Interreg
EUROPEAN UNION
North-West Europe
DGE-ROLLOUT

Socio-economic potential mapping for Deep Geothermal Energy

Focus: North Rhine-Westphalia

Deliverable T1.2.3

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Disclaimer

The purpose of the following report is to give a short overview of the aspect that has been defined as a milestone in the socio/economic mapping potential inside the DGE Roll-out project in Germany. It should provide general information to local, regional, and national public authorities, project developers, politicians and enterprises with heat demand. However, this report does not replace the own independent research on this topic. Appropriate legal advice should be obtained in actual situations.

The recommendations given herein are the authors' subjective opinions based on the research which has been done for this report. It does not rely on experience during drilling or seismic exploration in the field. It mainly sums up the opinion of experienced project partners and actual goals in contributing as much as possible to stop climate change.

We cannot guarantee the accuracy, reliability, correctness or completeness of the information and materials given in this report and accept no legal responsibility. For further reading, please refer to the literature mentioned herein about the socio-economics aspect above mentioned.

Contents

Introduction

Climate change is a global concern that requires regional action. Northwest Europe aims to reduce CO2 emissions through the transition from fossil fuels to renewable energy sources. The need for an opportunities overview is growing to meet the energy demand of the population and industry. The heat demand covers almost 50 % of the total energy demand. It can be substituted with geothermal energy. In this project, we focus on deep geothermal energy (DGE).

The success of DGE projects lies in an accurate estimation of the resources, considering geological and surface-level factors. The literature on geothermal projects written from a geological point of view is widely available, while the literature devoted to social aspects is limited and focuses on risk assessment. A google scholar search can show the reader this difference when a topic such as "geothermal reservoir" gives more than 350,000 results versus 800 for "geothermal socio-economics". It makes clear the need for more information on the subject.

The importance of evaluating both topics, social and reservoir factors, is described in the technical approach pyramid (Moeck, et al., 2020). It considers social and geological aspects in the exploration phase of geothermal projects and emphasizes the decisive surface and subsurface elements.

As part of the DGE-ROLLOUT project, deliverable 2.3 “Mapping of socio-economic potential for DGE” has been developed covering the decisive elements. Its aim is to inform the current socio-economic situation for new geothermal projects, considering the investor profile (van Melle, et al., 2021) and the heat demand (Fraunhofer IEG, 2021).

Inside the DGE ROLLOUT project, the economic aspects related to deep geothermal projects has been described and analysed in reports: WPT1 D3.1 Legal Framework (Van Malderen, 2020), WPT1 D3.2 Financial Risk Management (Taşdemir & Arndt, 2020) and WPT1 D3.3 Examination of the German regulatory framework and financial risk management of DGE, A recommendation approach (Taşdemir & Dombrowski, 2021) . These topics will not be covered in this report, so the reader is referred to them.

The report is a brief definition of the socio-economic factors and how they were defined for this project, the workflow for data compilation and the sources used - most of which are freely available. Each factor is accompanied by a map to visualize its spatial distribution in the state of North Rhine-Westphalia (NRW).

Socio-economic aspect in Geothermal Projects

The methodology for geothermal exploration is based on the existing one for hydrocarbons (Moeck & Beardsmore, 2014). The exploration phase distinguishes between geosystems, plays and prospects according size and detail of the geological model. The workflow suggested by Moeck (Moeck, et al., 2020) integrates the surfaces and subsurface parameters in groups to evaluate a geothermal project (Figure 1). The subsurface group is the geologic-technical focus pyramid with all the factors related to the reservoir. The geosystem includes the overall characterization of the reservoir rock, the play is an area of interest within the geosystem, and the prospect is the exploration target that will later be exploited. This process is called the scalability of the subsurface. The other group is the societal-technical focus pyramid, which characterizes the efficient use of these resources on the surface. Factors as demand, existing infrastructure and land access are considered. The next step is the determination of the project in the decision plane. The different possibilities of geothermal energy systems and the existing requirements, well documented, are analysed to match the best option. The socio-economic potential mapping report is a starting point, that is, a guide with the necessary information to communicate about the potential on the surface.

The difference between fossils and geothermal energy sources is at the surface, geothermal energy cannot be transported over long distances because of heat dissipation. Therefore, it becomes essential to know the surface conditions.

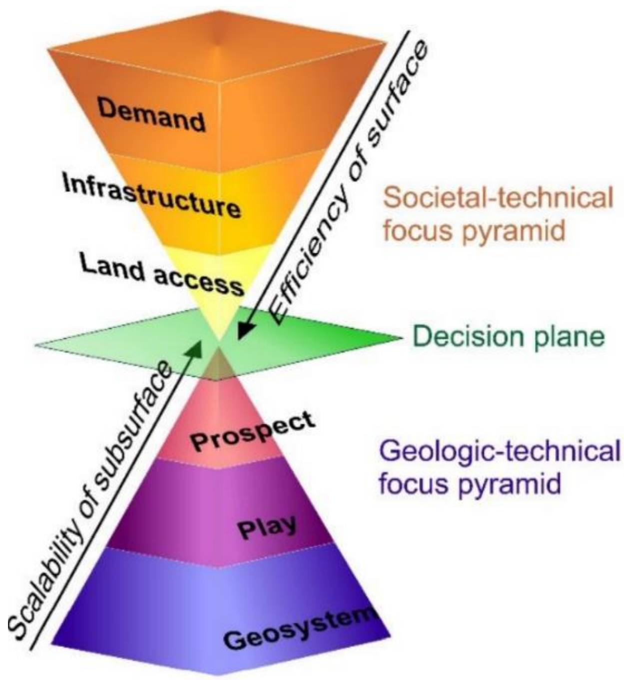

Figure 1 Decision-making factors to start a geothermal project, after (Moeck, et al., 2020).

The societal pyramid factors particularised are:

- Demand

  In the case of Northwest Europe (NEW), it can be classified in energy and heat demand, sector or end-user types, current supply and density population.

- Infrastructure

  This aspect holds the existing infrastructure to the distribution of energy or heat, for example, the district heating networks.

- Land access

  This factor includes data such as land ownership, environmental protection and culturally areas.

Additional to these considerations, the International Renewable Energy Agency (IRENA) incorporate other factors with a socio-economic focus. The Factors are related to the welfare improvements to the population and the environment such as reduction of gas emissions (International Renewable Energy Agency, 2017).

The importance is, for example, projects within regions with risk insurance or incentives could have a higher probability of investment, like the Balmatt energy plant in Mol (Belgium), which had investments from the Knowledge Institute and the Flemish government. In the case of heat demand, it is necessary to be situated in an area with heat demand because geothermal energy is not suitable to be transported over long distances. Kabel ZERO (NRW.Energy4Climate, 2022) is a German project to supply part of the heat demand of the paper factory Kabel Premium Pulp & Paper GmbH with deep geothermal energy. Proposal wells are located in the company's area associated with this project.

Methodology

The socio-economical factors to be considered in the geothermal project assessment can be established on diverse sources, based on literature, surveys and interviewing people involved in geothermal projects and policy (Chocobar, 2020). Those are methodologies widely used in social sciences to collect information and gathering the elements.

The methodology of this project was based on literature and surveys. The main categories Social, Economy and Environment are took from the literature, mainly the *societal pyramid factor* (Moeck, et al., 2020), *benefits for the society* (International Renewable Energy Agency, 2017) and *Identification of socio-technical factors within the play-based geothermal exploration process: Application and* *considerations in Central America* (Chocobar, 2020). Those categories are the typical groups for the factors involve in socio economic studies.

Socio-economic factors have been discussed with the different project partners. Their expertise in different phases of geothermal projects, from exploration to energy supply, is essential to select the correct parameters. Factors were defined by answering three questions:

- What information is needed to know about energy demand? e.g. population distribution and energy demand.
- What information is needed in general within the project proposal? e.g. infrastructure and regulation.
- What other factors could be related to the success of a DGE project? e.g. acceptance and investment.

In the social category were chosen factors that describe the community, the distribution of the population in the state, the heat demand, the percentage of employment-related to renewable energies, and the acceptance of renewable energies among the society. The economic category englobes the factors like income per capita, infrastructure (the existence of heating districts), the existence of investments in renewable energies or the existing regulations that promote or encourage the use of renewable energies. Finally, the environment category considers the current situation of factors that could be beneficial, such as greenhouse gas emissions reduction. Also, factors could limit the development of projects such as protected areas. The crucial factors defined in the DGE ROLLOUT project are summarized in Table 1.

Table 1 Categories and factors defined for the socio-economic analysis of geothermal projects.

Social	*Country information*	Population distribution
		Heat demand
		Employment / Forecast
		Social level map
	Acceptance	Political parties map / Election maps
Economic	*Infrastructure*	District heating
	Finance	Income
		Level of debt of municipalities
		Investment
Environmental	*Land access*	Land ownership
		Assigned land usage
		Environmentally sensitive areas
	Greenhouse gas emissions	

Collecting data

The data collection has been carried out through different official databases, such as those of the state statistical institutes, the official database or directly on the website of the mentioned institutions. The sources of information are divided into four groups that will be exposed below, three correspond to the categories (social, economic and environmental), and the fourth is the geographic data. It is the basis for the graphical representation of the information.

Social data

In this category are enclosed the aspects related to the population, including basic information of the region as population distribution and income. Other factors like the impact of the geothermal energy projects, in this case, the employment generation as a side result. The data for the country information section comes from the State Statistics Office, which has an online database with different levels of detail according to the area.

Economic data

The interest of the municipalities in geothermal energy has been related to the percentage of investment in environmental protection. The debt of the municipalities was considered important for the investment in renewable energies. Data can be found in the NRW Statistical Office.

Environmental data

The State Office for Nature, Environment and Consumer Protection of North Rhine-Westphalia regulates the general environmental database. The protected areas information can be found in the Landscape Information Collection (Landschaftsinformationssammlung, LINFOS) NRW and the greenhouse gases emissions through the Online Emission Register Air NRW. The data about land use is dense and with high resolution, so the graphical representation is not suitable for the project.

Geographic data

North Rhine-Westphalia is composed of 5 regions, divided into 31 districts and 23 urban districts, in total 396 municipalities. The data, in general, is available in one of those levels of spatial resolution, except for the election maps, divided into election districts. An election district can group several administrative districts until it reaches a certain number of persons. In the last election, it was around 200,000 persons per election district.

Socio-Economic Index

The different quantifiable factors of the socio-economic potential for deep geothermal energy were combined into a joint index. The factors population density, social progress index, acceptance of renewable energies, availability of district heating networks, gross domestic product, public debt, environmentally sensitive areas and greenhouse gas emissions were considered. For the other components, a harmonized and spatially resolved data set is not available, which is why they are not included in the calculation of the index.

