waterbodies [53]; Environmental Register [54]; Estonian Weather Service (available upon request) [102]	SIA Envirotech: Waterbodies, Watercourses, and Shoreline [55–57]; Latvian Environment, Geology and Meteorology Centre (available online) [78]	SE 'GIS-Centras': Annex I. Hydrography (INSPIRE dataset) [8]; MapCruzin.com: Waterways (based on the data from OpenStreetMap.org) [58]; Lithuanian Hydrometeorological Service, Hydrological Observations Division (available upon request) [103]
Seawater depth and distance from shore [59,60]		
The EU Urban Waste Water Treatment Directive [61]		

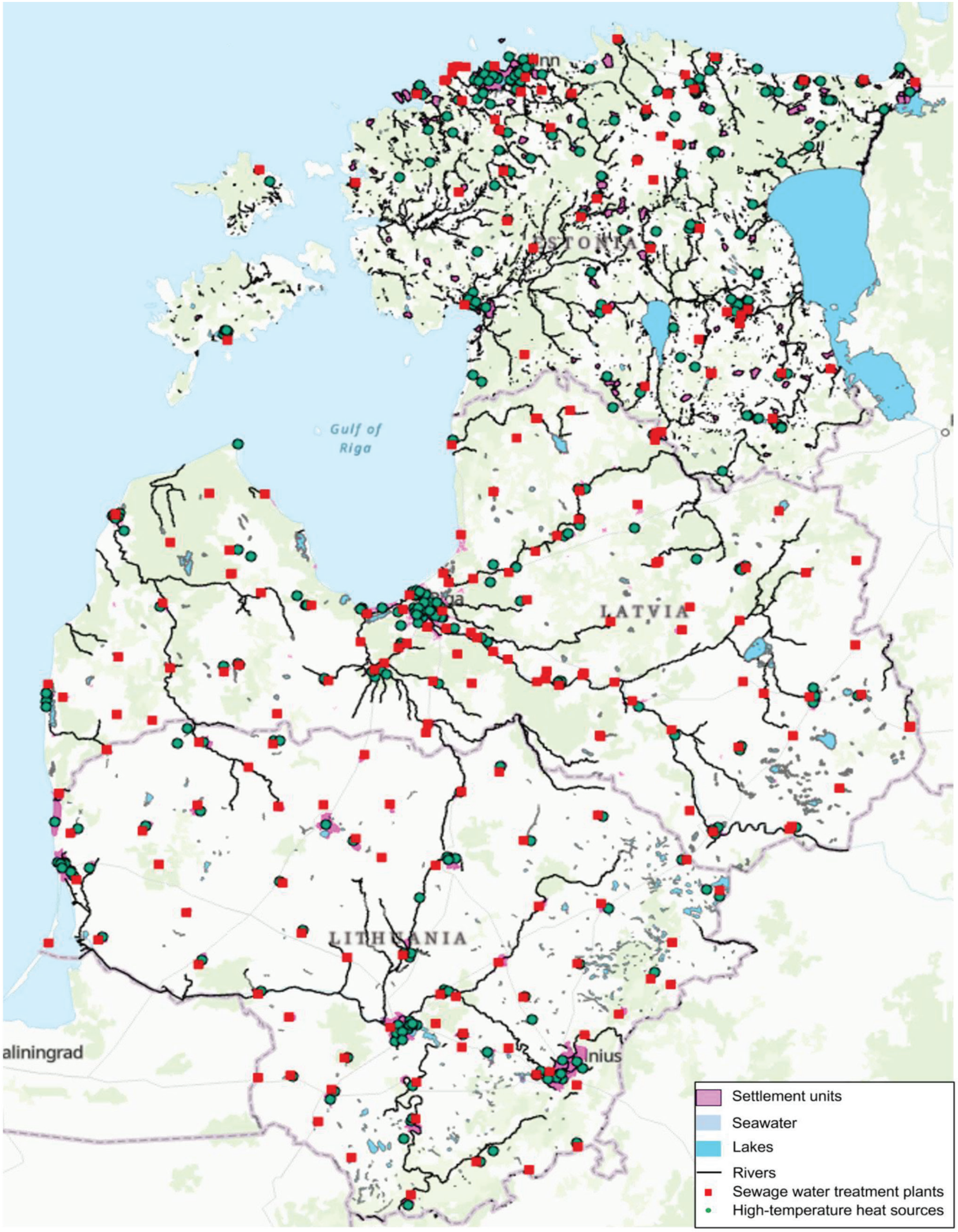

Figure 1: GIS results for the Baltics, displaying high- and low-temperature heat sources, as well as DH regions

