POLITECNICO DI TORINO
College of Architecture
Master of Science in Architecture for Sustainable Design

MSc Degree Thesis

Spinelli Park, a climate-adaptive open space
Adhering to northeast green corridor revitalisation
A beautiful form of renewable energy
Mannheim, Baden-Württemberg, Germany

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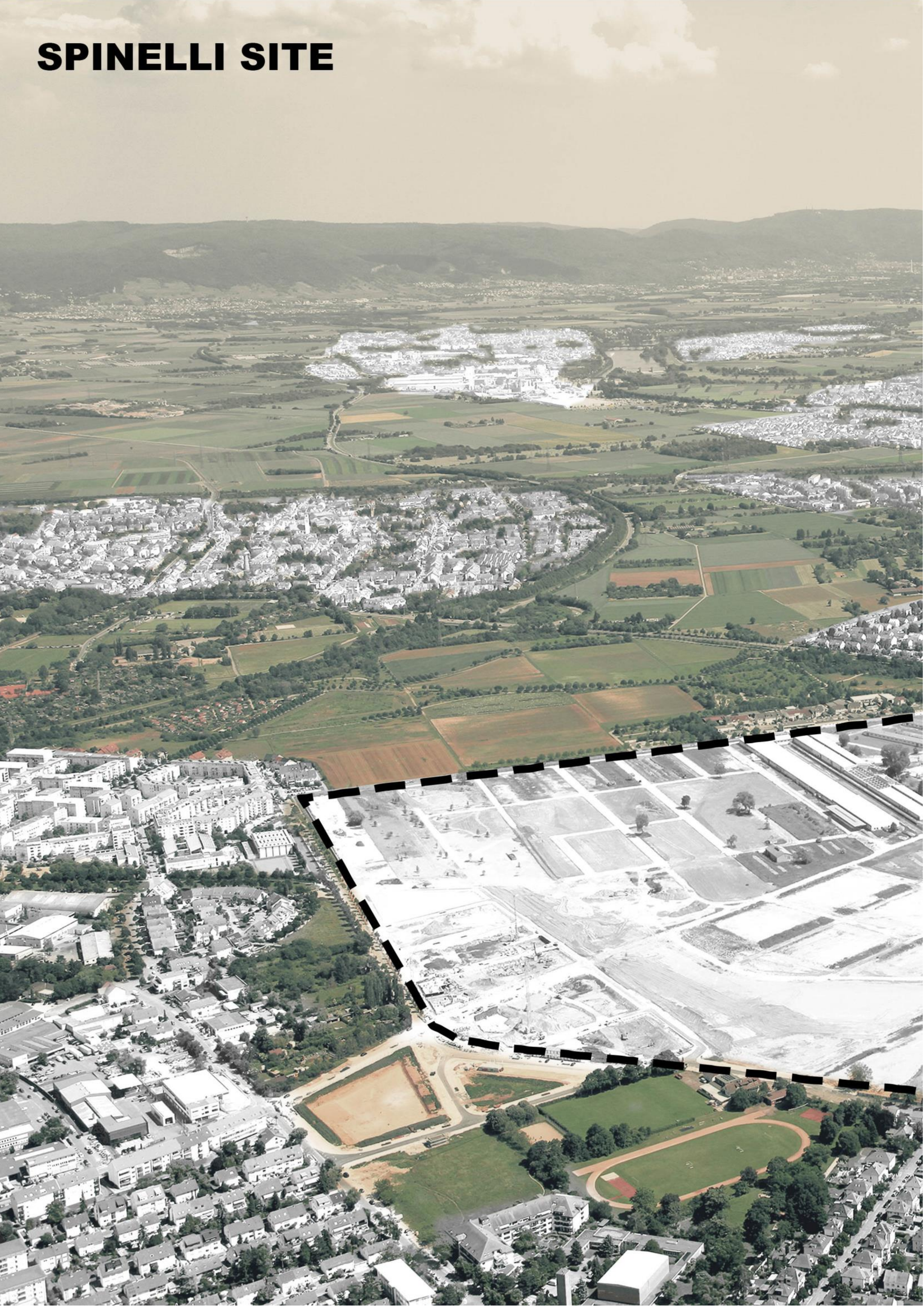
SPINELLI SITE

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Abstract

According to scientific research, the cities of the 2030s will generate a significant amount of their energy through solar and wind resources located within or near city centres, because bringing power production closer to where power is used will save capital, conserve natural landscapes, reduce the need for transmission lines, and deliver more resilient, reliable, and equitable electricity.

Over the next few decades, in addition to the transition to a 100% renewable energy world, it will be necessary that design and specifically architecture penetrate the aesthetics of sustainable kernels within our urban places and landscapes.

As renewables are one of the core pillars of climate protection strategies, the following equation thoroughly represents the whole thesis idea.
Climate protection + Climate adaptation = Thesis Project

In the city of Mannheim (Baden-Württemberg region, Germany) , "Mannheim Verbindet = Mannheim connects" (Bernhard Schwarz) is a *motto* of the local authorities' urban planning policies, which represents the procedure to close existing urban empty spaces (the large barrack sites) in the green corridors and by converting them to green open space, Mannheim's green belt can be extended throughout the entire city. The long-term effect is to improve the microclimate of the surrounding area and generate fresh/cold air.

The Spinelli former military site conversion project is one of the four largest conversion areas, at around 80 hectares. According to the available masterplan (Rahmenplan Spinelli, 2018), 70% of the site will be green open space, and the rest 30% is already under construction as an urban development process.

The focus is on the Spinelli open space development, as part of Mannheim's target, in partnership with Bundesgartenschau 23 (Federal Horticultural Show), to revitalise the northeast green corridor.

The thesis combines elements of research and design, conducting research to gather and analyse existing strategies, opportunities, and regulations for transitioning to renewable energy and meeting climate adaptation goals at the national and local levels.

The design proposal, while conforming to Germany’s energy transition policy and local climate adaptation plans, also endeavours to promote the appeal of renewable energy and present a positive image of life in a post-carbon world. This is achieved by incorporating features such as urban farming, recreation, public engagement, and interactivity into the open space, which will be powered by renewable energy technologies to generate clean energy for the community.

Keywords: Climate change, climate adaptation, energy transition, renewable energy, green corridor, conversion, open space

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INTRODUCTION

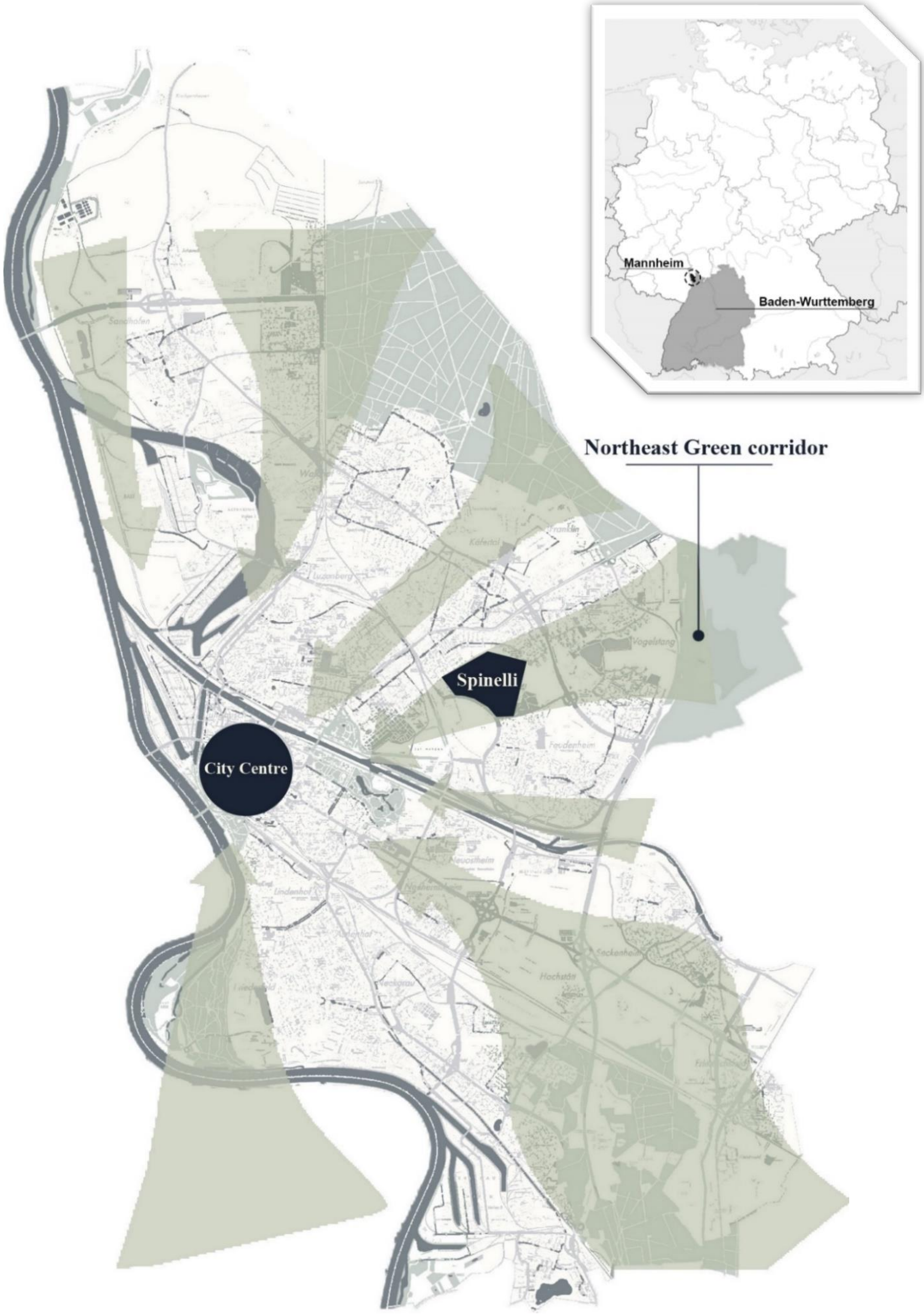
1.1. Spinelli site main overview

The city of Mannheim has set its sights on transforming 500 hectares of land used by the military in response to the evolving demands of the city. The city is facing a shortage of urban infrastructure and environmental resources, which has prompted this transformation. This conversion project will address these challenges by creating additional living spaces and open, green spaces to improve the overall quality of life in the city.

The Spinelli site, which covers approximately 80 hectares, is one of the four key areas undergoing conversion as part of the city's efforts to address the changing demands. The conversion project will not only provide much-needed living spaces for urban development, but it will also place a strong emphasis on creating open spaces. This will help to improve the environment and enhance the quality of life in the city. By focusing on both living spaces and open spaces, the city of Mannheim is taking a comprehensive approach to addressing its structural and environmental challenges.

The transformation of the Spinelli barracks presents a rare opportunity to create green and fresh air corridors (Figure 1) in the city through demolition and unsealing. This will allow the city to tackle its pressing need for climate-ecological adaptation, in light of changing weather patterns and weather events. This conversion project will be a systematic and comprehensive effort to address the city's environmental challenges.
By creating green and fresh air corridors, the city of Mannheim will be taking a significant step towards a more sustainable and liveable future. (Rahmenplan Spinelli, 2018).

Figure 1: Spinelli site location and the Northeast green corridor in Mannheim.



Source: Prepared by Author based on data from https://www.gis-mannheim.de

Source: Kay Sommer, Luftbild Spinelli

Spinelli site
before dismantling barracks
buildings

Site aerial views

Source: Kay Sommer, Luftbild Spinelli

Source: Kay Sommer, Luftbild Spinelli

Spinelli site
After dismantling barracks
buildings and start of the
construction of urban
development phase

1.2. Aims and objectives

The objective of this thesis is to create a sustainable and climate-responsive open space that incorporates renewable energy technologies. The ultimate goal is to provide the City of Mannheim with a source of clean energy. By taking into consideration the local climate and weather patterns, the design will aim to optimize energy efficiency and ensure that the space is comfortable and functional for users. Furthermore, by utilizing renewable energy technologies, the space will serve as a model for other cities in their pursuit of clean, sustainable energy solutions. Ultimately, my thesis aims to not only contribute to the design of a functional and visually appealing public space, but also to promote the wider use of clean energy technologies for the benefit of the environment and future generations.