Detailed discussions of aggregation of various indicators is given e.g. in Lustig (2011), Decancq and Lugo (2013) and Annoni and Bolsi (2020). Following this, a simplistic approach is adopted in this report, where the composite index I is calculated via an unweighted generalized mean:

$$I = \left(\frac{1}{n}\sum_{i=1}^{n} x_i^{\beta}\right)^{\frac{1}{\beta}}$$

Where n is the total number of components, x_i is the i-th component of the socioeconomic potential, and the constant β describes the compensability between the individual components. A β of 1 corresponds to the arithmetic mean. In accordance with Annoni and Bolsi (2020), a β of 0.5 was used, being between the arithmetic and geometric means.

Before the factors can be combined, a normalization is necessary to scale the parameters between 0 and 100 (for some parameters, like the social progress indices or the acceptance, this is already the case). For this purpose, a min-max transformation was performed:

$$x_{norm} = \frac{100 * (x - x_{min})}{(x_{max} - x_{min})}$$

Respectively for the parameter public debt (high debt corresponds to low potential):

$$x_{norm} = 100 - \frac{100 * (x - x_{min})}{(x_{max} - x_{min})}$$

The minimum and maximum values are either based on the database or were defined individually. They are summarized in Table 2.

Table 2: Min/max values of some components for the normalization.

Factor	Unit	Minimum	Maximum
Population density	Ppl/km²	45	3050

Total heat demand of municipality	MWh/ha/yr	0	5000
Gross domestic product	€/cap/yr	24600	85700
Public debt per capita	€/cap	37	3587
Household carbon footprint	t(CO_2e)/cap	2	562

Results

The data collected in general are direct measurements of the selected factors, except for geothermal-related acceptance data and employment forecasts. These are indirect data which are detailed explained in the corresponding section. Sections are formed by the definition of the factor and its characteristics in NRW. Maps have been created in QGIS, an open-source software dedicated to geospatial analysis. Some data are available in various sources at the Europe Union, country or state level. Preference was given to state sources as they have the highest spatial resolution of information. The version or date of data collection is the latest available.

Social

This category encloses the population characteristics in North Rhine-Westphalia. Knowing the number of inhabitants or energy demand makes it possible to identify zones with potential for DGE projects due to the corresponding customer structures.

Population distribution

North Rhine-Westphalia is the most populated state in Germany, it has over 18 Million citizens. The four biggest cities are Cologne, Dusseldorf, Dortmund and Essen. A quarter of the population lives in ten cities: Cologne, Dusseldorf, Dortmund, Essen, Duisburg, Bochum, Wuppertal, Bielefeld, Bonn and Munster. Most of the population is concentrated in the Ruhr Area – one of the biggest metropolitan areas in Germany (Figure 2). The Ruhr Area covers several cities from Duisburg to Dortmund. The growth of this region is due to the mining industry that was developed in the last century. The map shows an area where the population is concentrated from Cologne to Dortmund, called the Rhine-Ruhr region, which takes its name from the rivers that run through this area.

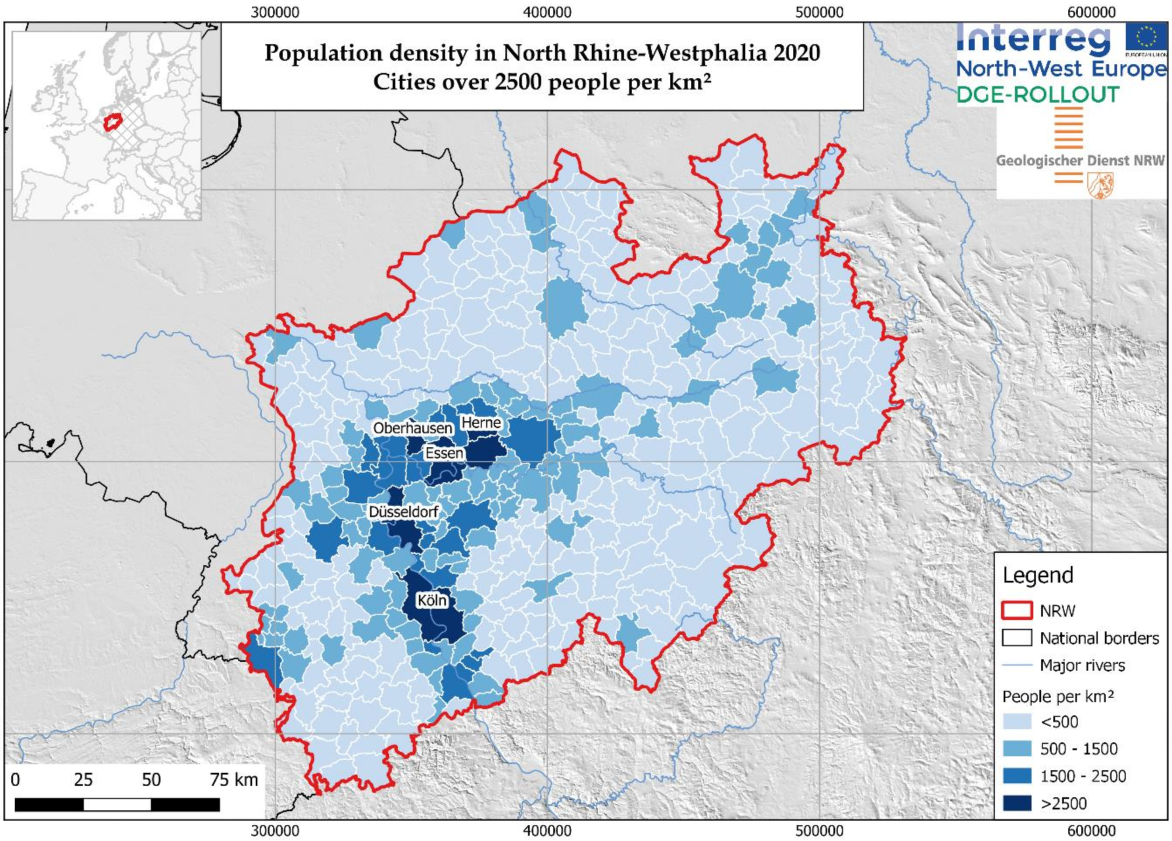

Figure 2 Population distribution in North Rhine-Westphalia

Heat demand

The heat demand in Northwest Europe was described and analyzed in the DGE-ROLLOUT report "WP T1 - 2.1 Map of the spatial distribution of the heat demand at the surface" (Strozyk et al. 2021). The map was generated from heat demand (HD) data measured or calculated by each project region in North-West Europe and has a spatial resolution of 100 x 100 m².

Figure 3 shows the map of residential and tertiary sector heat demand for North Rhine-Westphalia. The heat demand generally follows the population distribution. The highest demand is found in the metropolitan area of the Rhine-Ruhr.

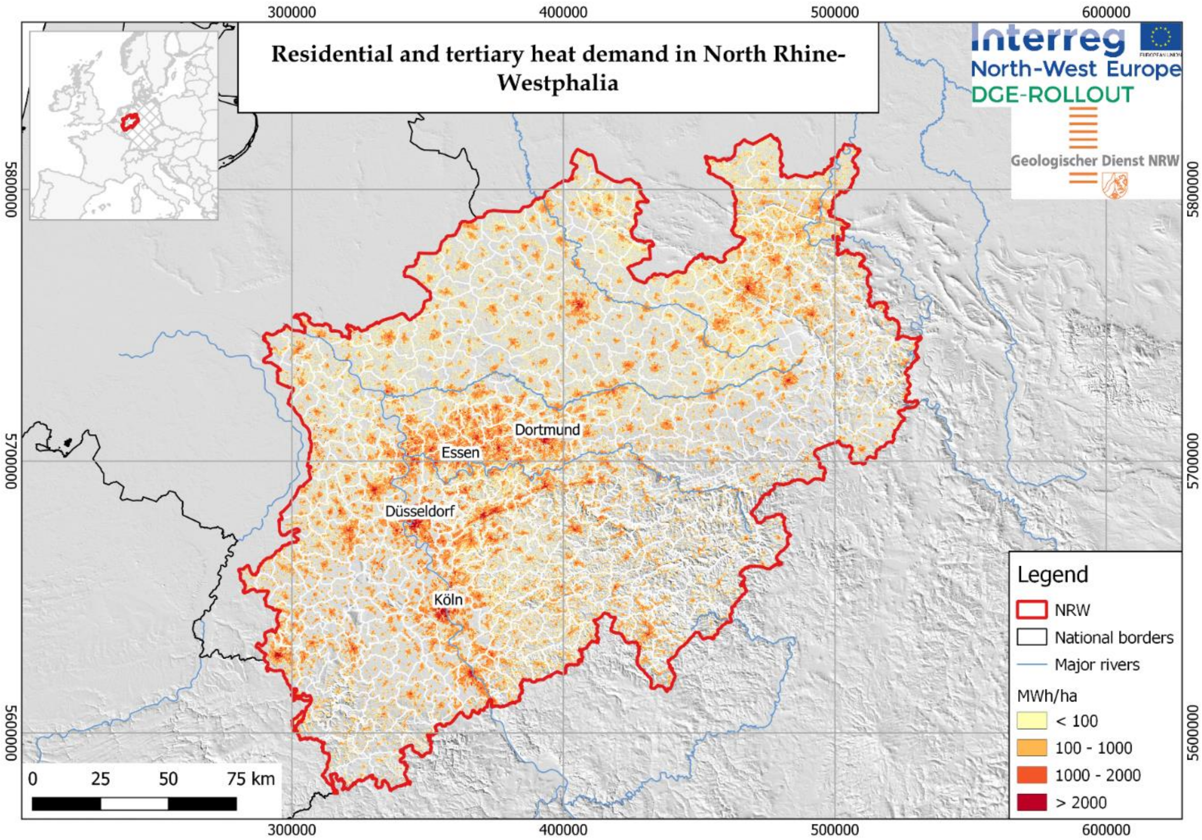

Figure 3 Map of residential and tertiary sector heat demand in NRW, the most populated cities in the Rhine-Ruhr metropolitan area are named.

Employment / Forecast

The number of jobs related to geothermal energy in Germany is 24,500. It represents 7.5% of the total number of renewable energy employees in the country (International Renewable Energy Agency, International Labour Organization, 2021).

Figure 5 Estimated jobs related to Geothermal energy in NRW shows the distribution at regional level. The job numbers have been estimated, based on the companies' investment in the air and environmental protection (see section investment) and the employees in the heating and cooling area. The Federal Employment Agency reports 1400 employees, which is underestimated with the geothermal energy area because the jobs in deep geothermal energy are not considered. Nevertheless, even without the jobs in deep geothermal energy it allows us to have an idea of the distribution of jobs related to geothermal energy.