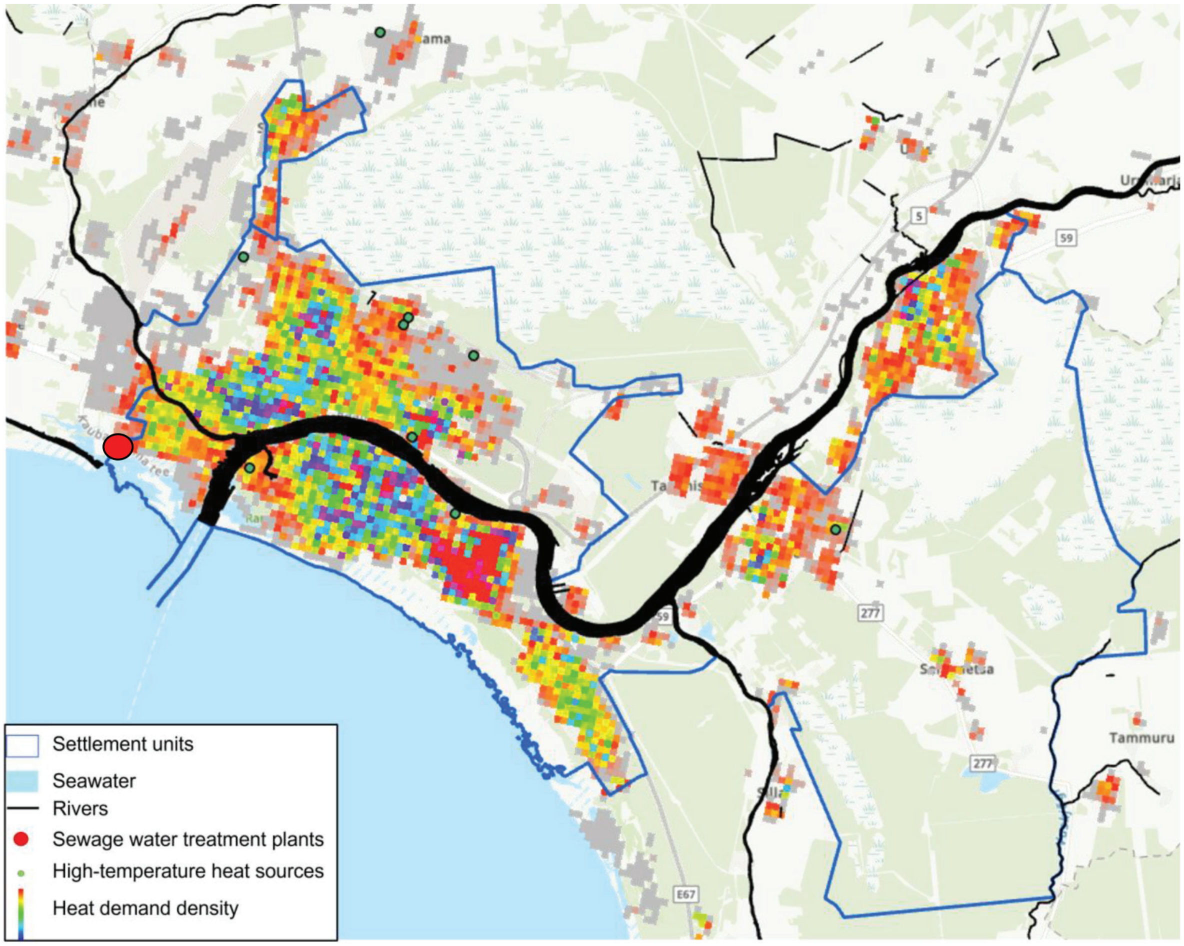

Figure 2: Municipalities, heat density areas, and accessible heat sources in the vicinity of Pärnu, Estonia