1.3. Problem statement; Research questions

As the world moves towards a future powered entirely by renewable energy, it's crucial that design and architecture reflect this shift by incorporating sustainable elements into our urban environments. To achieve this goal, several questions must be addressed:

-How can the selection of renewable technologies align with a country's energy transition policies?

-What design elements are crucial in promoting a climate-friendly outcome?

-How can the integration of renewable technologies into urban architecture not only be functional but also provide a sense of joy and satisfaction to the community? The goal is to see these technologies not only as utilitarian, but also as a form of creative expression that enhances the aesthetic experience.

-How can sustainable infrastructure become a seamless part of a city's cultural identity?

-Finally, how can this approach to urban design ensure that access to energy is democratized and available to all?

1.4. Methodology

In order to achieve the objectives of the thesis and address the research questions, the following steps have been carried out:

1. Study of German Renewable Energy Policy through two approaches:

Study of Article 194 in the Treaty on the Functioning of the European Union: The examination will encompass a study of Article 194 in the Treaty on the Functioning of the European Union, which deals with the advancement of fresh and sustainable sources of energy in member countries. This analysis will shed light on the European Union's position on sustainable energy and the obligations placed on its member states. (Renewable Energy, Fact Sheets on the European Union, European Parliament, 2022)

The second approach will be a review of the International Energy Agency's (IEA) ‘’energy policy review of Germany in 2020’’. This review will provide an overview of Germany's current energy policies and performance with respect to renewable energy, as well as identify areas for improvement.

2. Examination of Regional Strategies for Climate Protection and Adaptation: This will offer an understanding of ways to minimize the impacts of climate change and adapt to its impacts.

3. Research of the Municipal Climate Adaptation Plan in Land-Use Planning in the Pilot Project of the Spinelli Site: This research will provide insights to address climate change in the Spinelli area.

4. Analysis of the Urban Climate, Urban System, Green Corridors, and Spinelli Site: This analysis will provide a comprehensive understanding of the context and challenges associated with the Spinelli area.

5. The synthesis of the research and analysis results to establish design Ingredients

6. This final stage will involve the development of the Spinelli open space integrated with renewable energy technologies, incorporating the design ingredients established in the previous stage. This will provide a practical solution for addressing the challenges associated with the Spinelli area and promote the integration of renewable energy technologies in urban spaces.

1.5. Expected outcomes

The result of the extensive research and design effort will be a project that features several key components.
Firstly, the activation of the northeast green corridor will play a critical role in enhancing the area's ecological profile. By generating cold air and reducing the heat island effect in the city centre during the night, the green corridor will help to create a more comfortable and liveable environment for residents.

Additionally, the project will incorporate a variety of local recreational areas, providing opportunities for leisure and relaxation in the midst of a bustling city. This will help to promote a healthy lifestyle for residents and visitors alike.

To further improve the quality of life in Mannheim, the project will also facilitate new connections and provide better access by creating a meaningful connection between the different conversion areas and the city centre, residents will have a greater sense of community and be able to enjoy all that the city has to offer.

Finally, the project will deliver accessible clean megawatt-hours to both the community and the city, providing a source of clean energy that will help to reduce dependence on traditional sources of power and contribute to a more sustainable future. Overall, this project promises to be a transformative effort that will have a lasting impact on the residents of Mannheim and the surrounding area.

2

EUROPEAN UNION RENEWABLE ENERGY DIRECTIVE

2.1. Overview

Replacing fossil fuels with renewable energy sources (solar, wind, water, geothermal, biomass, biofuels, and storage), helps reduce greenhouse gas emissions, diversifies energy supplies, and reduces our dependence on unreliable and volatile oil and gas markets.
The promotion of renewable energies has evolved significantly in the past 15 years.

Since 1991 when Germany introduced the first feed-in tariff for renewables, there have been different phases of target setting for the involvement of renewable energies in EU countries. The followings are the directives and revisions carried out by the EU so as to achieve the ambition of carbon neutrality by 2050.

According to the official website of the European Union:

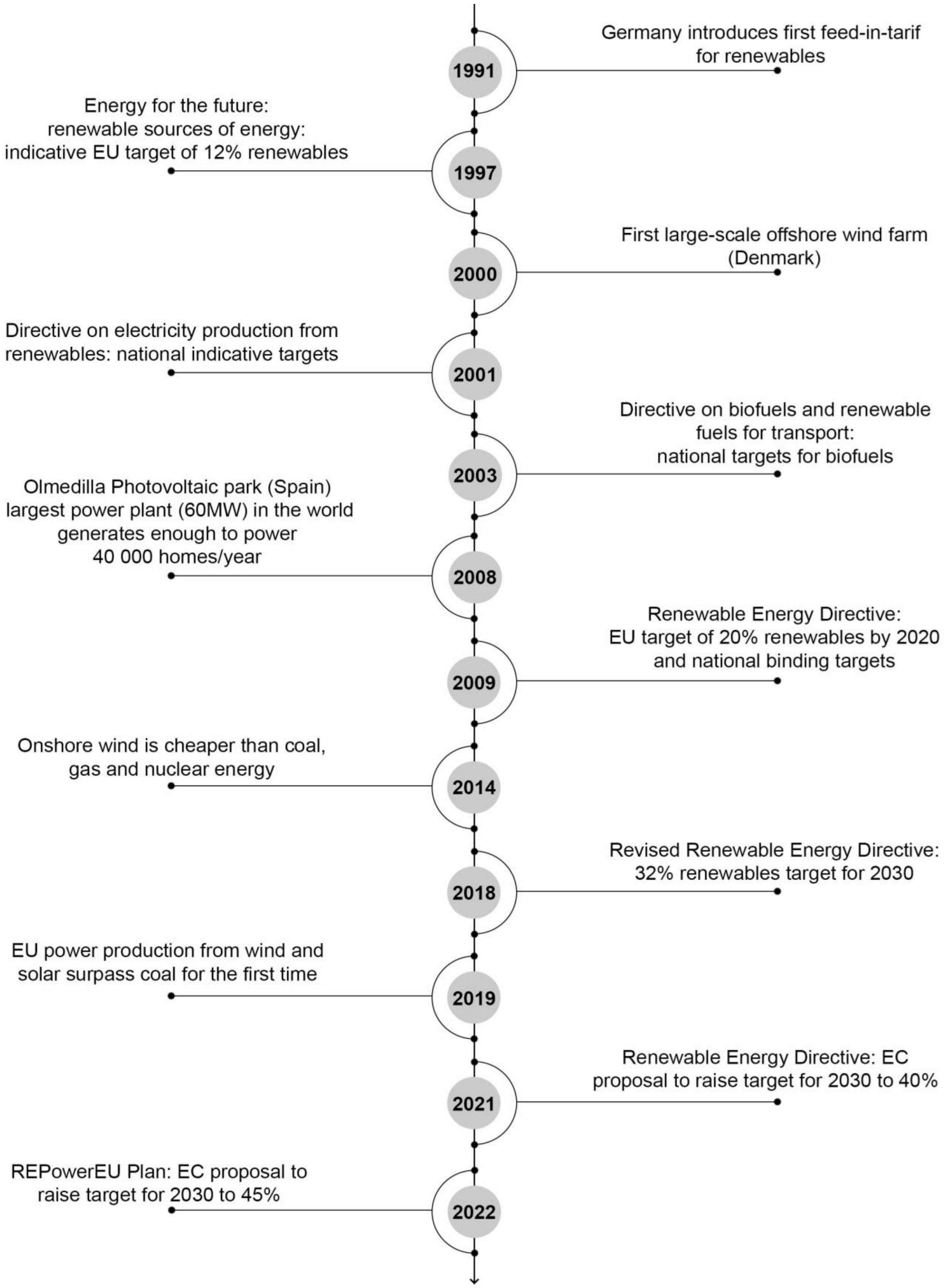
- ‘’Since the implementation of the Renewable Energy Directive (2009/28/EC) in 2009, the use of renewable energy has been continuously increasing, reaching over 22% in 2020. The study from 2022, entitled "EU's global leadership in renewables," confirms that the EU is already a leader in the development and deployment of renewable energy technologies, but it suggests that its competitiveness in the global renewable energy market could be enhanced even further.

- The Renewable Energy Directive was revised in 2018 and is legally binding since June 2021.
  The existing directive sets the overarching European target for renewable energy and includes rules to ensure the uptake of renewables in the transport sector and in heating and cooling, as well as common principles and rules for renewables support schemes, the rights to produce and consume renewable energy and to establish renewable energy communities, and sustainability criteria for biomass.

- In July 2021, the European Commission put forward another proposal aimed at boosting the adoption of renewable energy in the EU and reaching the energy and climate goals for 2030. The directive establishes a shared goal, currently set at 32%, for the proportion of renewable energy in the EU's total energy consumption by 2030.

- The goals and actions outlined in the Renewable Energy Directive have undergone multiple evaluations in order to meet the pressing need for emission reductions (at least 55% by 2030) to fulfil the EU's heightened climate goals. In July 2021, the European Commission proposed an updated version of the directive (COM/2021/557 final) with a heightened target of 40% as part of its efforts to implement the European Green Deal. In May 2022, the Commission proposed to further increase this target to 45% by 2030 in its REPowerEU plan (COM/2022/230 final).’’. (Renewable Energy Directive, n.d.).

Figure 2: Timeline for renewable energy in the EU



Data Source: Renewable energy directive. (n.d.). Energy. https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en.
Graphic by author

Figure 3: First large-scale offshore wind farm (Vindeby-Denmark)
Was powering 2200 Danish homes.

Source: https://orsted.com/en/insights/white-papers/making-green-energy-affordable/1991-to-2001-the-first-offshore-wind-farms

Figure 4: Olmedilla Photovoltaic Park (Spain) - largest power plant (60MW) in the world - generates enough to power 40 000 homes/year

Source: http://solarenergypowerplants.blogspot.com/2010/10/olmedilla-photovoltaic-park.html

2.2. The European Green Deal

A communication describing the European Green Deal was released by the Commission on 11 December 2019 (COM (2019)0640). By supplying clean, affordable, and secure energy, this green pact intends to make Europe climate-neutral by 2050.