The number of inhabitants in a zone is directly related to the energy demand in services and residential zones. Shallow geothermal has increased in recent years for heating and cooling by households. Figure 4 shows the final energy consumption by households from geothermal energy in Germany during the last two decades. The increase has been 263 GWh according to the report time series for the development of renewable energy sources in Germany (Federal Ministry for Economic Affairs and Energy, 2021).

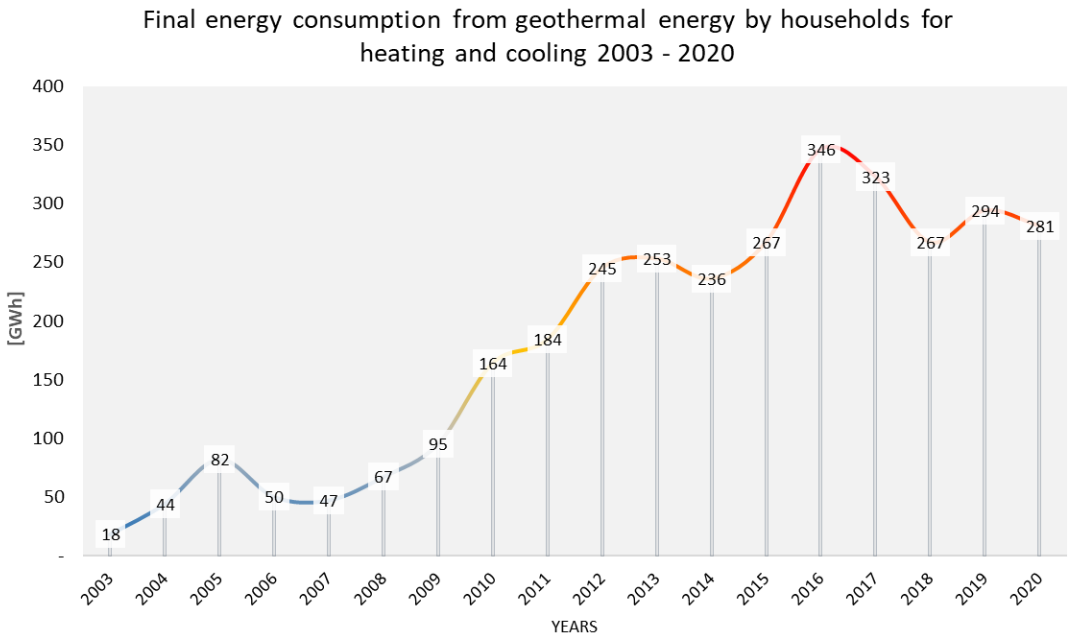

Figure 4 Time series of the final energy consumption from geothermal energy.

The international renewables energy agency proposes a forecast with scenarios for employment in the transition to clean energy. For Europe in the case of Geothermal energy, the increase is 10 % for the "planned energy scenario" in the year 2030 and remains the same value until the year 2050, in case of applying the "transforming energy scenario" the employment increases 30% for the year 2030 and 50 for the year 2050 (International Renewable Energy Agency, 2020).

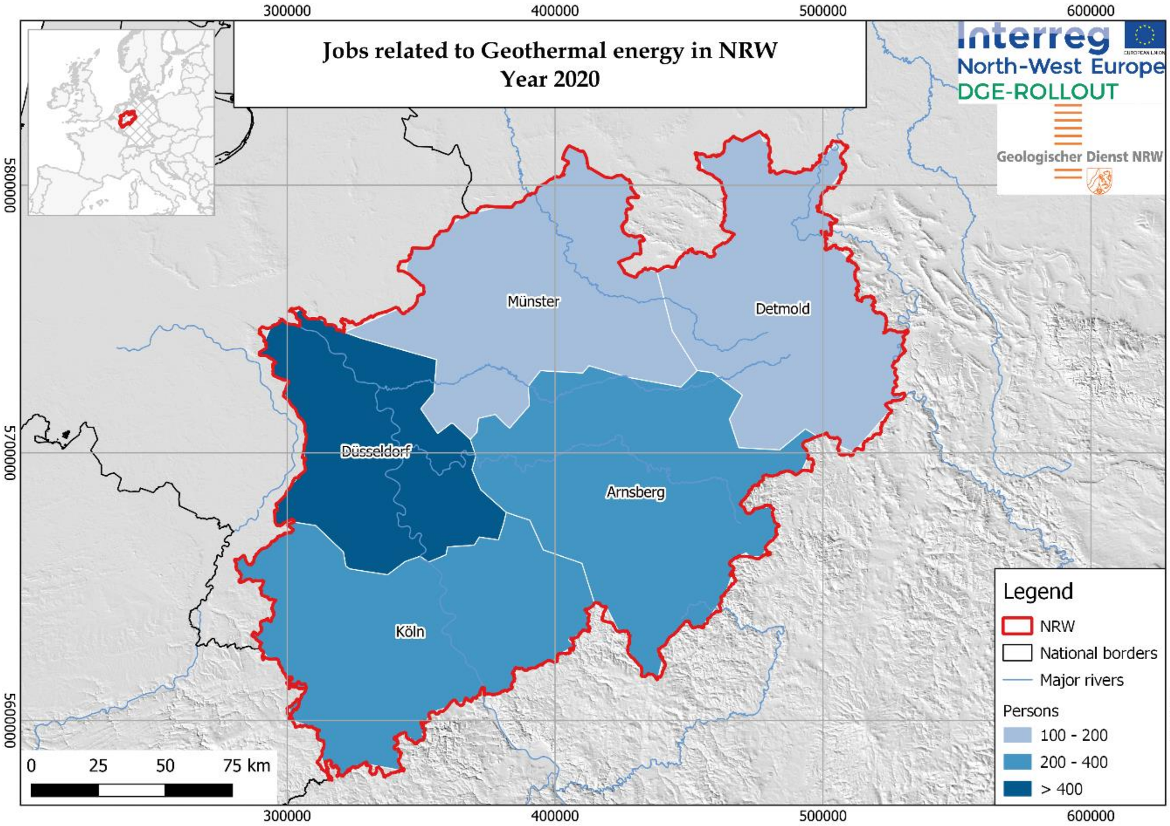

Figure 5 Estimated jobs related to Geothermal energy in NRW

Social level map

The social level has been described through different indexes, for example, the Human Development Index or the European Social Progress Index. The first encloses three dimensions, each with one indicator: life, education and income to evaluate a decent standard of living. The second has three dimensions, each with four indicators: Basic human needs, Foundations of well-being and opportunity, excluding the economic indicators. Every indicator group defines components, 55 in total.

The European Social Progress Index (EU-SPI) was selected to create the map because of the factor "environmental quality". It has eight components air, noise and general pollution, plus nature protection areas.

Figure 6 shows the EU-SPI in 2020 for the five regions, all over 67, the average of the EU. The various factors between regions have a maximum variation of 3 points, except for personal safety, environmental quality and advanced education. The first two are led by the district of Detmold with up to 8 units. Cologne district has the highest factor for advanced education with five units above Düsseldorf, the lowest in these factors.

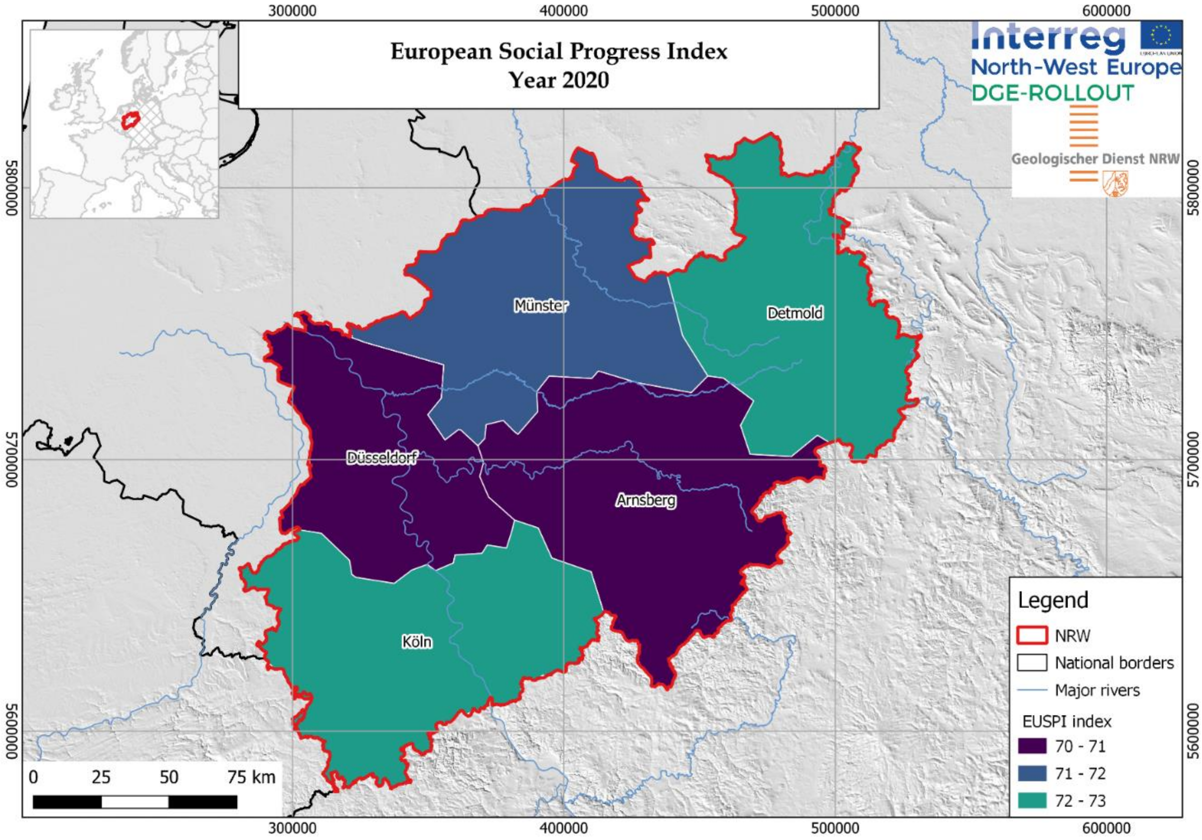

Figure 6 European Social Index in NRW

Political parties map / Election maps

In Germany, renewable energies are part of the agenda for climate protection, which states that it is necessary to increase the use to achieve the climate goals and, the expansion of the energies is supported by the population. The Renewable Energies Agency of Germany commissioned a survey to research how significant is the growth of renewable energies for the population in 2021. 83 % of the 1051 interviewed persons consider it is important or very important.