the form of a boiler house that can generate 9GWh of heat per year from flue gas. All other high-temperature heat sources are in Pärnu, including two sources located on the outskirts of the city: an asphalt plant (1.5GWh) and a CHP plant (33.5GWh flue gas). Two asphalt plants (0.8GWh and 1.7GWh), a fibreboard factory (19.3GWh), and two boiler houses (10.7GWh and 10.6GWh) make up the remaining five. Asphalt plants are often idle during the winter, making it more difficult to make use of such excess heat sources that have restricted availability during times of high demand for heat.

In addition, there are several low-temperature heat sources in and around Pärnu. The large Pärnu river flows through the city and can serve as both a heat source and a heat sink for Pärnu, Sindi, and Paikuse. Besides, Pärnu is located by the sea, so DH and/or DC can be supplied using sea or river water based on location. In particular, DC networks are usually smaller in size, so having a heat sink nearby becomes very important. Moreover, a sewage water treatment plant can serve as a potential heat source for large-scale HPs, since it maintains higher temperatures in winter, as opposed to sea and river water. As a result, a higher HP coefficient of performance (COP) can be achieved.

3.3. DC areas: comparison of GIS data and Hotmaps data

Figure 3 shows a comparison of Tartu's projected cooling demand based on the *Hotmaps* project [4] and the first DC network in the Baltics. It can be seen that the DC network was constructed in an area that the *Hotmaps* project described as having cooling needs.

Figure 4 shows another comparison, this time of the *Hotmaps* project results and Tallinn's cooling demand. Three DC regions with potential cooling demand of 60MW, 10MW, and 30MW have been discovered in Tallinn. As of today, the latter is considered a new development area with minimal cooling needs [41].

Figure 3: Tartu DC network (left) and for the same area the cooling demand resulting from the *Hotmaps* project (right) [62,63]

Since future cooling needs are not reflected in the project, the 30MW DC area could not be defined. The 60MW DC area is only partly defined, and the 10MW region is adjacent to the one shown. Instead, the project found other areas where there could be a higher cooling demand.

3.4. High-temperature heat sources

In the Baltics, 13 separate industrial sectors have been identified. Facilities unrelated to the identified sectors were categorised as ‘Other’. Table 2 provides an overview of the total PEC of high-temperature heat sources within each Baltic state. Estonia and Lithuania both have a high level of PEC in the industry. In terms of boilers and CHPs, Latvia has a fairly high PEC.

Estonia is dominated by the chemical, cement, refinery, and wood industries. They have a PEC of 16011GWh per year. With 63 (asphalt) and 10 (food) heat sources, the asphalt and food industries make up 1449GWh. Furthermore, since CHPs and boilers have an annual