According to Matteo Ciucci (2021):

‘’On 14 July 2021, the Commission published a new legislative package on energy entitled ‘Fit for 55: delivering the EU’s 2030 Climate Target on the way to climate neutrality’ (COM(2021)0550). In the new revision of the Renewable Energy Directive (COM(2021)0557), it proposes raising the binding target for the share of renewables in the EU energy mix to 40% by 2030 and new targets at national levels, such as:

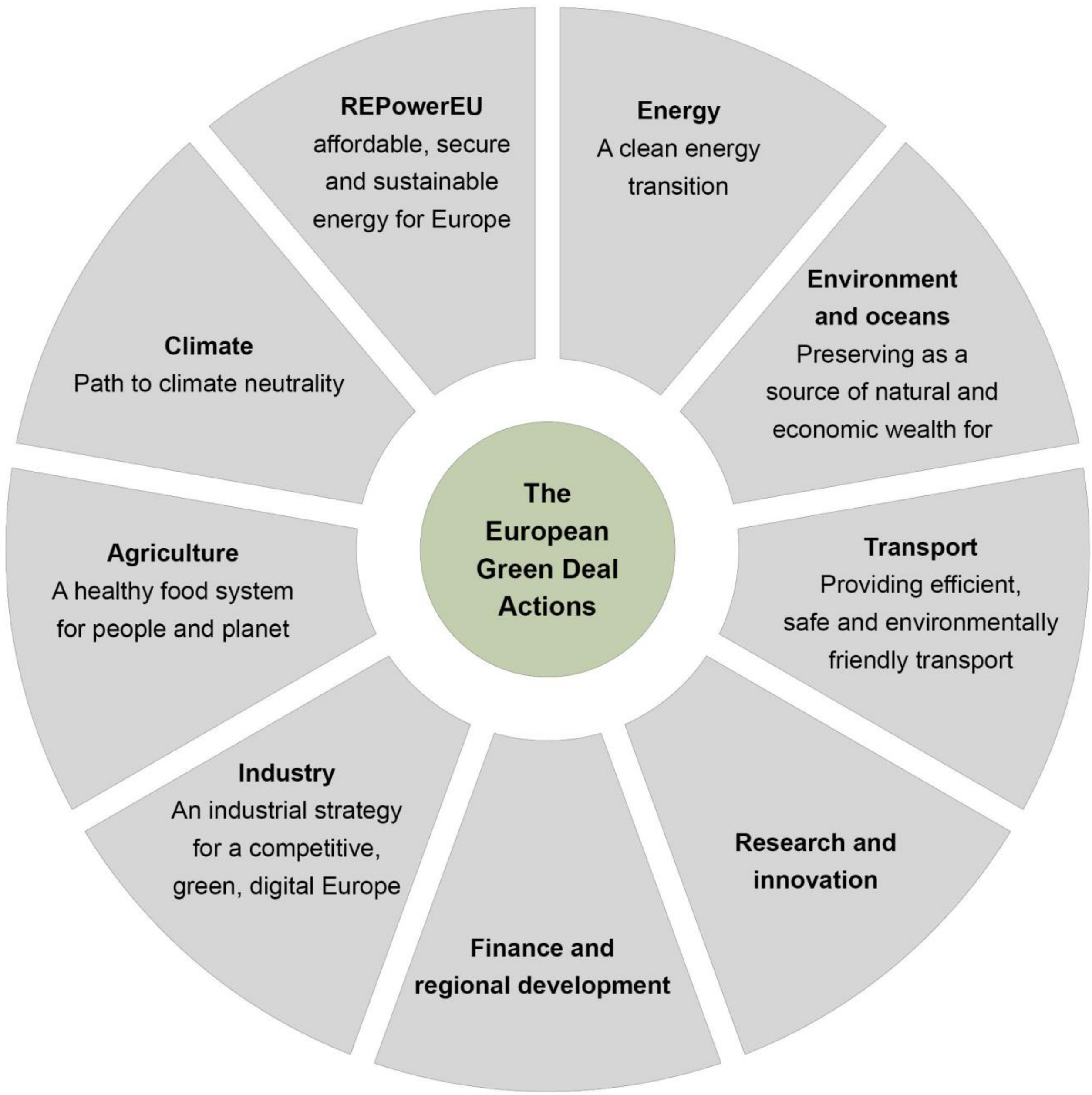
- A new benchmark of 49% renewables uses by 2030 for buildings.
- A new benchmark of a 1.1 percentage point annual increase in renewables use for industry.
- A binding 1.1 percentage point annual increase for the Member States in the use of renewables for heating and cooling.
- An indicative 2.1 percentage point annual increase in the use of renewables and waste heat and cold for district heating and cooling’’. (Renewable Energy, Fact Sheets on the European Union, European Parliament, 2021b)

By providing the following benefits to citizens and future generations, the European Green Deal will improve their well-being and health:

- Fresh air, clean water, healthy soil, and biodiversity.
- Renovated, energy efficient buildings.
- Healthy and affordable food.
- More public transport.
- Cleaner energy and cutting-edge clean technological innovation.
- Longer lasting products that can be repaired, recycled, and re-used.
- Future-proof jobs and skills training for the transition.
- Globally competitive and resilient industry.

(European Green Deal, 2019b)

Figure 5: The EU green deal actions



Data Source: European Green Deal. (2019, October 12). European Commission.
https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
Graphic by author

2.3. Clean energy for all Europeans package

The Clean Energy for All Europeans package included the implementation of the Renewable Energy Directive 2018/2001/EU, which took effect in December 2018. This initiative aims to maintain the EU's position as a leading force in renewable energy and to fulfil its obligation to reduce emissions as stated in the Paris Agreement. (Renewable Energy Directive, n.d.).

According to Matteo Ciucci (2021), ‘’the directive promoting the use of energy from renewables by:

- Further deploying renewables in the electricity sector.
- Mainstreaming renewables in the heating and cooling sector (an indicative annual increase of 1.3% for renewables in heating and cooling has been introduced).
- Decarbonising and diversifying the transport sector by introducing:
    - A 14% share of renewables in the total energy consumption of the transport sector by 2030.
    - A 3.5% share of advanced biofuels and biogas by 2030, with an intermediary target of 1% by 2025 (double-counted).
    - A 7% cap on the share of first-generation biofuels in road and rail transport and plans to phase out the use of palm oil and other food-crop biofuels that increase CO^2 emissions by 2030, through a certification scheme.
- Strengthening the EU sustainability criteria for bioenergy.
- Making sure the EU-level binding target is achieved on time and in a cost-effective way’’. (Renewable Energy, Fact Sheets on the European Union, European Parliament, 2021b).

2.4. Renewable energy financing mechanism

The Clean Energy for All Europeans package established an EU financing mechanism, outlined in Regulation 2020/1294 and based on Article 33 of the Governance Regulation (EU) 2018/1999. This mechanism became effective in September 2020 and is still being carried out by the Commission.

This mechanism is intended to assist countries in achieving their renewable energy targets individually and collectively. The financing mechanism creates a connection between countries that provide funding for projects (contributing countries) and countries that allow the construction of new facilities within their borders (host countries). All participating countries will be able to count the energy generated through this financing mechanism toward their renewable energy targets. Moreover, it contributes to the European Green Deal's goal of carbon neutrality by 2050. (Renewable Energy, Fact Sheets on the European Union, European Parliament, 2021b).

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3

AN OVERVIEW OF GERMANY ENERGY POLICY

3.1. Overview

As of late 2010, Germany initiated the ‘’Energiewende’’ (Energy transition), a significant effort to make its energy system more efficient and to rely mostly on renewable energy. By 2022, the country will phase out nuclear power rapidly as part of a 2050 energy strategy.

The energy transition can be clearly seen in the increase in renewable energy in electricity generation. Although Germany has lowered its overall emissions, it struggles to meet its near-term emissions reduction targets, primarily because progress is uneven across sectors. Transport and heating are two of Germany's biggest challenges.

There are clear objectives for the Energiewende by 2030: It is projected that renewable energy sources will provide half of the total electricity. The intention is to entirely eliminate coal, which is currently the main source of power generation, by 2038. Germany has been a trailblazer in offshore wind and solar PV and has set ambitious goals, including 20 GW of offshore wind by 2030 and 40 GW by 2040, as well as investments in 5 GW of hydrogen by 2030. (IEA, 2020)

The International Energy Agency (IEA)

In 1973-1974, industrialized countries could not deal with the oil embargo imposed by significant producers, which pushed oil prices to unprecedented heights. As a result, the International Energy Agency was born.

The International Energy Agency plays a central role in the global dialogue on energy. It provides expert analysis, data, policy recommendations, and practical solutions to help countries achieve secure and sustainable energy development.

The IEA's founding members included Austria, Belgium, Canada, Denmark, Germany, Ireland, Italy, Japan, Luxembourg, The Netherlands, Norway (under a special agreement), Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. They were followed by Greece (1976), New Zealand (1977), Australia (1979), Portugal (1981), Finland (1992), France (1992), Hungary (1997), the Czech Republic (2001), the Republic of Korea (2002), Slovak Republic (2007), Poland (2008), Estonia (2014), and Mexico (2018) and Lithuania (2022). Chile, Colombia, and Israel are seeking full membership. (IEA)

Energy policies in its member countries are regularly reviewed by the International Energy Agency (IEA) in a periodic cycle. In addition to supporting the development of energy policies, this process encourages the exchange of international best practices and experiences.
Each of these reviews covers all major forms of energy produced, imported, and consumed in the country concerned. Energy policies are assessed in terms of climate change, energy efficiency, renewables, energy markets, taxes and prices, regulation, and competition, as well as technology and innovation.

Germany is an influential and active member of the IEA. During the last decade, there have been two reviews of Germany's energy policy done by the IEA in 2013 and 2020.

This chapter is dedicated to them. Furthermore, it contains recommendations from the IEA designed to assist Germany in managing its energy sector's transformation smoothly.

3.2. Energy insights

3.2.1. Synopsis

Over the last four decades, the clear dominance of coal and oil in Germany's energy supply has gradually given way to a more diverse system. Nuclear energy, which has been used since the 1970s, is increasingly being replaced by renewable energies in accordance with the targets of the energy transition. Additionally, the complete phase-out of coal as the most significant source of electricity generation is planned by 2038 at the latest. (IEA, 2020)

Nonetheless, Germany is struggling to meet its climate change targets and is likely to miss its near-term emissions reduction targets. The higher share of renewable energies in electricity generation has led to emission reductions, but these are partially counteracted by the nuclear phase-out and higher electricity exports. However, the planned coal phase-out could put the country back on track to meet its long-term emission reduction targets in the power sector. (Germany Energy Policy Review, 2020)

The climate protection program 2030 recently adopted by the federal government, which includes CO2 pricing in the transport and heating sector is an imperative step in the right direction. The program also takes into account the distributional effects of climate policy and is mindful of a balance between the various sectors and actors. (IEA, 2020)

3.2.1.1. Emissions targets

The national climate protection strategy of the Federal Republic of Germany is defined in the climate protection plan 2050, which describes the long-term development paths for reducing emissions in the various sectors as part of the energy transition. The main goals are to reduce greenhouse gas emissions by at least 55% by 2030, 70% by 2040, and 80-95% by 2050 compared to the base year 1990. By the middle of this century, greenhouse gas neutrality should be achieved. These goals are supplemented by short and medium-term goals for cutting energy consumption, increasing energy efficiency, and expanding renewable energies. (BMU, 2016)

As a member of the European Union (EU), Germany is involved in climate protection in the EU's energy and climate policy, particularly with regard to the 2020 climate and energy package and the 2030 climate and energy framework. (European Commission, 2018)

Despite some success in reducing emissions, Germany is facing difficulties in reaching its short-term goals, largely due to disparities in progress across different sectors, particularly in transportation and heating. Despite a significant boost in renewable electricity production, total emissions in Germany have not decreased to the same extent. (IEA, 2020)

3.2.1.2. Electricity transition

So far, Germany's energy transition has been most noticeable in power generation. The share of renewable energies was successfully increased. While coal (mainly lignite) continues to provide the largest share of electricity generation, over the past decade nuclear power has largely been replaced by renewable energy. Since 2017, wind energy has ranked second in electricity generation, ahead of nuclear power and natural gas. The continuing expansion of renewable energies in accordance with the energy and climate goals of the Federal Republic requires a series of measures to increase the degree of electrification and the system integration of renewables. These include improvements in the area of taxation and market regulation as well as the expansion and increase in the performance of the transmission and distribution grid infrastructure. (IEA, 2020)

Germany aims to increase the utilization of renewable energy in electricity generation as a fundamental aspect of its Energy transition. In the 2010 Energy Concept, the country set a target of having renewables make up 35% of its total electricity consumption by 2020, and this goal was exceeded with 38% in 2018 and 44% in the first half of 2019. The German government has also established further objectives to raise the share of renewable electricity to 50% by 2030, 65% by 2040, and 80% by 2050. (BMU, 2010)

German electricity market regulation was reformed to improve the system integration of variable renewable energies. However, the growth of renewable power generation brings with it other challenges. (IEA, 2020)

3.2.1.3. Development beyond the electricity sector

Despite the progress made and planned in reducing emissions in the electricity sector, significant efforts are needed in other sectors in order to achieve the overall targets for reducing CO2 emissions. This applies in particular to the heating and transport sectors. (IEA, 2020)