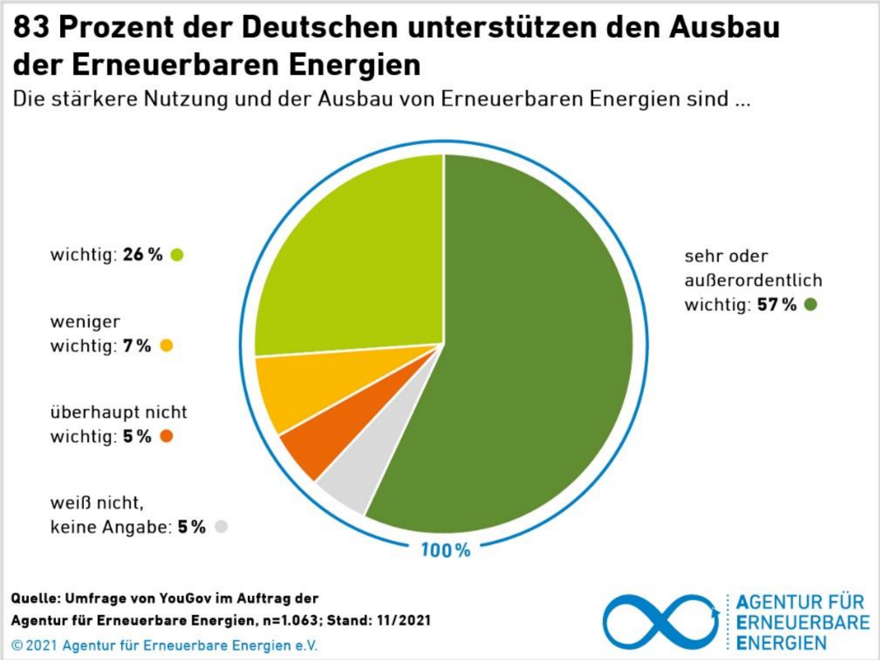

Figure 7 Acceptance Survey 2021 in Germany. (Agentur für Erneuerbare Energien e.V., 2021)

Because of the importance of energy transition and the population opinion, renewable energies are considered in the campaign commitments. The renewable Energy Federation (Bundesverband Erneuerbasere Energie e.V., BEE) carried out a survey on energy policy to the parties which are part of the Parliament: CDU/CSU, BÜNDNIS 90/DIE GRÜNEN, SPD, FDP, DIE LINKE.

One of the questions is directly related to geothermal energy, about renewable heat expansion. Parties' commitments, in general, refer to continuing with the promotion of the heating districts, support and federal funding's programs. On the other hand, the party AfD relies the energy plan on coal and nuclear energy. Based on that statement, the correlation of the population vote with renewable energies acceptance is proposed.

76,4 % of the possible voters participated in the election of 2021, which means 9,960,984 persons. 88% of those almost ten million persons voted for one of the six parties with active proposals related to heating districts. As result, the assumption that 8.7 Million people agrees with the expansion of renewable heat sources.

For example, Figure 8 shows the election district Krefeld II-Wesel II. It combines part of the administrative districts Krefeld and Wesel; the total number of eligible voters in this district are 175,852 persons. On the left side are the per cent of votes from each of the six established parties, in total 94%. The rest, 6%, corresponds to other parties or invalid votes. The total votes of the five established parties with an active green agenda are 84%. The estimation was done for all the cities, and the results are shown in the following maps.

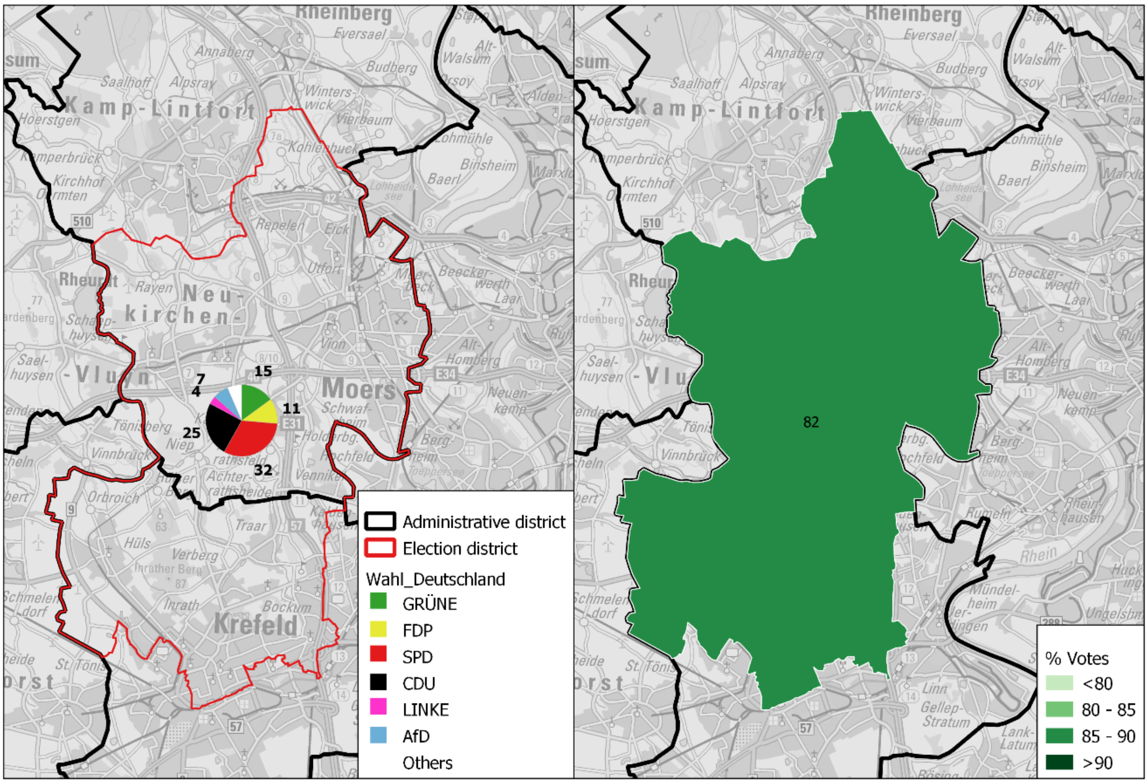

Figure 8 Example of correlation between parties and acceptance.

Figure 9 shows the result of the established parties in NRW. Boundary colour corresponds to the winning party. The majority of the votes are concentrated in the established parties. The three winner parties in NRW are SPD (red), CDU (black) and Grüne (green). The current government is a coalition of the Grüne, FDP (yellow) and SPD parties.

The distribution of those voters is shown in Figure 10. It shows all the districts are above 78 % votes related to a party with a green agenda. This percentage doesn't consider minor parties that could agree with the energy transition, but so far have not been considered in this study. As a result, it could be underestimated.

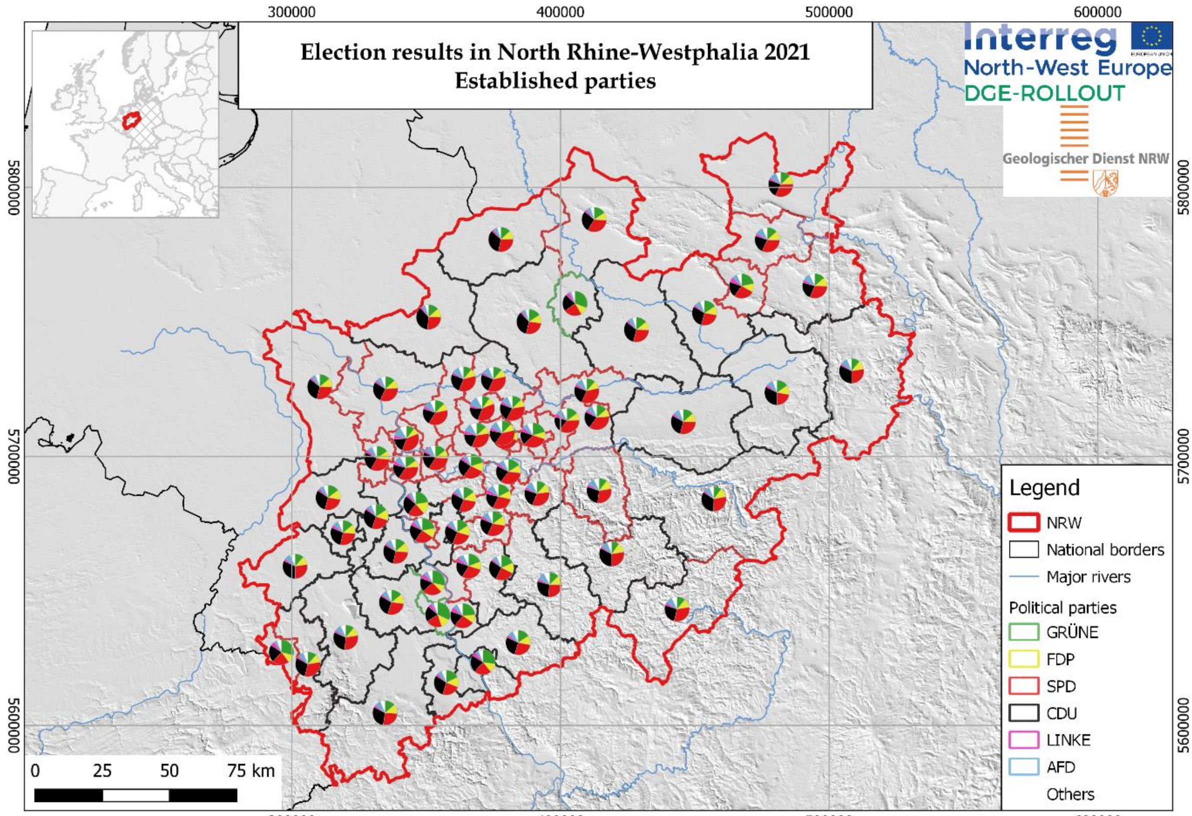

Figure 9 Result of the established parties in the last election in NRW.