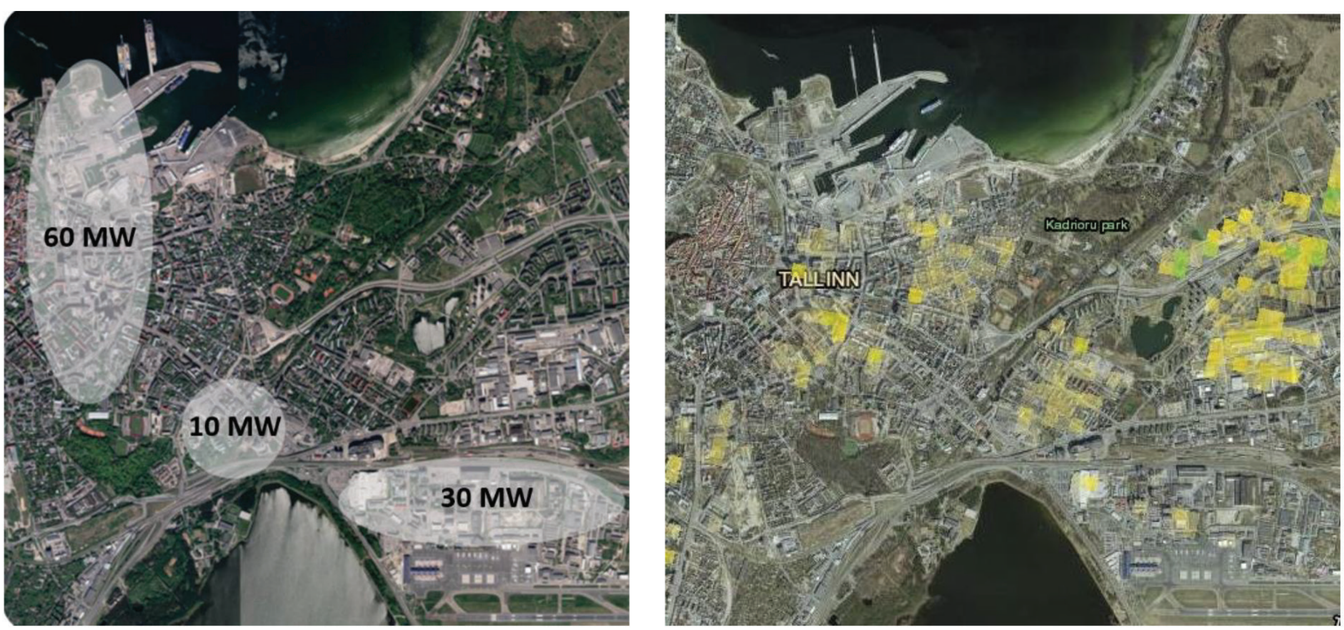

Figure 4: Tallinn DC potential (left) and for the same area the cooling demand resulting from the *Hotmaps* project (right) [41,63]

Table 2: Primary energy consumption in each country

Primary energy consumption, GWh	Estonia	Latvia	Lithuania
Industrial excess heat	18867	6257	15598
CHP plants and boilers	14029	22002	13654

PEC of 14029GWh, they provide extra capacity for excess heat from flue gas.

Cement and wood are the most prominent industrial sectors in Latvia, with a PEC of 3779GWh per year. Refineries, food, and pharmaceuticals have a PEC of 993GWh per year. At 22002GWh, the PEC for boilers and CHPs is very high.

With an annual PEC of 14064GWh, Lithuania is dominated by the chemical, cement, and paper industries. The food industry consumes 601GWh of energy per year. There are also many boilers in Lithuania, which consume a total of 10385GWh of primary energy per year. Compared to other countries, the CHP plants' excess heat potential is still very low. This could change once new CHP plants are introduced into the system.

3.4.1. Theoretical high-temperature excess heat potential

PEC, excess heat factors, and directly supplied heat or through HPs can all be used to calculate the theoretical potential of high-temperature excess heat sources, as can be seen in Figure 5. The possibility of the high-temperature excess heat source already providing excess heat to the DH network was not considered. Should the need arise, this should be evaluated separately for each source. Figure 5 does not reflect the chemical industry's potential. It is, however, significantly higher compared to other industries. In Estonia, the chemical industry has an excess heat potential of 1351GWh and in Lithuania, it has an excess heat potential of 1804GWh. Cement (EE, LV, LT), refineries (EE), wood (EE, LV), asphalt (EE), and food (EE, LV, LT), as well as boilers (EE, LV, LT) and CHP plants (EE, LV, LT) have a high excess heat potential.

Table 3 provides an overview of each country's total theoretical excess heat potential. The excess heat potential was split into two components: direct supply using a heat exchanger (2/3) and the supply by using HPs (1/3). In terms of CHPs and boilers, excess heat potential refers to flue gas after a flue gas condenser.

3.4.2. Practical high-temperature excess heat potential

Table 4 provides an overview of the potential excess heat and number of high-temperature heat sources and their accessibility in DH regions.