The transport sector in particular is lagging behind when it comes to reducing emissions and is currently the main obstacle to achieving climate protection goals. In addition to efficiency improvements in accordance with EU specifications and the promotion of electromobility, the climate protection plan 2050 also recognizes the critical role of local public transport, rail, bicycle, and pedestrian traffic as well as digitization for achieving the climate protection goals in the transport sector. (IEA, 2020)

The heating industry consumes more than half of all energy used and contributes to about 40% of emissions. The federal government is currently in the process of developing a plan to reduce carbon emissions in this sector, just as it is in the transportation sector. The heating market in Germany is heavily dependent on fossil fuels (e.g., the share of oil heating in the residential sector is 25%, which is partly due to the low taxation of heating oil), and a high proportion of district heating from cogeneration plants is supplied from fossil fuels. A necessary first step is to increase energy efficiency - not only in newly constructed buildings but also by increasing the renovation rate. In addition, the increased use of renewable energies in heating systems plays a key role in the decarbonization of the heating sector in Germany. The rapid growth of clean electricity generation in Germany offers a significant opportunity to both expand the direct use of renewables for heat generation and to advance sector coupling to use more electricity from renewable energies in the heating sector. However, high electricity costs due to taxes hamper the chances of more extensive use of electricity in the heating sector, especially given the low taxation of fossil fuels. (IEA, 2020)

3.2.2. General energy policy

3.2.2.1. Supply and demand

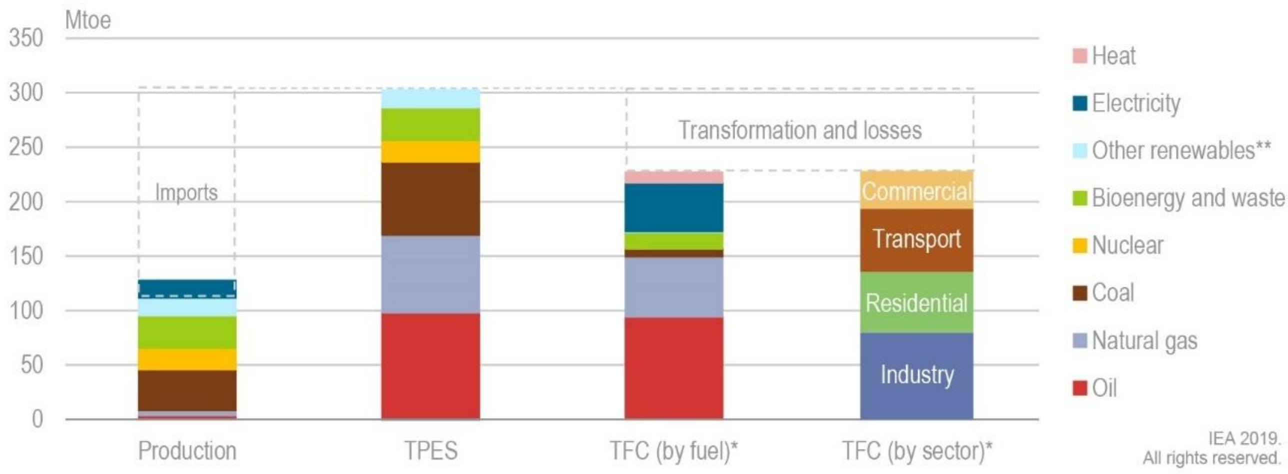
Germany's energy system still relies heavily on fossil fuels despite recent advances in renewable energy. (IEA, 2020)

Figure 6 shows that oil and gas dominate total primary energy supply (TPES) and total final energy consumption (TFC), while coal remains the primary source of power generation. However, renewable energy sources, such as bioenergy, wind, and solar, continue to make significant progress.

Oil and natural gas are imported because the country's domestic production is small. In 2018, total domestic energy production was 112 Mtoe, just over a third of TPES. Despite coal's prominent role in Germany's energy production, it does not cover national demand, so nearly half of the country's coal is imported. (IEA, 2020)

Bioenergy and waste account for the second-largest share of domestic production, half of which is used in heat and power generation and the other half in final consumption, either as biofuels in transport (8% of total bioenergy supply), for heating in residential and commercial buildings (28%), or for industrial purposes (13%). (IEA, 2020)

Figure 6: Overview of the German energy system by fuel and sector, 2018



Germany depends on imports of oil and gas to meet its energy needs; they are the largest energy sources in TPES (1) and TFC (2) across all sectors.

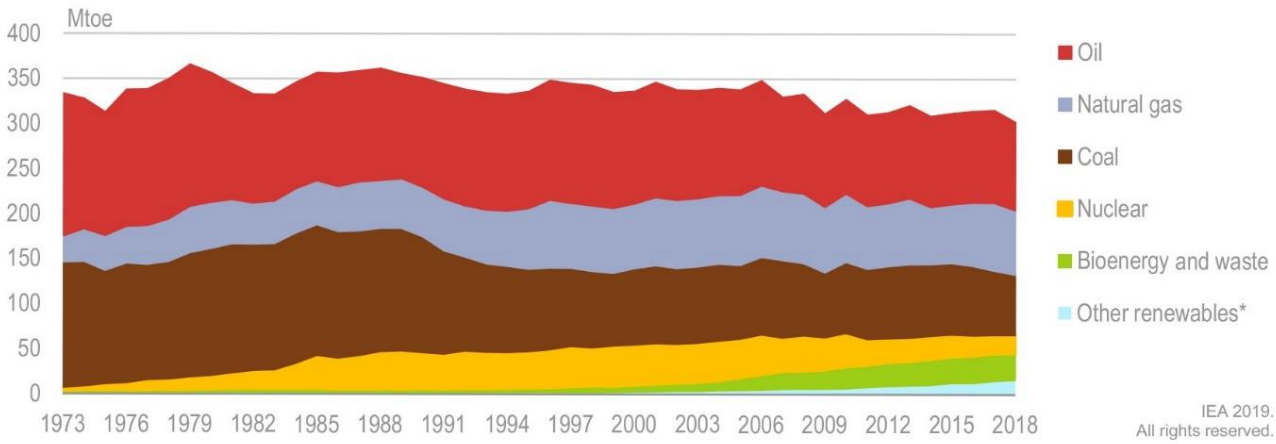
*2017 data.
***Other renewables* include wind power, geothermal, hydro, and solar energy.
Notes: Mtoe = million tonnes of oil equivalent. Supply data for 2018 are provisional. Bunker fuels of around 12 Mtoe are not included in TPES. Electricity exports that account for 1.4% of TPES (negative) are not shown in the chart.
1. TPES comprises production + imports - exports - international marine and aviation bunkers ± stock changes. This equals the total supply of energy that is consumed domestically, either in transformation (e.g., power generation and refining) or in final use.
2. TFC is the final consumption of energy (electricity, heat, and fuels, such as natural gas and oil products) by end users, not including the transformation sector (e.g., power generation and refining).
Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

Primary energy supply

Over the last four decades, the clear dominance of coal and oil in Germany's energy supply has gradually given way to a more diverse system (Figure 7). In 2018, oil accounted for 33% of TPES, natural gas for 24%, coal for 23%, and low-carbon energy sources for 22% (while electricity exports deduct 1.4% from TPES). The use of nuclear energy was introduced in the 1970s and accounted for up to 13% of the total primary energy supply. But now, it is being phased out and replaced by other sources. (IEA, 2020)

In line with Germany's energy transition targets, more renewable energy will enter the energy system. Nuclear energy will be completely phased out of the energy mix by 2022 and replaced by more renewables. Furthermore, coal used in electricity generation, which represents around 80% of all coal in TPES, is planned to be phased out by 2038. (IEA, 2020)

Figure 7: TPES by source, 1973-2018

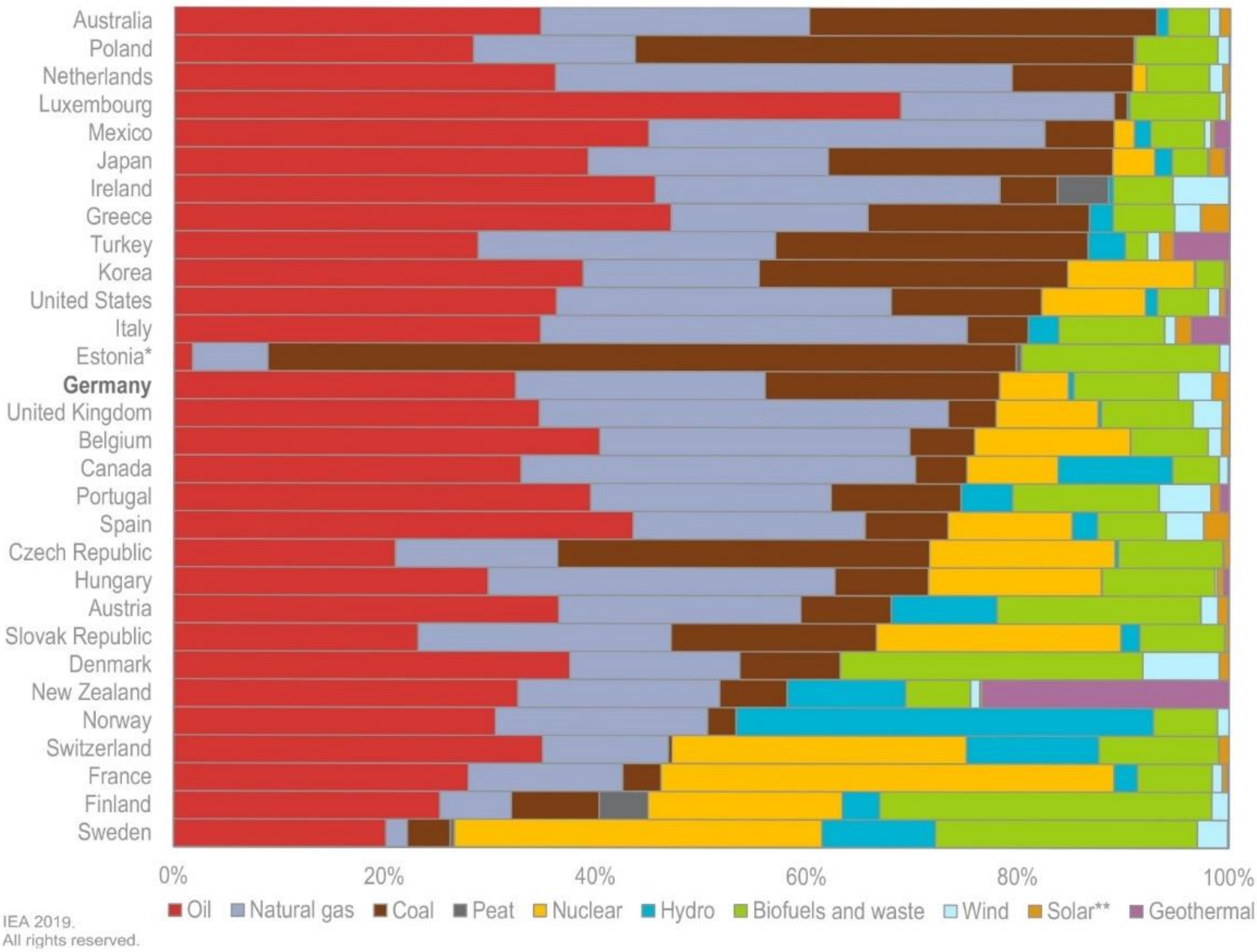


TPES has been relatively stable at around 310 Mtoe in recent years, with growth in renewable energy sources that have mainly replaced nuclear.

**Other renewables* include electricity from wind, solar, hydro, and geothermal.
Notes: Data for 2018 are provisional. TPES does not include bunker fuels. Electricity imports and exports are not shown in the chart.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Renewable energy has so far largely replaced nuclear power as a low-carbon energy source. Despite falling in absolute terms in 2018, fossil fuel shares have remained consistent at around 80% for the last decade. Among IEA member countries, Germany has an average share of fossil fuels (Figure 8).

Figure 8: Breakdown of TPES in IEA member countries, 2018



Fossil fuels account for around 80% of TPES in Germany, close to the median among IEA member countries.