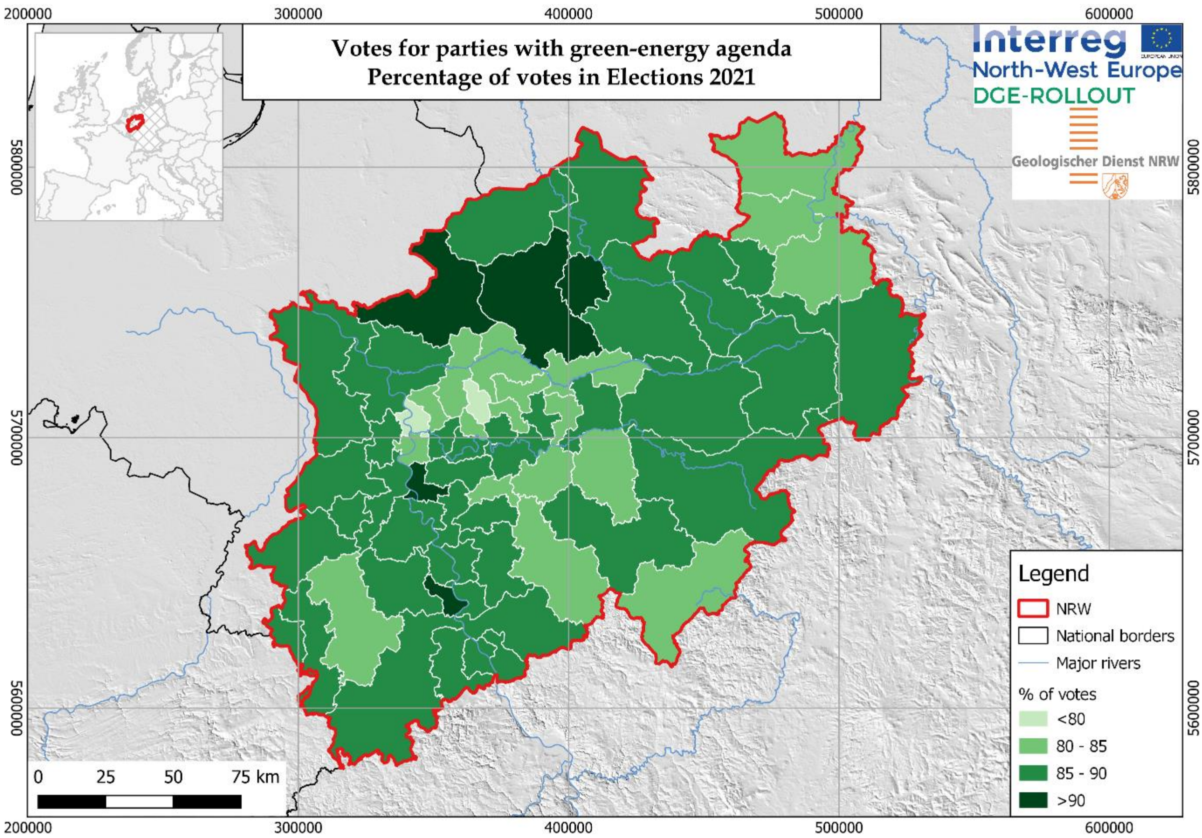

Figure 10 Total votes for the established parties with energy policy in agreement

Economic

Income

The Gross Domestic Product (GDP) at the market is an indicator of the national economic situation. This number is the total value of all goods and services produced in a region minus the ones consumed in their intermediate production (European Commission, 2022).

Figure 11shows the distribution in the state. The named cities had a GDP larger than € 50,000 per inhabitant in 2018. In the case of NRW, the highest numbers are located in the districts with the top ten cities most populated with the exception of Leverkusen (see population section).

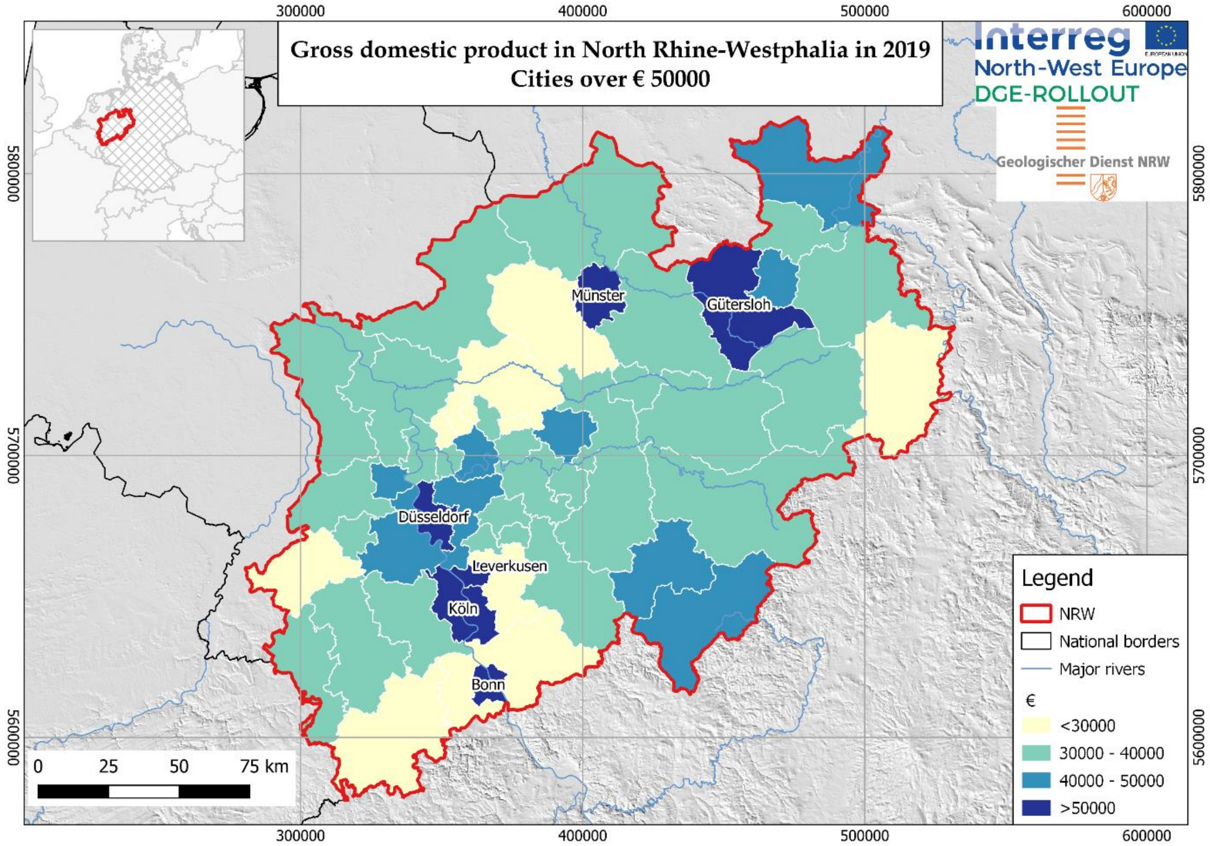

Figure 11 GDP in NRW with data updated in 2018

Level of debt of municipalities

The possible funding at the municipality level is highly dependent on the public debt. In Figure 12, the public debt of the municipalities of NRW per capita is shown. The cities with the largest public debt are located in the Ruhr area and the south of the state close to big cities like Cologne and Bonn.

The initial phases of geothermal projects are funded by the government (section Financial Risk Management). Public debt is acquired to pay for municipalities' expenses and new investments, therefore can not be directly correlated with the opportunity to promote new projects or vice versa.

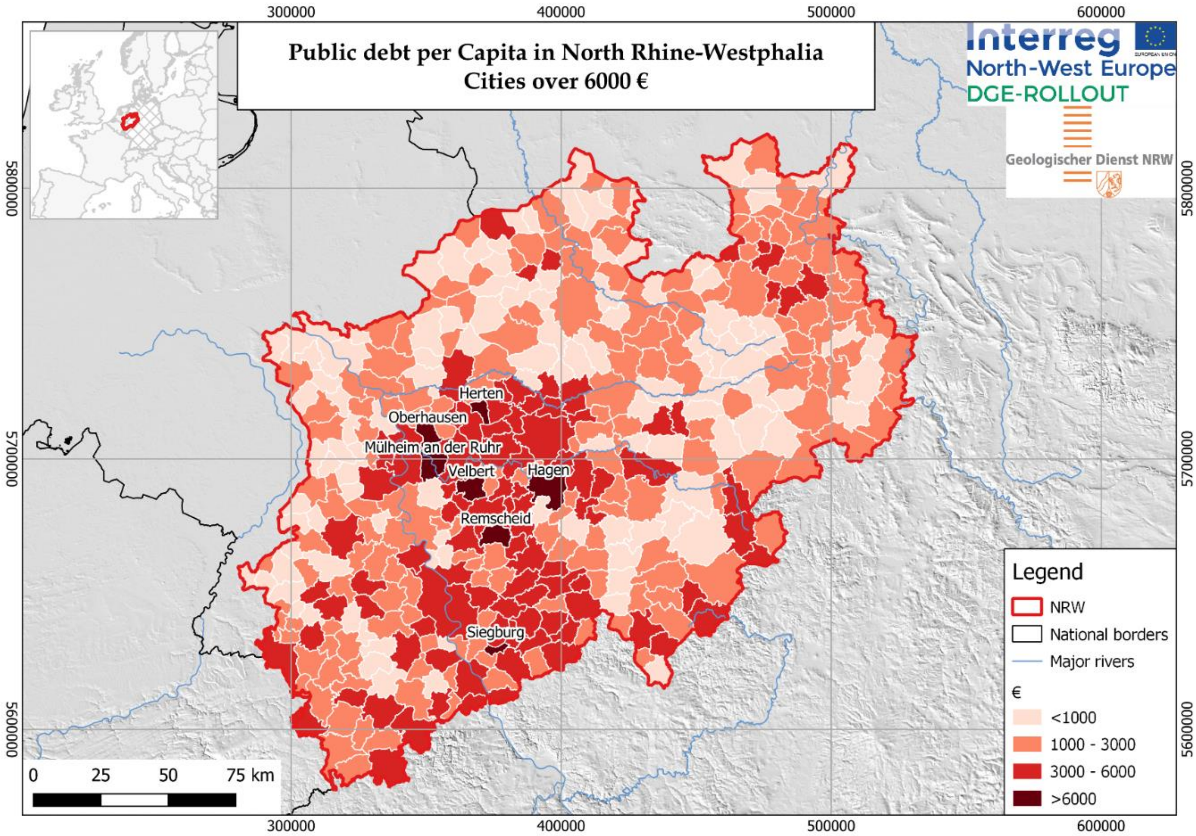

Figure 12 Public debt in NRW

Private Investment

Private companies allocate a percentage of their investments to environmental protection. These are classified into Waste management, Wastewater management, water protection, Noise and vibration protection, Air pollution control, Species and landscape protection, Soil, groundwater and surface water protection and remediation, Soil remediation and climate protection. Air pollution control and climate protection investments are directly related to the benefits of geothermal energy.

Figure 13 shows the percentages of investment for environmental protection in relation to the total investments of the companies for the year 2017 in NRW. The cities with the highest investment are Bottrop and Essen, belonging to the Ruhr region known for its past in the mining industry.