As can be seen, the DH regions have many industrial excess heat sources within their boundaries. However, a considerable portion, especially in Latvia, is concentrated in rural areas. This may be due to the kind of geospatial data used to represent the DH regions in this paper. In

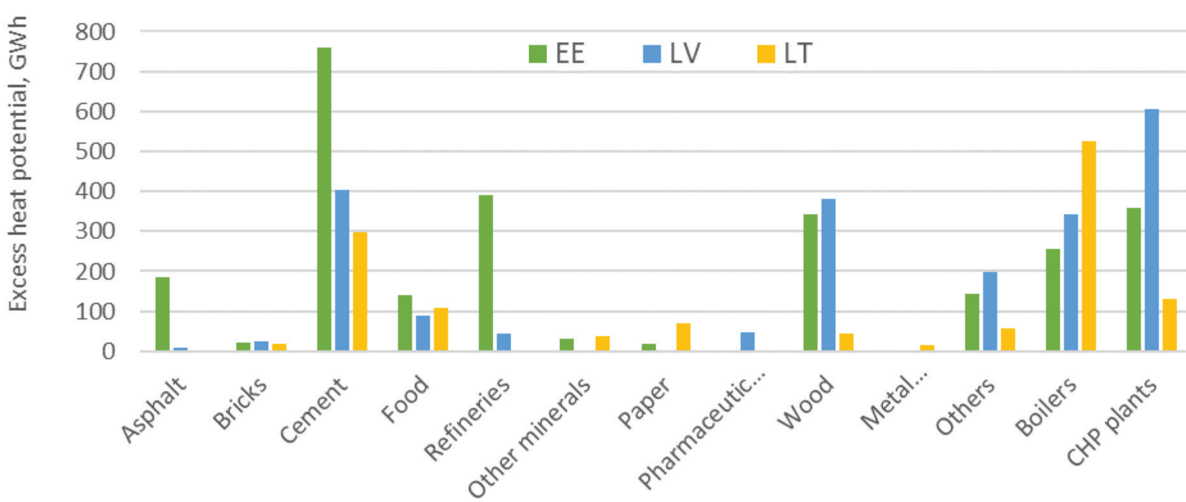

Figure 5: Theoretical excess heat potential of high-temperature heat sources in Estonia (EE), Latvia (LV), and Lithuania (LT)

Table 3: Theoretical excess heat potential of each country

Theoretical excess heat potential	Estonia (GWh)	Latvia (GWh)	Lithuania (GWh)
Industrial excess heat (total)	3370	1199	2490
Industrial excess heat (direct supply)	2247	799	1660
Industrial excess heat (HP supply)	1123	400	830
Boilers and CHPs (flue gas HPs)	590	949	650

Table 4: Practical excess heat potential of each country

Practical excess heat potential	Distance (km)	Estonia (#, GWh)		Latvia (#, GWh)		Lithuania (#, GWh)	
Industrial excess heat (direct supply and HPs)	0	44	2601	21	394	21	436
	<1	18	322	4	110	1	1730
CHPs and boilers (flue gas HPs)	0	46	445	54	901	63	413
	<1	1	66	1	5	1	0

Latvia, DH regions were defined in accordance with densely populated areas, while in Estonia and Lithuania, DH regions were defined on the basis of municipality borders. As a result, the areas in ArcGIS Pro that are considered to be the DH regions of the two countries may appear larger than they are, as can be seen in Figure 2. Therefore, the heat sources that must be considered for possible DH supply should be concentrated in these areas and not further out. The majority of boilers and CHPs are found in DH areas, which makes sense given that they supply DH. A separate evaluation should be carried out if any heat sources are further considered.

3.5. Low-temperature heat sources

Figure 6 provides an overview of water temperature measurements for various heat sources. As shown, sewage water retains higher temperatures throughout the colder months, when the heat demand is typically higher. Lake, river, and seawater temperatures are close to the freezing point in January and February. As a result, extracting extra heat from these sources during times of high demand of heat can be particularly difficult. Lakes, rivers, and the sea should be accessed from below the surface (≈10m), if possible, to prevent freezing. A steady temperature of 2-4°C can be reached this way, as demonstrated by the temperature of the lake water in Figure 6, which was measured at the lake's bottom (at the depth of 4m).