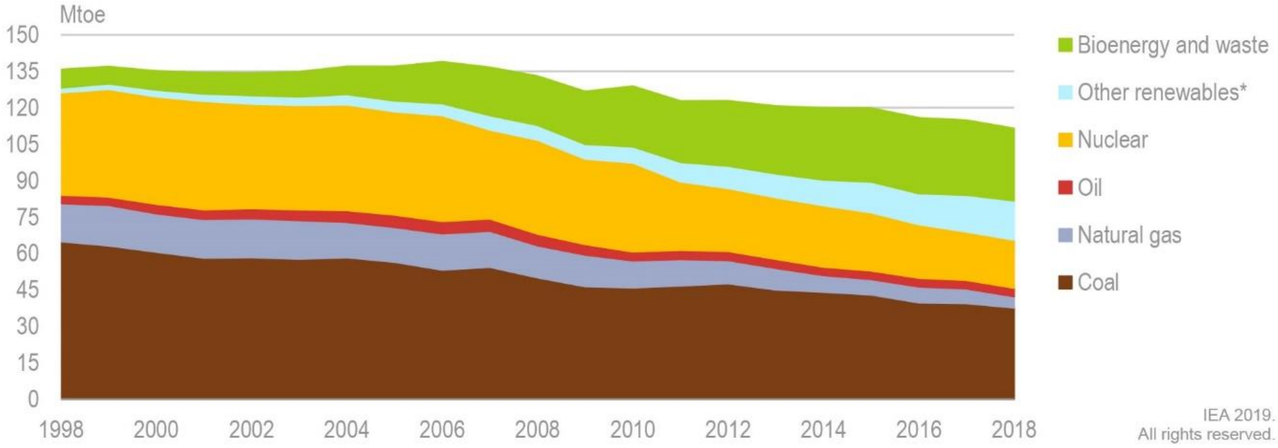
*Estonia's coal is represented by oil shale.
***Solar* includes solar photovoltaic (PV), solar thermal, wave and ocean power, and other power generation.
Note: Data are provisional.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Energy production and self-sufficiency

Germany's energy transition is clearly visible in domestic energy production. Fossil fuel production declined by a third between 2008 and 2018, whereas nuclear production declined by nearly half. Due to the increased production of renewable energy, these declines were largely offset, and thus total domestic energy production decreased by only 16% (Figure 9).

In 2018, renewables and waste accounted for 41% of total domestic production. The growth in renewable energy production has also helped Germany achieve a steady level of energy self-sufficiency of around 40% of TPES. (IEA, 2020)

Figure 9: Energy production by source, 1998-2018



Renewable energy and waste have increased rapidly in the last decade and accounted for 41% of total energy produced domestically in 2018.

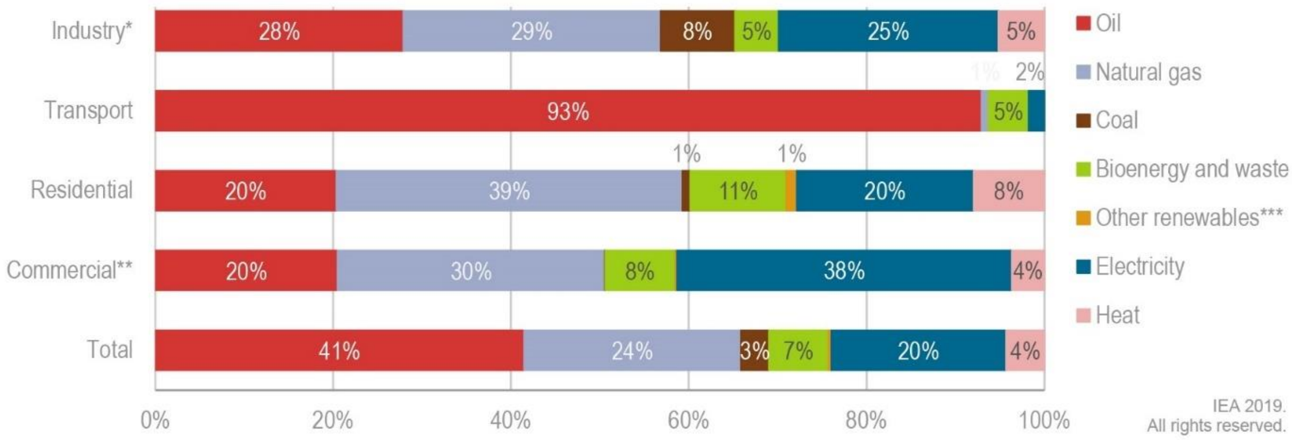
Other renewables include electricity from wind, solar and hydro (and a minor share geothermal).
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

Energy consumption

In contrast to the decline in TPES and the changing fuel composition, Germany's final energy consumption by sector has remained relatively stable. TFC fluctuated between 215 Mtoe and 229 Mtoe in the last decade, a difference of just 6%. Heating accounts for the largest share of energy demand in the residential sector, and its demand varies with outdoor temperatures. (IEA, 2020)

In 2017, fossil fuels accounted for two-thirds of the total fuel consumption (Figure 10). Heating is primarily provided by natural gas and oil for residential and commercial purposes, while appliances are powered by electricity. The industry sector is the single largest energy consumer, accounting for over one-third of total energy consumption in 2017. This includes fuels used for non-energy purposes, which represent 28% of total industrial consumption, mainly oil and gas in the chemical and petrochemical industry. There are few biofuels, electricity, or natural gas added to transport fuels, as they are mostly derived from oil fuels. The recent increase in transport energy demand was largely met by increased diesel consumption. (IEA, 2020)

Figure 10: Total final consumption (TFC) by source and sector, 2017



Oil is the largest energy source in TFC, with a dominant position in transport and high shares in industry and buildings; fossil fuels together account for nearly 70% of TFC.

Industry includes non-energy consumption.
***Commercial* includes commercial and public services, agriculture, and forestry.
****Other renewables* include solar heat and a minor share of geothermal.
Source: IEA (2019), *World Energy Balances 2019*, www.iea.org/statistics/.

3.2.2.2. Institutions

In Germany, both the federal government and the Länder are responsible for energy policy. However, the federal government is primarily responsible for enacting energy policy legislation. The Länder shape energy policy through the federal council (Bundesrat), where they participate in federal legislation.

At the federal level, the Federal Ministry for Economic Affairs and Energy (BMWi) is in charge of energy policy, the energy transition, and the climate policy aspects of the energy transition. Given that BMWi is also the ministry in charge of overseeing Germany's industries, one of its primary goals is to ensure that the energy transition does not jeopardize German industry's competitiveness. It is in charge of renewable energy market launch, energy efficiency, and oil, gas, and electricity emergency planning. It is also in charge of energy research policy, institutional energy research, and applied for energy research project funding. BMWi is Germany's energy policy representative in the European Union and internationally. BMWi and the Federal Ministry of the Interior, Building, and Community (BMI) both deal with building energy conservation issues. (BMWi, 2019)

Environment and climate change policies are the responsibility of the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety (BMU). In response to the Chernobyl nuclear disaster, the ministry was established in 1986 as a dedicated ministry to address environmental issues. Among its mandates are the protection of the public from environmental toxins and radiation, the efficient use of raw materials, the advancement of climate action, and the promotion of natural resource use to conserve biodiversity and secure habitats. (BMU, 2016)

The Federal Ministry of Transport and Digital Infrastructure is responsible for the government's fuel strategy and coordination of the energy transition in the transport sector. (BMDV)

In the energy context, the Federal Ministry of Food and Agriculture is mainly responsible for overseeing the bioenergy sector, including biofuels and biomass. (BMEL)

The Federal Ministry of Education and Research is responsible for institutional and project funding in basic and applied energy research. (BMBF)

The Federal Ministry of Finance oversees all aspects of German fiscal and tax policy, including managing the federal budget. (BMF)

The Federal Network Agency is a federal organization that operates independently and alongside the BMWi (Federal Ministry for Economic Affairs and Energy). Its role is to promote liberalization and deregulation in several industries, including telecommunications, postal services, railways, and energy. The agency has the authority to oversee these markets and ensure that they are functioning competitively and efficiently. (Bundesnetzagentur)

The Federal Cartel Office is an independent federal agency within BMWi. Its mission is to protect competition in Germany. (Bundeskartellamt)

The Federal Office for Economic Affairs and Export Control is also an agency within the BMWi with the responsibility to implement export controls, oversee economic development (especially for small and medium-sized enterprises), and financial measures in the energy sector that promote wider use of renewables and more energy savings. (BAFA)

The Monopolies Commission is a permanent and independent committee of experts that advises the government on issues related to competition. (Monopolkommission)

The German Environment Agency was founded in 1974 as Germany's primary environmental protection agency. Its mandates include waste avoidance, climate protection, and pesticide approvals. (Umweltbundesamt)

The Federal Institute for Geosciences and Natural Resources is the central geoscientific authority providing advice to the German federal government. It is subordinate to BMWi. (BGR)

3.2.2.3. Energiewende = Energy transition

The Energiewende is Germany's major energy transition plan intended to make the energy system more efficient and dependent on renewable energy.

The German federal government adopted the Energy Concept document in 2010, which outlines the country's energy policy until 2050, focusing on renewable energy sources and energy efficiency. Additionally, in 2011, it was determined that nuclear power generation would be totally phased out by 2022. In this way, the Energiewende aims to make Germany a nuclear-free, low-carbon energy nation by 2050. (BMU, 2010)

There are three objectives to the energy transition strategy:

1. The consumption of energy in all sectors should be reduced (following the principle of “efficiency first”).

2. Renewable energy should be used directly wherever it is economically and ecologically feasible.

3. Cover the remaining need for energy by renewables-based electricity.

Energy Concept

The German Government's Energy Concept reinforces the importance of affordability, security of energy supply, and protection of the environment, and it remains a guiding document for achieving the "energy transition" even today.
According to the document, emissions must be reduced by at least 80% by 2050 from 1990 levels. To achieve this goal, the concept emphasizes significant increases in renewable energy as well as rapid improvements in energy efficiency. The Energy Concept, in particular, establishes a goal of reducing primary energy consumption by 50% by 2050 (from a base year of 2008). Furthermore, it calls for a 55% reduction in greenhouse gas (GHG) emissions by 2030 and an 80-95% reduction by 2050 (from a 1990 baseline), as well as an increase in the share of electricity consumption from renewable sources to at least 50% by 2030, 65% by 2040, and 80% by 2050. (IEA, 2020)

Nuclear phase-out

In 2002, the government decided to phase out the commercial use of nuclear power for electricity generation after existing nuclear power plants reached their legally defined residual electricity production volumes. Following the 2009 parliamentary election, the federal government modified its energy policy to include the concept of using nuclear energy as a "bridge technology" to more renewable generation. As a result, under the 11th Act Amending the Atomic Energy Act, which went into effect in December 2010, the government extended the operational lifetimes of nuclear power plants by an average of 12 years. (IEA, 2020)

Emissions targets

The Climate Action Plan 2050 defines Germany's most recent national climate change policy, which lays out a long-term pathway for sector-specific emissions reductions, as expressed in the Energy Concept. The primary aims are to achieve a 40% reduction in GHG emissions by 2020, 55% by 2030, 70% by 2040, and 80- 95% by 2050 when the country hopes to be mostly GHG-neutral. These aims are supplemented with emissions targets for the short and medium term. Consumption of energy and supply of renewable energy. (BMU, 2010)

In December 2018, the German government submitted a draft National Energy and Climate Plan to the European Union. This plan outlined five difficult areas for emissions reduction efforts, such as energy efficiency and grid extensions. (European Commission, 2018)

To accomplish its ambitious GHG emissions reduction target for 2030, the government established a climate cabinet in March 2019, led by the chancellor and comprised of ministers from relevant ministries, including BMWi and BMU, as well as the transport, interior, agriculture, and finance ministries. On September 20, the cabinet announced a package of measures (Climate Action Programme 2030) that includes a phased carbon pricing scheme for the buildings and transport sectors, a prohibition on oil-based heating in buildings beginning in 2026, larger subsidies for electric vehicles (EVs), stronger incentives for building retrofitting, and more public investment in public transportation. The climate cabinet recommended cutting expenses for consumers and businesses by offering tax relief and lowering taxes and fees on power prices (but without lowering financial assistance for renewables). Furthermore, the proposal provides a method for monitoring and evaluating progress in all sectors. This would necessitate annual modifications by the government if carbon reductions were not on track to meet commitments. The German parliament passed the package into law in December 2019. (IEA, 2020)

Energy efficiency

Germany has made strides toward increasing energy efficiency and decoupling energy demand and economic growth.