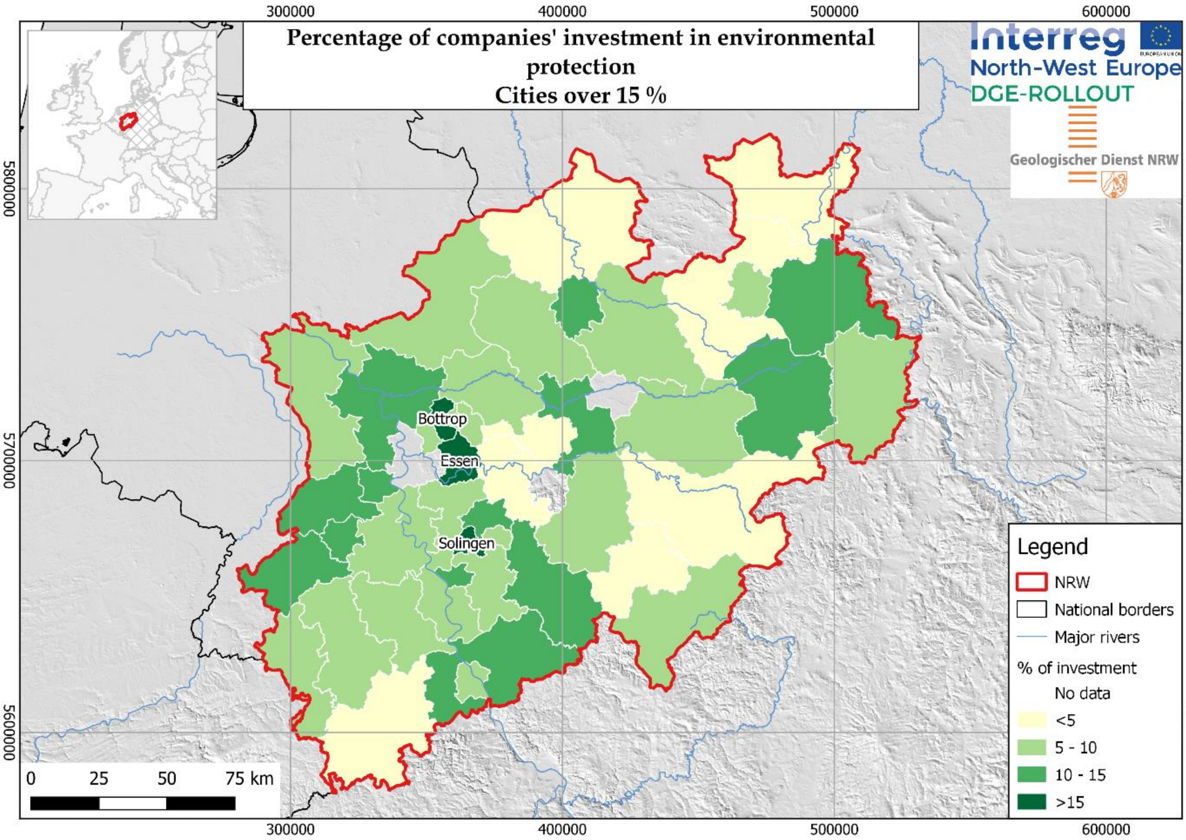

Figure 13 Percent of the private investment in the environmental protection.

District heating

The importance of the District Heatings (DH) lies in the potential of the heat that these can generate, the capacity of heat distribution with the existence infrastructure with different level of costumers. The costumers can be small- local companies, public services and end users. In NRW in the year 2050, the DH could reach a quarter of the heat supply, according to the Minister of Economic Affairs and Energy. Figure 14 shows the cities with existing district heating networks, the cities with the highest heat demand are named.

The GeoDH project (European Geothermal Energy Council, 2014) mentions among the strengths of the heating districts the adaptation of existing infrastructure with renewable sources to replace fossil fuels. The current renewable energy sources used are the biogenic fraction of waste, biofuels (solid, liquid and gaseous), biomethane, solar and geothermal energies. The increase of the solar and geothermal has been from 61 GWh in 2013 to 480 GWh in 2020 in Germany, a trend expected to continue.

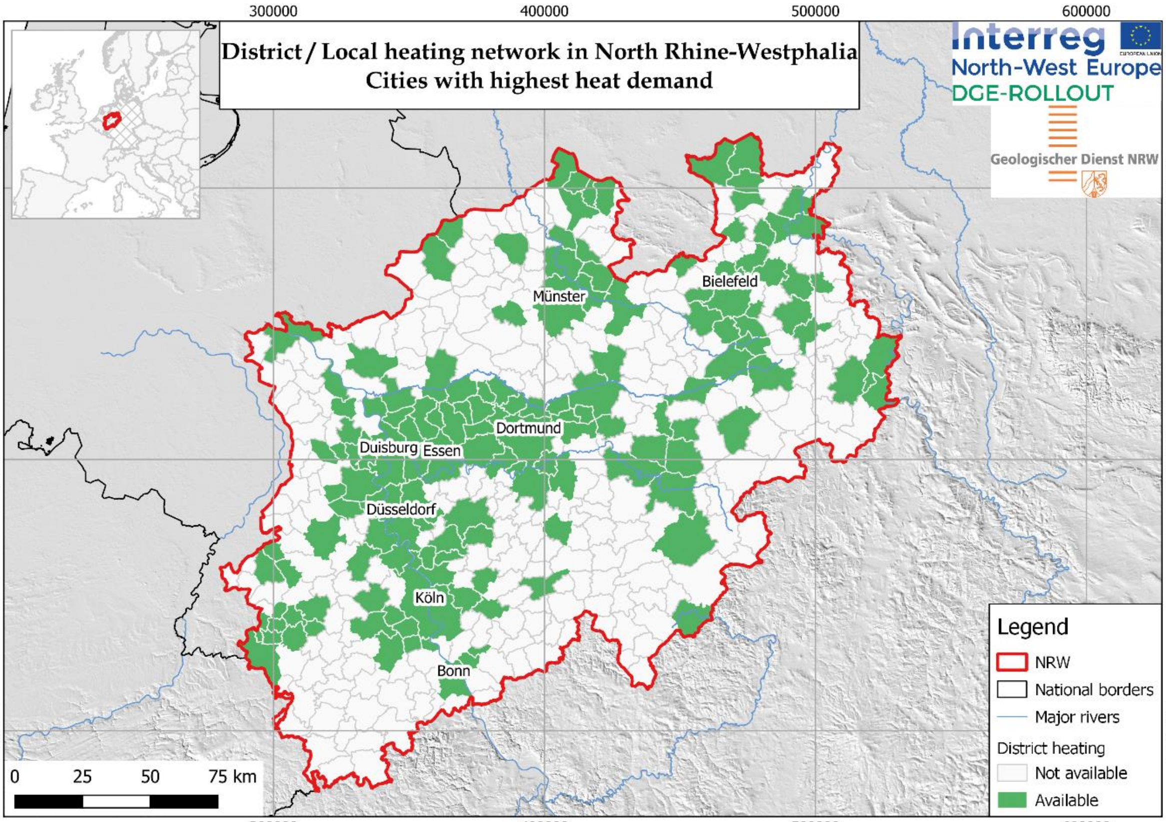

Figure 14 Cities with existence of district heating network in NRW.

Environmental

Land access

The environmental data for NRW is provided by LANUV. Several areas have been defined, protection of nature (BSN), protection of the landscape and landscape-oriented recreation (BSLE), open space in general and agriculture areas (AFAB), as well as areas for commercial and industrial uses (GIB). The institute aims to conserve the nature in NRW through the landscape planning and development of protected area designations. Figure 15 shows the distribution of Nature Conservation Areas in NRW. These have been chosen for their easy recognition among the population. The environmental assessment in a geothermal project will offer a detailed evaluation of the areas around the project.

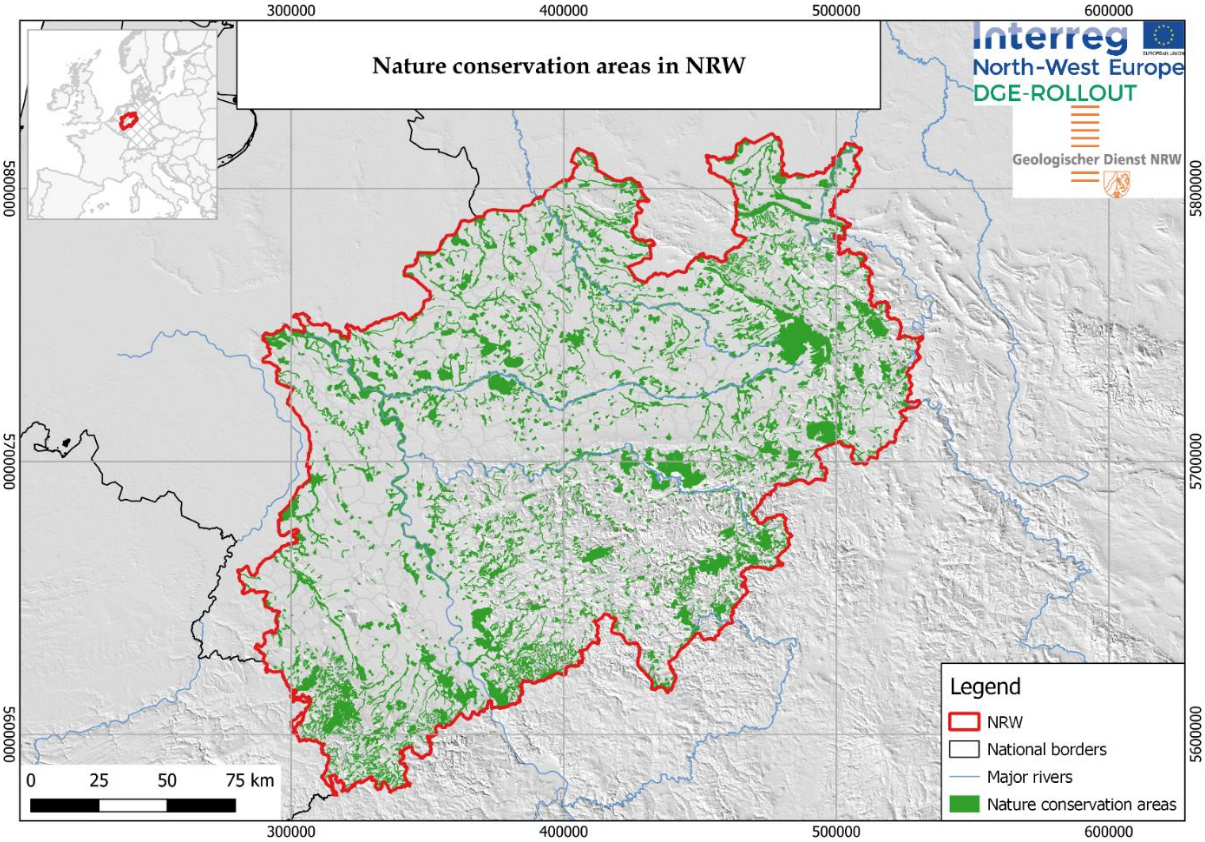

Figure 15 Nature and Landscape conservation areas in NRW.