Crucial, but not the only selection criteria will play the heat source temperature. Other relevant criteria include distance to DH, available capacity, special equipment and/or investments, which may differ from heat source to heat source.

Table 5 provides an overview on which DH regions contain low-temperature heat sources or are within 1km

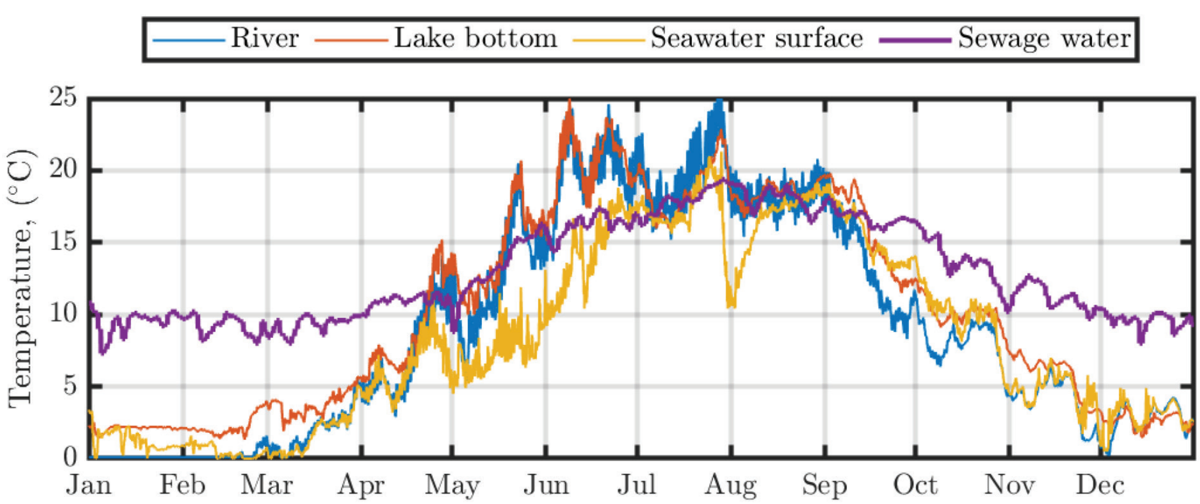

Figure 6: Heat source temperatures

Table 5: Potential of low-temperature heat sources of each country

Heat source potential	Distance (km)	Estonia (#)	Latvia (#)	Lithuania (#)
DH areas with access to seawater	0	18	9	3
	<1	4	0	0
DH areas with access to sewage water treatment plants	0	33	41	23
	<1	11	28	10
DH areas with access to large rivers	0	79	40	18
	<1	25	17	3
DH areas with access to large lakes	0	11	11	16
	<1	8	10	7

of them. As can be seen, the majority of DH regions with access to seawater are in Estonia, followed by nine in Latvia, and the city of Klaipėda, Klaipėda county, and the town of Palanga in Lithuania. Sewage water treatment plants are typically found in all major cities, although they are sometimes located outside of city limits. As a result, many DH regions have a sewage water treatment plant in the region or within 1km. Many DH regions with river access are in Estonia and Latvia, along with quite a few in Lithuania. The majority of DH regions with access to large lakes are in Lithuania, while a few are in Estonia and Latvia.

4. Discussion

As shown, existing GIS datasets can be used for a variety of purposes, including DH area visualisation. The limitations and uncertainties in describing the desired regions should be considered for future analysis. It has been shown that settlement units can represent densely populated areas; however, the unit itself is often a very large region in a rural area.

The *State of the European Territory* report [64] describes the impacts of climate change on the main biogeographic regions of Europe. It shows what potential changes to heat sources can be expected in the future, and which of them should be taken into account in terms of use and regional energy planning. The Baltics belong to the boreal region, in which a decrease in lake and river ice cover and an increase in precipitation and river flows can be expected, which may be relevant in terms of heat source usage.