The National Action Plan on Energy Efficiency (NAPE), which went into force in 2014, was a critical step toward lowering energy demand. The initial area of attention was to provide consumers with energy efficiency information and guidance. The second priority was to encourage targeted investment in energy efficiency through incentives. The third area of concentration was to demand more action, such as compelling large corporations to do energy audits and implementing updated requirements for appliances and newly constructed buildings. (BMWK)

The government is now developing a new energy efficiency policy that will encompass all sectors. "Efficiency first" will be the guiding principle. Germany intends to identify concrete efficiency measures as part of a new National Action Plan on Energy Efficiency 2.0 and to comply with the EU Energy Efficiency Directive in order to meet the 2030 targets. In addition, the government intends to develop a roadmap to achieve the national goal of halving primary energy use by 2050 (relative to 2008). A particular emphasis will be placed on energy demand in the heating industry and in buildings. (IEA, 2020)

Renewable energy

The German Energy Concept of 2010 established targets for renewable energy in power generation and total energy supply. The German government intends to expand the renewable proportion to 30% by 2030, 45% by 2040, and 60% by 2050. Wind and solar are predicted to be the most important renewable energy sources, followed by biomass and hydropower. (BMU, 2010)

The German government has established long-term targets of at least 50% renewable electricity by 2030, 65% by 2040, and 80% by 2050. Furthermore, the March 2018 coalition agreement outlines the government's desire to raise the 2030 objective to 65% renewable electricity, subject to a proportionate increase in grid capacity. The climate cabinet also reiterated the more aggressive goal. (IEA, 2020)

System integration of renewable electricity

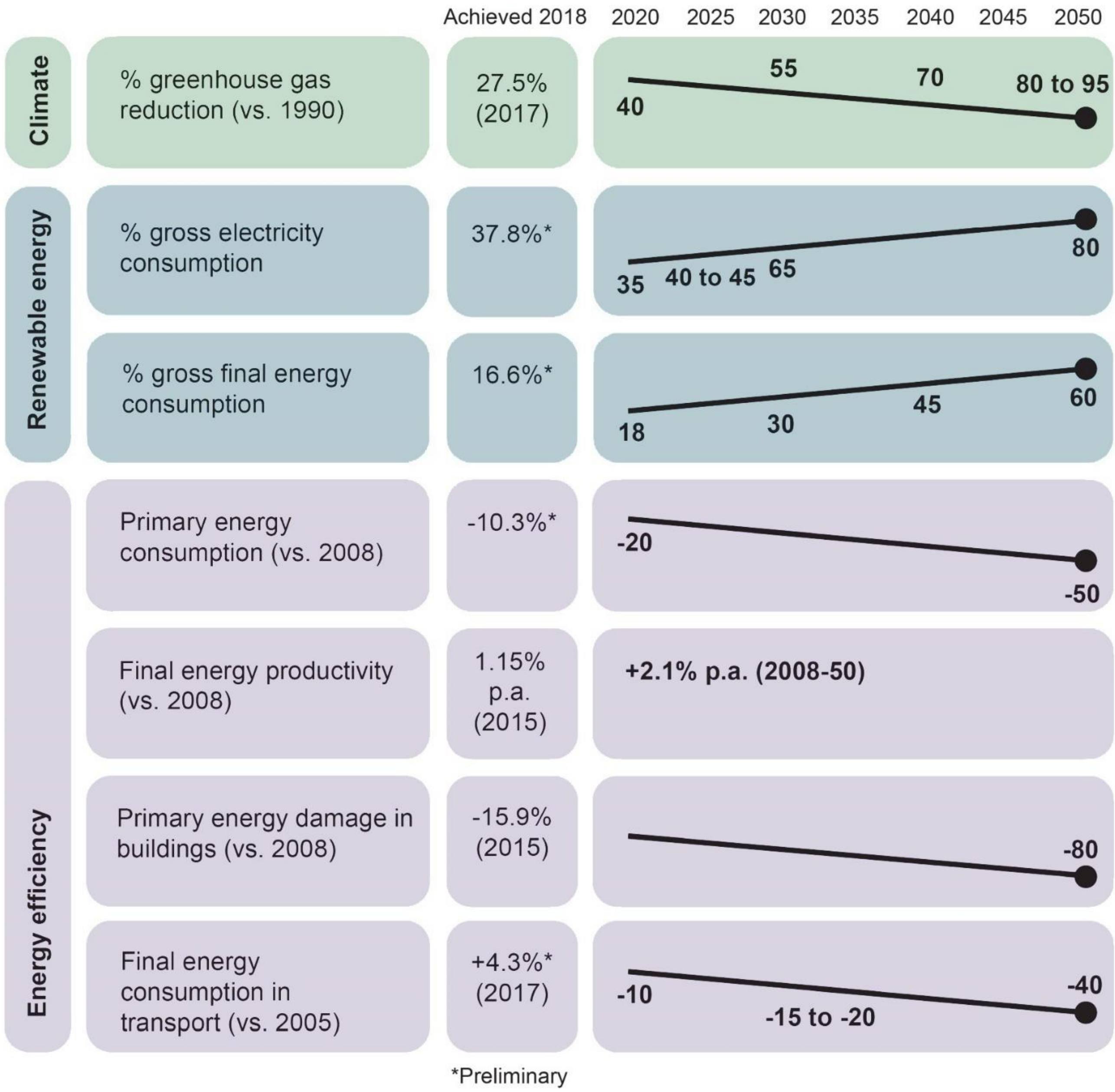
In Germany, the Energiewende is evident in the electricity production sector. Nuclear power has been reduced by about half in the recent decade, with biofuels and waste, wind, and solar electricity largely replacing it. Renewables' percentage of electricity consumption has consistently increased over the last few years, rising from roughly 6% in 2000 to nearly 38% in 2018. According to the EEG, by 2025, at least 40-45% of electricity consumed in Germany is expected to come from renewable sources. (IEA, 2020)

The majority of wind power capacity in Germany is located in the northern regions of the country, while the highest demand for electricity is in the southern and western metropolitan and industrial areas. This mismatch in supply and demand has led to an imbalance, with northern states having a surplus of wind power while southern states have a deficit. an imbalance that will exacerbate as the country's last commercial nuclear power reactors close and offshore wind starts up. (IEA, 2020)

Coal phase-out

As part of attempts to cut energy-related carbon emissions in half, Germany intends to phase out coal-fired power as part of its attempts to cut energy-related carbon emissions in half by 2030. In June 2018, the federal government established a Commission on Growth, Structural Change, and Employment to obtain broad social consensus on the coal phase-out plan. In January 2019, the commission released its report, which recommended that coal power be phased out entirely by 2038. Furthermore, the commission suggested providing billions of euros in transitional support to coal mining regions, coal miners, ratepayers, and coal plant owners. The government has accepted the suggestions. (IEA, 2020)

Figure 11: Synopsis of Germany's energy and climate targets



Note: p.a. = per annum.
Source: Ritter, J. (2019), *Germany's Energy Policy Overview*, BMWi, Berlin.

3.2.2.4. Pricing and taxation

Germany's energy taxation is in line with the EU Energy Taxation Directive of 2003, and it was enacted into national legislation by the Energy Duty Act of 2006 and the Electricity Duty Act of 1999. The European Union directive establishes minimum excise tax rates on energy items in member countries. Germany has set higher national prices (for example gasoil/diesel, petrol, liquefied petroleum gas [LPG], and natural gas). The following tax schemes are used by the government.

An energy tax is levied on oil, natural gas, coal, and coke products, with rates varying depending on whether the product is used for transportation, heating, or other purposes. (OECD,2018)
The Energy Duty Act includes many tax breaks based on environmental and economic policy considerations. Fuels, for example, are exempt from taxation if they are used to generate electricity at power plants with capacities more than 2 megawatts or if they meet specified co-generation standards with heat and power. The government provides tax breaks for heating fuels and electricity used in manufacturing and agriculture, which also receives tax breaks for diesel. Natural gas and LPG used as motor fuels are also taxed less: natural gas is taxed at EUR 13.90 per megawatthour (MWh) instead of EUR 31.80/MWh until 2024 (then lowered until 2027), and LPG is taxed at EUR 226.06/1 000 kilogrammes (kg) instead of EUR 409/1 000 kg until 2020 (then reduced until 2023). Previous biofuels tax incentives have expired; since January 2015, biofuels have only been subsidized through the EU biofuels goals, which value various biofuel categories based on their capacity to reduce GHG emissions. (IEA, 2020)

Germany also participates in the EU ETS, a cap-and-trade program that establishes a carbon price for the program's obligated participants, which include power providers, big industrial sites, and airlines flying within the European Union. Germany has enacted a carbon tax on non-ETS emissions (i.e., buildings and transportation), with a set price of EUR 25/tonne in 2021 rising to EUR 55 in 2025. (IEA, 2020)

A surcharge is added to consumer (industrial and home) electricity bills as part of the EEG, proportional to their power usage (as a per kilowatt-hour rate), to pay for renewables facility subsidies. Most energy-intensive sectors qualify for at least partial exemptions from the tariffs, shifting a larger portion of the burden to consumers. The EEG surcharge covers market premiums and FiTs given to renewable technology, as well as the average electricity trading price. Due to high FiTs locked in from earlier phases of the EEG, German households pay the third-highest energy price among all IEA member nations in 2018, at USD 353/MWh. (IEA, 2019c)

3.2.3. IEA Recommendations according to 2020 review

‘’The government of Germany should:

- Expand the scope and ambition of energy and climate policies beyond a focus on the electricity sector, especially to transport and heat, to achieve a genuine energy transition across all sectors.

- Ensure that when ministries develop energy and climate strategies, in particular sectoral ones, they work closely together to ensure effective co-ordination and that targets and policies are aligned and not working against one another.

- When designing climate and energy policies, ensure that there is efficient and equitable sharing of effort and benefits across Germany’s energy sectors and economic stakeholder groups.

- Ensure that energy market participants, investors, and consumers across the energy system and end-use sectors face price signals that are consistent with Germany’s emissions reduction and energy savings targets.