Greenhouse gas emissions

The three major Greenhouse Gases are Carbon dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O), reaching 98% of the gases related to the Greenhouse effect. The other 2 per cent correspond to Fluorinated gases. The sources of the C02 emissions are the heat and electricity production by fossil fuels combustion, among others. The production of greenhouses gases due to energy production can reach one-quarter of the human-driven emissions. (Natural Resources Defense Council, 2022) Germany has the national target to reduce the Greenhouse gas emission in 65 % by 2030 and reach the neutrality to 2050.

Figure 16 shows the emissions per capita in the municipalities in the year 2016. Cities with the largest emissions rate are Grevenbroich, Duisburg, Bergheim, Eschweiler and Cologne. Grevenbroich is at the top even it is not at the top of population or heat demand. The two coal power plants located in the area are the reason for this large amount of CO_2 emissions. The same reason applies for Eschweiler and Bergheim, each with a coal power plant. This region is characterized for huge lignite mining. In the case of Duisburg, there are some plants of fossil fuels and the well-known steel industry. The coal-powerplant Weisweiler is part of the DGE- ROLLOUT project to support the phase-out of coal and transition to clean energies. An example of socio-economic analysis of this and the Dusseldorf municipality is in the discussion section of this report.

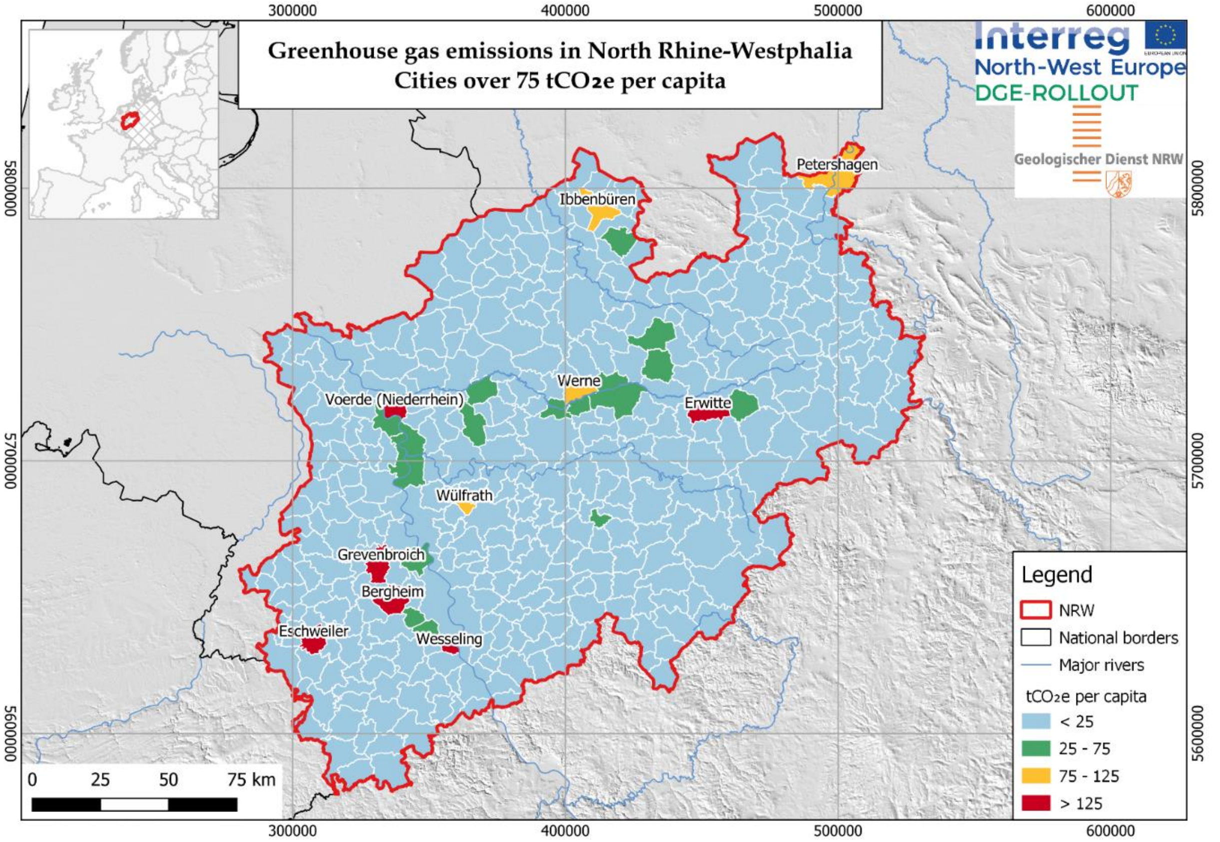

Figure 16 Greenhouse emissions in NRW, considering CO2, N2O, and CH4.

Socio-Economic Potential

Based on the data described above, a composite index for the socio-economic potential for deep geothermal energy in the NRW was calculated (Figure 17). The absolute values are strongly dependent on the calculation approach, which is why the map is mainly suitable for a qualitative interpretation of the potential. In general, a clear urban-rural trend is observed in the Rhine-Ruhr area, which is due to the concentration of population and industry in the major cities.

Some other cities with potential are visible at the border with Belgium and in the East part of the state. Those have the opportunity to improve the environmental quality or use of the existing infrastructure.

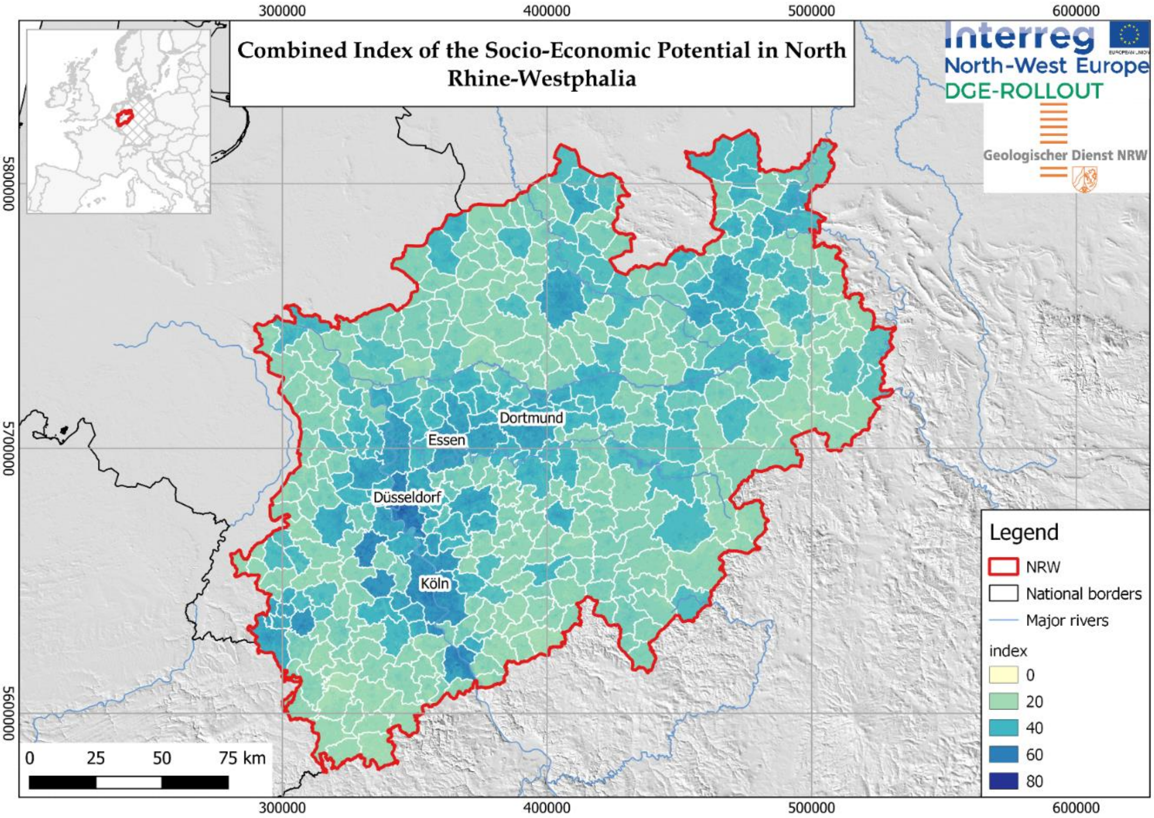

Figure 17 Composite index for the socio-economic potential for deep geothermal energy in the NRW

Discussion

The results are evaluated and compared with the socio-technical pyramid. In the social category, population and heat demand are directly related. Gross domestic product (income factor) and geothermal-related jobs (employment factor) show the same trend in the area around the river Rhine. These are the large cities, Cologne, Düsseldorf and Bonn. The last two factors are the social level and the acceptance of geothermal projects, linked to the European Union Social Progress Index (EU-SPI) and the latest election votes, respectively. In the case of North Rhine-Westphalia, both factors can be neglected due to constant values for the area, the estimated acceptance in the state is above 75%, and the EU-SPI exceeds 70%. In the economic category, the infrastructure is the decisive factor for the use and distribution of geothermal energy, the area for this factor is similar to the social group. The factors investment and debt of municipalities show a different tendency. In this case, the zone with the highest values is around the Ruhr river. In the case of NRW, the factors of the regulation subsection, legal framework and financial risk are uniform in the state, so it is no distinction between cities for those topics. Lastly, in the environment category, protected areas are the critical factor due to the limitation to developing projects. But those are the majority in the south and north of the state. It is considered not an obstacle for the projects in the areas given for the two categories abovementioned. The gas emissions factor highlighted a new opportunity area. It is located around the cities of Grevenbroich, Bergheim and Eschweiler.

The analysis of two municipalities with future DGE projects is carried out. It is based on the resulting critical factors. The first is Dusseldorf, a city located at the Rhine river. The second-largest populated city in NRW. Figure 18 shows the social category, at the top the residential and tertiary sector heat demand. The municipality has one of the highest heats demands in the state, as expected due to the population. Then the economy category, with public debt and infrastructure factors. The amount of public debt per capita is in the lowest category of the state, in the city and the surroundings exist district heating systems. The environmental factors are greenhouse gas emissions and the protected natural areas. The emissions are above the average value in the state, despite is not as high as the case of the industrial cities. The protected natural areas are at the border of the municipality, which means the possibility to develop geothermal projects. Finally, the combined index of the socio-economic potential with some of the highest values of the state, 74. The average of the municipality is 58.

The city has experience with geothermal energy, like in the case of the residential building Monastere supplying heat through a shallow geothermal system and heat pumps. The benefit is calculated in saving 100 T CO2 per year and 40 % heating supply cost, compared with gas as the source (EnergieAgentur.NRW GmbH, 2014). Nowadays, the state carries out a feasibility study to include deep geothermal energy in the existing district heating network (Ministerium für Wirtschaft, Innovation, Digitalisierung und Energie des Landes Nordrhein-Westfalen, 2021).