The ESPON *FUTURES* project [22] shows how Europe could look like, if the entire energy system was based on 100% RES concerning the usage of regional RES, energy consumption and transport/mobility. Regarding the Baltics, for example a good wind energy potential per km^2 is shown compared to the rest of Europe. Once, this potential is used, HPs could use renewable electricity to provide also renewable heating.

Currently, all Baltic states have invested in biomass-based plants to provide heating and/or power. In 2018, Estonia, Latvia and Lithuania heat was produced by 47%, 61% and 80% using biomass, respectively [65–67]. In addition, biomass is also used for other purposes, such as construction inside the countries and as export product abroad. The ESPON HyperAtlas “REGICO” [68] was used to compare the share of forest area to the total land area (ha/ha) per country. In 2018 this ratio was 0.49, 0.39 and 0.31 in Estonia, Latvia and Lithuania, respectively. Estonia has the second highest share in Europe. Since the forest area ratio in Lithuania is much smaller, the biomass usage for different purposes, such as providing heating, should be carefully overseen.

To limit the biomass use and competition with other sectors for this resource, HPs, wind, hydropower and solar (PV, thermal) could be used more in the future to balance the sustainable usage of resources. The province Voralberg, Austria, can be used as an example of how the transition of the energy supply can be initiated. According to the ESPON *LOCATE* case study report of Rheintal [69], the share of oil and liquid gas on the energy use of households between 2003 and 2014 decreased from 45% to 29%. The biomass share has decreased from 21% to 16%, while the share of DH has almost doubled from 7% to 13% (93% biomass-based). However, the share of solar and HPs has increased enormously from 2% to 19% during the same period. Considering the generally high demand and use for biomass/wood for various purposes, its usage for the energy supply should be considered and a variety of RES be considered for the energy supply.

A high biomass usage was also reported in the case study report about Copenhagen, Denmark [70] of the

ESPON *LOCATE* project. Denmark managed to increase its production of renewable energy from 2000 until 2015 by 72%, from which biomass and wind power were the largest contributors. The consumption of renewable energy has increased by 249% during the same period, which shows that locally produced renewable energy could be used locally using e.g. the DH infrastructure. Advantageous for the biomass usage was the generally high share of heat supply by DH, which has increased from 34% to 64% from 1981 till 2015. Over the last decade, large-scale HPs have experienced an enormous growth in Denmark, because they are seen as the key technology to increase the share of RES in the energy consumption further. The growth can be explained by the regulatory framework, which has been changed in favour of large-scale HPs [71]. In the Baltic countries, a similar trend as in Denmark can be observed, namely a high share of citizens supplied by DH and a large share of biomass usage. If a similar pathway, as described in [70] for Denmark as a country and for Copenhagen as a major city, is continued, the Baltics may be on a good way for a sustainable supply of energy.

5. Conclusion

Geospatial data were applied to the Baltic states to identify DH areas, high-temperature heat sources for possible DH supply, and low-temperature heat sources that can be used for heating and cooling purposes. The available geographic data were compared with heat and cooling demand density maps. It was discovered that they contain similar information, but using settlement units as DH areas can overestimate the size of the region, especially in rural areas.

Over 350 high-temperature heat sources have been identified and their excess heat potential has been quantified. It was found that the industrial excess heat potential is 3370 GWh in Estonia, 1199 GWh in Latvia and 2490 GWh in Lithuania. From these quantities, 2601 GWh, 394 GWh and 436 GWh are located within existing DH areas in Estonia, Latvia and Lithuania, respectively. In addition, seawater, rivers, lakes, and sewage water treatment plants were considered as potential heat sources and sinks. It was found that sewage water treatment plants are located in the most major cities and that most cities, in particular in Estonia and Latvia, have access to either seawater or rivers, which all can serve as a suitable heat source for large-scale HPs. The proximity of over 350 DH areas has been analysed to identify synergy regions where excess heat or low-grade heat can be used for DH or natural heat sinks can be used for DC.

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