- Identify vulnerable consumers that are particularly exposed to more cost-reflective price signals and provide support to enable them to adjust, including through targeted energy savings measures, applying revenue-neutral changes to taxes and levies, phasing in reforms over time, and transitional exemptions.’’ (IEA, 2020)

3.3. Energy system transformation

3.3.1. Energy and climate change

Germany's 2010 Energy Concept sets ambitious greenhouse gas emission reduction targets. By 2030, total greenhouse gas emissions must be reduced by at least 55% compared to 1990 levels. While Germany's renewable electricity generation has grown rapidly (38% of its gross electricity consumption in 2018), its emissions have not decreased proportionally. As of 2017, Germany had reduced its total GHG emissions by 28% compared with 1990. Over 80% of all greenhouse gas emissions come from the use of energy in buildings, industry, and transportation. (BMU, 2010)

3.3.1.1. Energy-related CO2 emissions

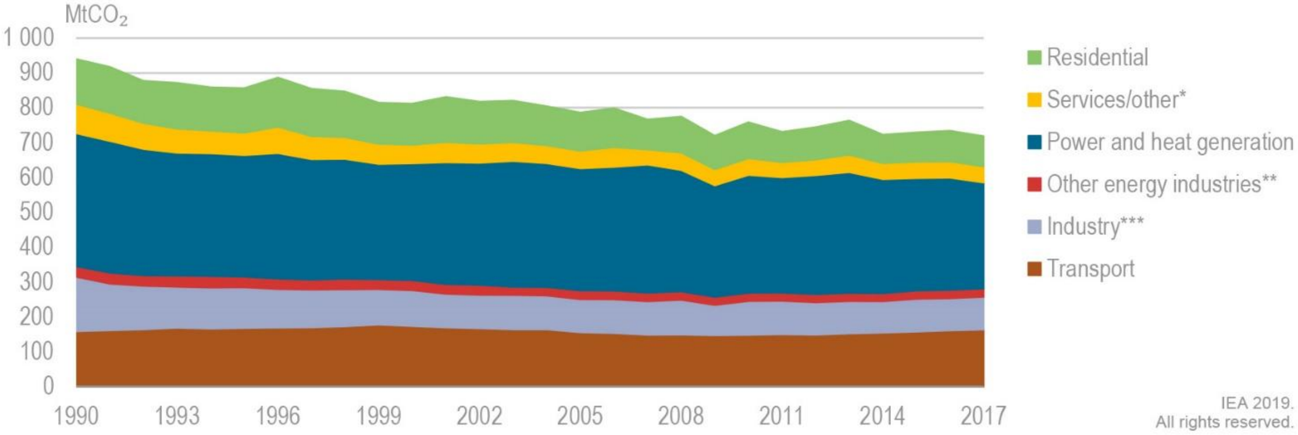
In Germany, over 80% of the total greenhouse gas emissions come from combustion in power plants, vehicles, industries, and buildings. Energy-related CO2 emissions have fallen over the last decades (Figure 12). In 2017, emissions were 719 MtCO2, 9% below the 2005 value and 24% below 1990. Energy-related CO2 emissions in Germany are primarily generated by power and heat generation. In 2017, the sector accounted for 42% of total emissions, followed by transport (22%), industry (12%), residential (12%), commercial (6%) and other energy industries (3%). (IEA, 2020)

In recent years, emissions have decreased in almost all sectors. Residential emissions have decreased by 21% since 2005 as a result of energy efficiency improvements and fuel switching, which has resulted in lower oil consumption for heating. Furthermore, electricity and heat generation have improved significantly, with a 13% reduction in emissions since 2005 (though the nuclear phase-out may have offset some advances in the power sector). The transportation industry is an outcast, with emissions increasing by 5% between 2005 and 2017. (IEA, 2020)

The reliance of the power industry on coal is reflected in the emissions profile by energy source. Coal (including blast furnace gas and other recovered gases) accounted for 39% of overall power generation in Germany in 2017, as well as around 40% of total energy-related CO2 emissions (Figure 13). Oil contributed the second-largest amount of emissions (34% in 2017), followed by natural gas (24%). Coal emissions have decreased in recent years, in keeping with the power sector's fuel transition. (IEA, 2020)

Oil emissions, on the other hand, have remained steady, with decreases in the residential sector offset by increases in transportation. Natural gas emissions have marginally grown in recent years, owing to increased gas usage in industry and buildings. (IEA, 2020)

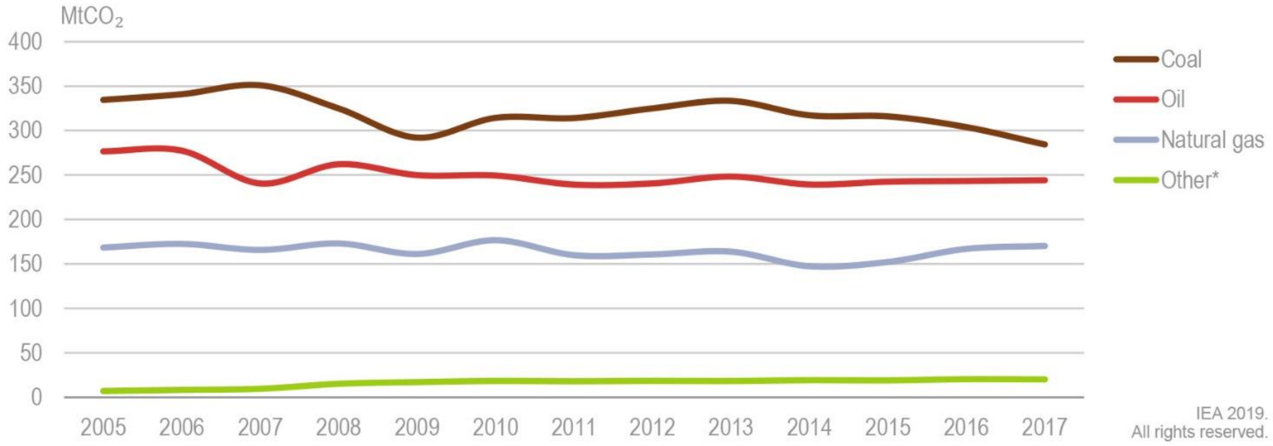
Figure 12: Energy-related CO_2 emissions by sector, 1990-2017



Energy-related emissions are declining, mainly led by the power sector, whereas transport emissions have increased in the last decade.

*Services/other includes commercial and public services, agriculture/forestry, and fishing.
**Other energy energies include emissions from coal, oil and gas extraction, oil refineries, blast furnaces, and coke ovens.
***Industry includes CO_2 emissions from combustion at construction and manufacturing industries.
Note: MtCO2 = million tonnes of carbon dioxide.
Source: IEA (2019), CO_2 Emissions from Fuel Combustion 2019, www.iea.org/statistics/.

Figure 13: Energy-related CO_2 emissions by energy source, 2005-2017



Coal is the largest source of energy-related emissions, mainly from the power sector, coal emissions have declined with reduced coal power, while oil and gas emissions are stable.

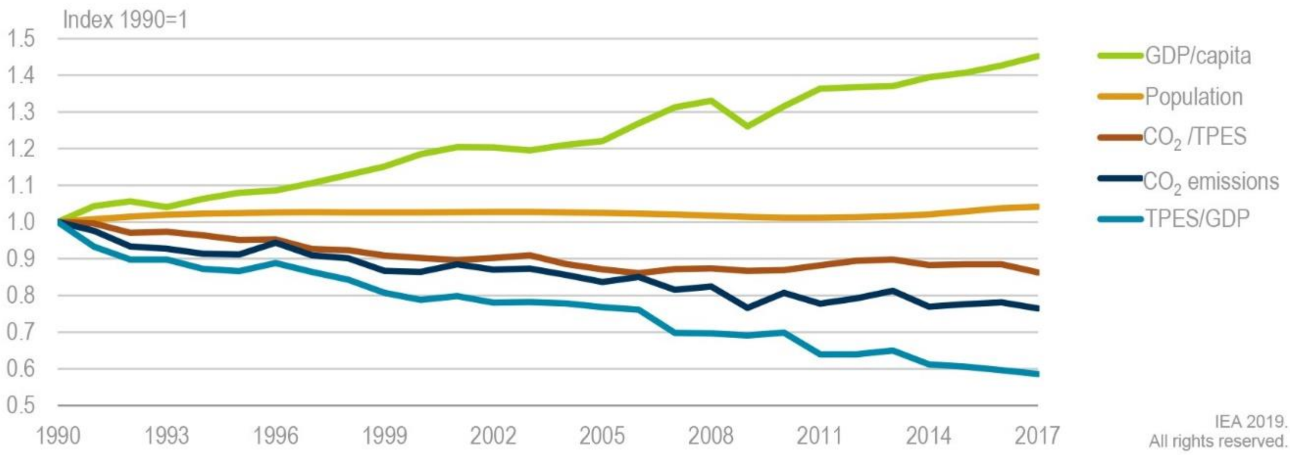
Other includes emissions from non-renewable waste.
Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

3.3.1.2. CO2 drivers and carbon intensity

Overall CO2 emissions in a country are influenced by rising population and economic growth, as well as changes in the economy's energy intensity (measured as total primary energy supply [TPES] divided by GDP) and carbon intensity of the energy supply (CO2/TPES). (IEA, 2020)

Between 1990 and 2017, Germany's GDP per capita climbed by 45%, its population increased by 4%, and CO2 emissions decreased by 24% (Figure 14).
This was primarily accomplished through a 40% drop in the energy intensity of the economy (owing in part to German reunification and the contraction of the previous East German economy), as well as a minor decrease in the carbon intensity of energy supply. (IEA, 2020)

Figure 14: Energy-related CO2 emissions and main drivers in Germany, 1990-2017



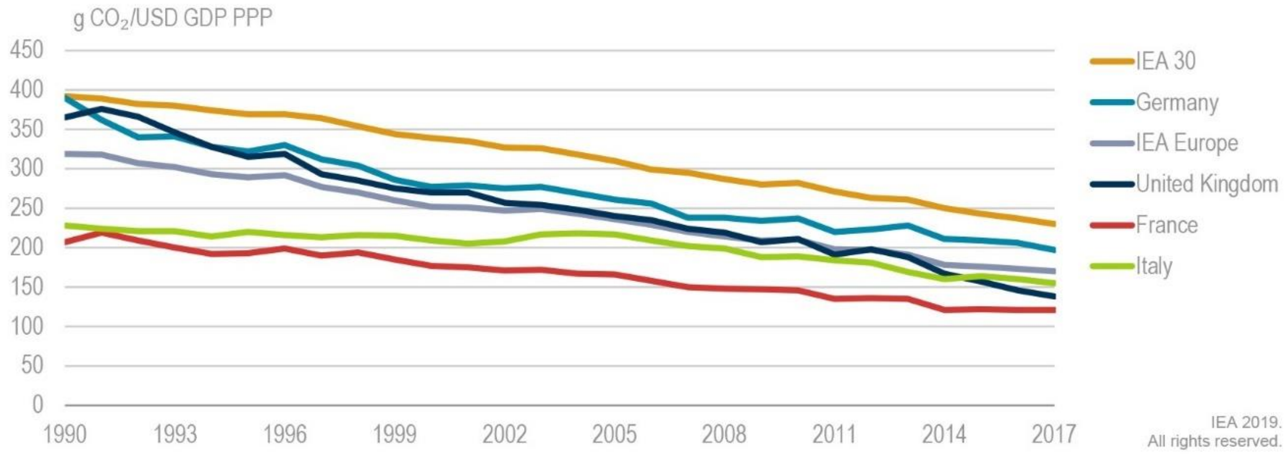
Despite large economic growth per capita, energy-related CO2 emissions have declined, mostly thanks to the reduced energy intensity of the economy.

Note: Real GDP in USD 2010 prices and purchasing power parity (PPP).
Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

Despite significant improvements in CO2 intensity, Germany had the tenth-highest CO2 emissions per capita and the twelfth-highest emissions per GDP (in PPP) according to the International Energy Agency (IEA). In 2017, Germany's CO2 intensity was 197 kgCO2/USD (PPP), which was 14% lower than the IEA average but higher than many other European countries (Figure 15). (IEA, 2020)

Emissions per kilowatt-hour (kWh) of heat and power are the main reason for Germany's comparatively high CO2 intensity per GDP. Despite the expansion of renewable energy, Germany's expanding electricity export surplus and the phase-out of nuclear power constrained the ability to reduce power sector emissions further. In 2017, Germany emitted 390 grammes of CO2 per kWh (gCO2/kWh) for electricity and heat, which was more than many other European countries and the IEA normal. With sustained increase in renewable electricity generation and a scheduled coal phaseout by 2038, emissions intensity can fall more quickly. (IEA, 2020)

Figure 15: CO2 intensity in Germany and selected IEA member countries, 1990-2017



Germany’s CO2 intensity per GDP (PPP) is steadily falling and below the IEA average, but it is higher than many other European countries and the IEA Europe average.

Note: IEA 30 = the 30 member countries of the IEA.
Source: IEA (2019), *CO_2 Emissions from Fuel Combustion 2019*, www.iea.org/statistics/.