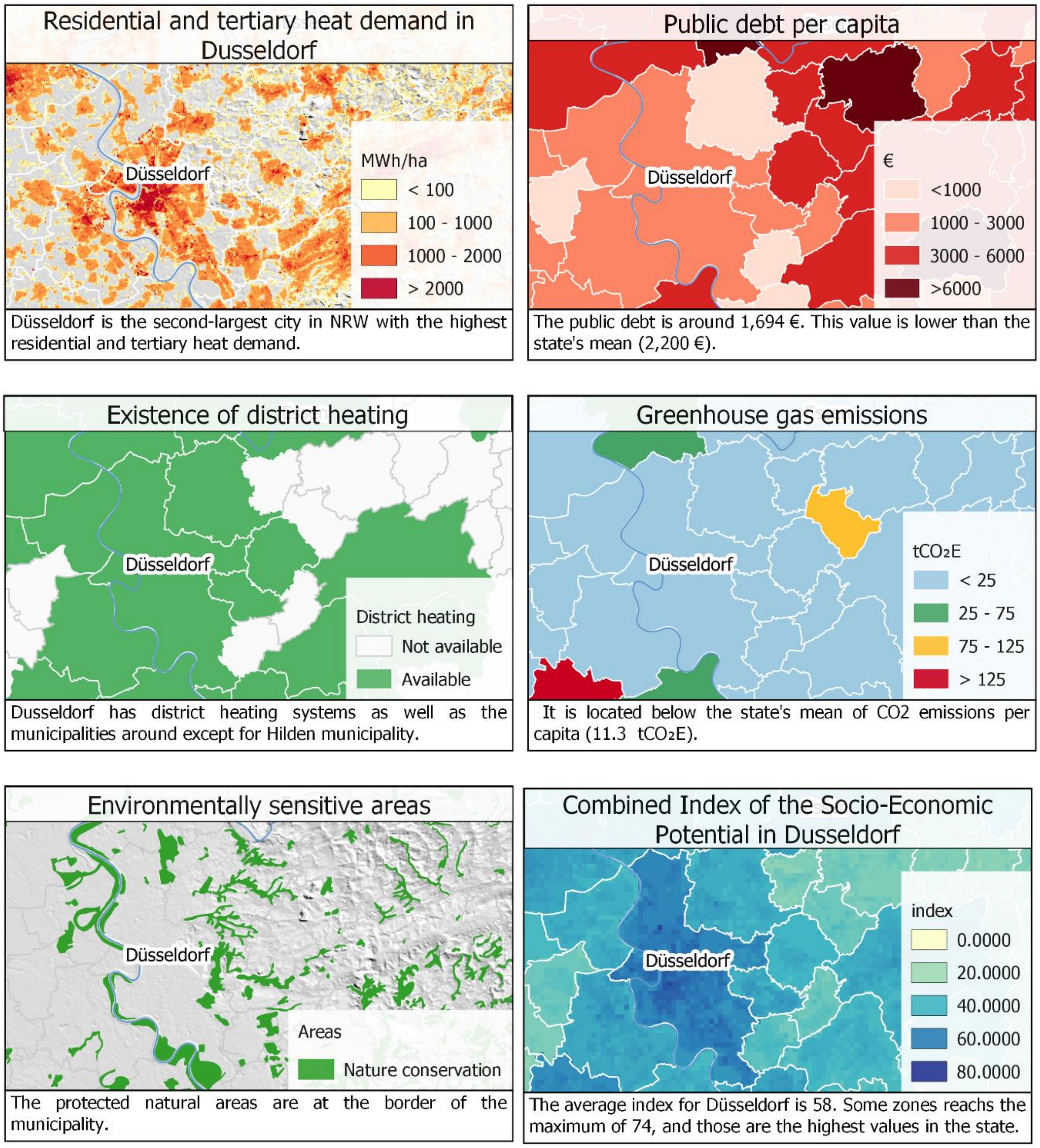

Figure 18 Analysis of socio-economic factors in Dusseldorf. Top: social category, middle: economic category and bottom: environmental category.

The second example is Eschweiler (Figure 19), which is situated on the border of Germany with Belgium and the Netherlands. The residential and tertiary sector heat demand are located in the lowest category (top). About the economic factors, the public debt per capita is higher than the average value, which could be a barrier to investment or promotion by the local government. Eschweiler has district heating systems, essential for the distribution of energy. Lastly, the environmental factors, the greenhouse gas emissions are more than twenty times the average value in the cities of NRW. The reason is the coal-powerplant Weisweiler, as abovementioned, is part of the DGE- ROLLOUT project to support the phase-out of coal and transition to clean energies. The benefits expected are an increase in the temporal employment related to geothermal energy. The year 2030 is the latest to close all the coal mining. The conversion of the power plant allows energy independence from fossil fuels importation, and the greenhouse gas emission will decrease. The environmentally sensitive areas are located in the south area of Eschweiler at the bottom of the figure with the combined index of the socio-economic potential with some of the highest values of the state, 63 and average of 51.

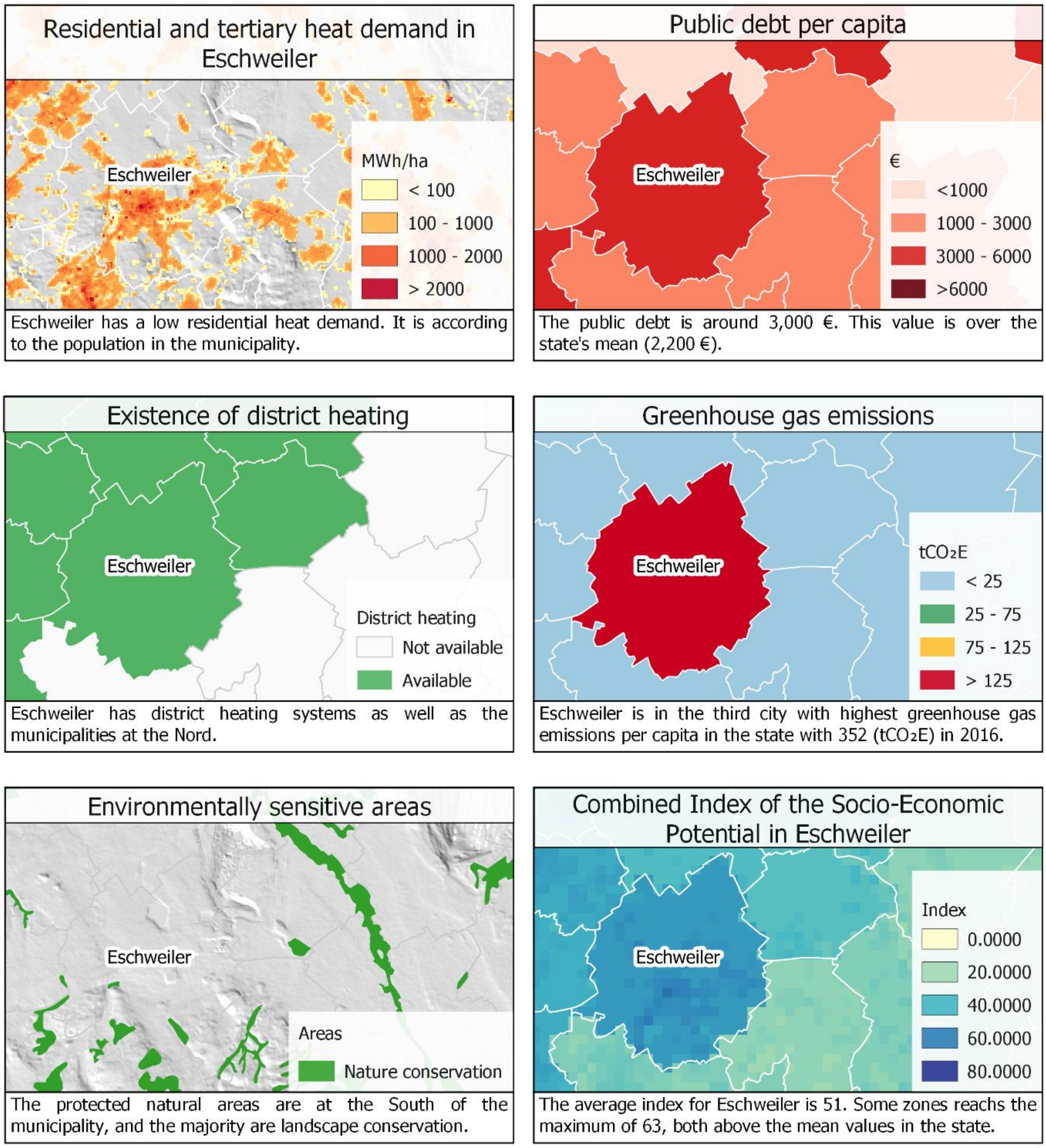

Figure 19 Analysis of socio-economic factors in Eschweiler. Top: social category, middle: economic category and bottom: environmental category.

Conclusion

This analysis reaffirms that the heat demand, infrastructure and environmentally sensitive areas are critical for developing geothermal projects from the socio-economic point of view. As is proposed in the societal-technical focus pyramid (Moeck, et al., 2020). Although the analysis must consider the three levels of the decision pyramid, the potential zones for DGE projects are separated into two groups in agreement with the benefits of the society. First, the areas with infrastructure and heat demand, as the example of Dusseldorf, where heating districts exist, and the residential heat demand is high. Second, areas with the environmental factor, as the example of Eschweiler. It is a critical zone to change the source of energy to reach the climate change goal.

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Appendix A

Factor	Database
Population distribution	Landesdatenbank Nordrhein-Westfalen: Tabelle abrufen (nrw.de)
Heat demand	Energieatlas NRW
Income	Statistics | Eurostat (europa.eu)
Employment / Forecast	Branchen im Fokus - Statistik der Bundesagentur für Arbeit (arbeitsagentur.de)
Social level map	EU Social Progress Index - 2020 | Data | European Structural and Investment Funds (europa.eu)
Political parties map / Election maps	Wählerstimmen in Ländern und Wahlkreisen | Bundestagswahl 2021 | Zahlen und Fakten | bpb.de
District heating	Energieatlas NRW
Official national geothermal development plan	Landesdatenbank Nordrhein-Westfalen: Tabelle abrufen (nrw.de)
Investment	Landesdatenbank Nordrhein-Westfalen: Tabelle abrufen (nrw.de)
Level of debt of municipalities	Landesdatenbank Nordrhein-Westfalen: Landesdatenbank NRW
Legal framework	legal-framework-with-contributors_dge-rollout.pdf (nweurope.eu)
Financial risk management (funding/investment)	Financial Risk Management Report (nweurope.eu)
Environmentally sensitive areas	Landscape information collection (LINFOS) NRW

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