3.3.1.3. Institutions

The Federal Ministry of Economic Affairs and Energy (BMWi) is principally in charge of the Energiewende's climate policy aspects, which include measures relating to the increase of renewables and energy efficiency. The Federal Ministry for the Environment, Nature Conservation, Nuclear Safety, and Consumer Protection (BMUV) is in charge of overseeing environmental and climate change policies, such as emission reduction plans, climate protection, and climate adaption. Both the BMWi and the Federal Ministry of the Interior, Building and Community (BMI) are in charge of building energy saving concerns. The Federal Ministry of Transport and Digital Infrastructure (BMVI) is in charge of regulations guiding emissions reduction and transportation fuel strategy. (IEA, 2020)

Germany's primary environmental protection organization is the Federal Environment Agency (UBA). In this role, UBA collects information on the state of the environment, looks into pertinent factors and their interactions with the environment, and makes predictions about environmental trends. The administration of Germany's participation in the EU ETS is handled by the German Emissions Trading Authority (DEHSt), which is a division of the UBA. Additionally, it handles the licensing of Joint Implementation and Clean Development Mechanism projects under the direction of the United Nations and emissions trading. (IEA, 2020)

3.3.1.4. Emissions reduction targets and policies

There is currently no national climate change law in Germany, but the country's climate policies are embedded in a variety of national regulations, EU regulations, and international agreements.

Germany's climate policy, as a member of the European Union, is regulated by the framework of EU climate policies: the 2020 climate package and the 2030 climate framework. The EU ETS covers large combustion facilities in the electricity and industry sectors, whilst non-ETS emissions are subject to the Effort Sharing Decision (ESD). Around half of Germany's GHG emissions are covered by the EU ETS system, and the other half by the ESD. The European Union pledged to reduce GHG emissions by 40% from 1990 levels by 2030 as part of the Paris Agreement (Germany, like other EU nations, did not issue a separate Nationally Determined Contribution as part of the Paris Agreement). (BMU, 2019a)

According to the ESD, Germany must reduce emissions from non-ETS sectors by 14% by 2020. Non-ETS emissions in Germany are expected to be 11-12% below 2005 levels by 2020. (EEA, 2018b)

Germany has struggled to reduce emissions in its transportation sector in particular. The European Union has established new non-ETS targets for 2030, with Germany expected to reduce non-ETS emissions by 38% from 2005 by 2030. Failure to fulfill the targets would force Germany to rely on flexibility measures, such as borrowing from other member countries or obtaining international tradeable credits, to make up the difference, with the latter option being phased out under the new commitment term beginning in 2021. (European Commission, 2019b)

In order to meet the 2030 targets, EU member countries must submit National Energy and Climate Plans (NECPs). In December 2018, the German government submitted a draft NECP to the European Commission, highlighting five areas for emissions reduction initiatives that are still in the works, including energy efficiency and grid extensions. (European Commission, 2018)

Climate Action Programme 2020

The German cabinet enacted the Climate Action Programme 2020 in December 2014, outlining steps to be undertaken by 2020 in order to meet the Energy Concept's target of reducing GHG emissions by at least 40% from 1990 levels by 2020. (BMU, 2018b)

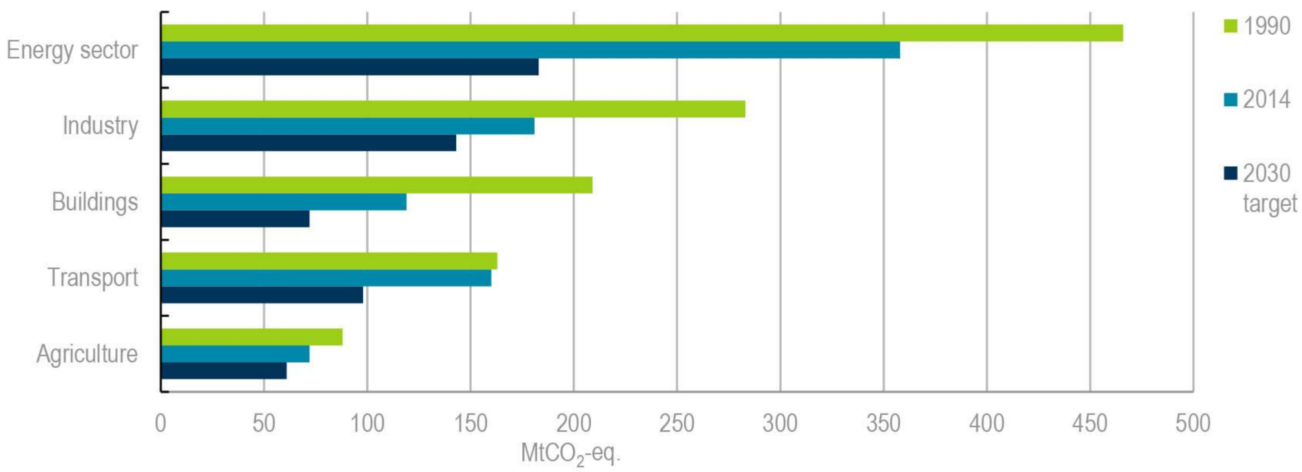
Approximately 100 implementation measures are included in the strategy to help achieve the goal. The National Action Plan on Energy Efficiency (NAPE), the Climate-Friendly Building and Housing Approach, transportation sector measures (including mileage-based levies for road freight vehicles and federal grants for long-distance public transportation), and electrical sector measures (to expand renewable energy, modernize fossil fuel power plants, and create more co-generation plants) are among the key policy strategy areas listed in the program. The government also launched a process to monitor implementation of the measures and publish an annual climate action report outlining progress on implementation, emissions trends and projected reductions. (IEA, 2020)

Climate Action Plan 2050

The Climate Action Plan 2050, enacted in 2016, reiterated the roadmap of emissions targets (including intermediate targets) outlined in the Energy Concept through 2050, with a long-term goal of being nearly GHG-neutral by that year (emissions reduction of 80-95%). The Climate Action Plan 2050 includes 2030 targets for sectors (energy, industry, buildings, transportation, agriculture, land use, and forestry) that are based on a linear road to the 2050 targets. (BMU, 2018a)

For industry, through initiatives such as R&D and energy efficiency programs, the Climate Action Plan 2050 aims to reduce greenhouse gas emissions by 49-51% from 1990 to 2030. The strategy aims for a 66-67% decrease in the buildings sector by 2030, with the goal of achieving a "virtually" climate-neutral building stock by 2050, through measures such as tough regulations for new buildings, incentives for updating existing structures, and initiatives to phase out the use of fossil fuels in heating (BMU, 2019b).

Figure 16: Sectoral targets in the Climate Action Plan 2050



Source: IEA (International Energy Agency) (2020), Germany Energy Policy Review, P.45
https://www.bmwk.de/Redaktion/DE/Downloads/G/germany-2020-energy-policy
review.pdf?__blob=publicationFile&v=4

Climate Action Programme 2030

Among the measures to be compiled by the German government are those based on the coal and mobility commissions' work. As part of this effort, and to place the topic of climate change on the policymaking agenda, the government appointed a climate cabinet in March 2019. On September 20, the government issued the Climate Action Programme 2030, a package of actions that included climate legislation that became law in December 2019. (IEA, 2020)

By 2030, the climate policy package aims to reduce carbon emissions from the energy sector by 175 million tonnes (Mt). It recommends 65% renewables target for the power industry by 2030 (as adopted by the coalition agreement). To that aim, it proposes expanding the solar assistance plan by eliminating the present capacity cap of 52 gigatonnes (GW), raising the target for offshore wind capacity to 20 GW, and establishing a minimum distance of 1000 meters between onshore wind projects and dwellings to address popular acceptance. (IEA, 2020)

3.3.1.5. Focus area: Decarbonising heat and sector coupling

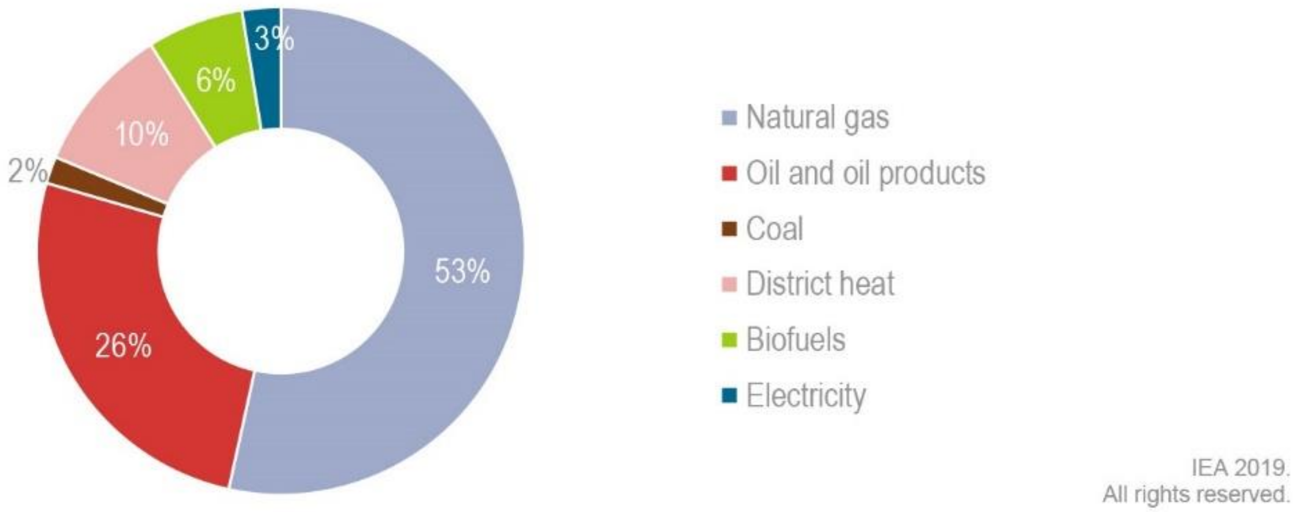
Although Germany has started the process of decarbonizing the electricity sector and has a long-term strategy in place to reduce emissions in the power sector further, the government acknowledges that further progress in other sectors, especially heating and transportation, is required to achieve the overall carbon reduction targets outlined in the Climate Action Plan 2050. The mobility commission was established to assist in developing a plan for decarbonizing the transportation sector, but heating - which accounts for more than 50% of final energy consumption and roughly 40% of emissions - remains a sector in which the government is still developing a plan for decarbonisation. (IEA, 2020)

According to BMWi, over 10 million heating systems (mostly residential and commercial) in the country are over 15 years old and frequently inefficient. Approximately 25% of heating systems are still based on oil (but no new buildings are constructed with oil boilers, therefore the use of oil boilers will reduce over time as the existing stock is restored). Furthermore, many residences (particularly in isolated, rural regions) are not connected to the gas grid or district heating systems. In contrast, heat pumps are used in only 2% of buildings, while their use is increasing in new construction. As a whole, the heating sector in Germany is heavily reliant on fossil fuels, accounting for 81% of direct heat delivery in domestic space heating in 2016 (Figure 17). Furthermore, a considerable portion of district heating and electricity is generated by fossil energy sources, resulting in a renewable energy share of less than 10% in residential space heating. (IEA, 2020)

Natural gas accounts for 36% of total consumption in the residential and commercial sectors (where over 80% of energy use is for space and water heating), followed by electricity at 27% and oil at 21%. In a decade, direct use of biomass for heating has climbed by 60%, accounting for around 10% of total energy use in residential and commercial buildings.

District heating's percentage of residential and business use fell to 6% in 2017 over the last decade. (IEA, 2020)

Figure 17: Energy supply in residential space heating in Germany, 2016



Source: IEA (2018), *Energy Efficiency Indicators 2018*, www.iea.org/statistics/.

Using more renewable energy in heating systems, in addition to increasing efficiency, will be a significant component of decarbonizing Germany's heating sector. Renewable energy can be supplied directly or indirectly in heating. Solar heating, biomass, geothermal heat, and biogas (supplied into gas networks) are all examples of direct use. District heating or electric heating produced from renewable sources are examples of indirect use. (IEA, 2020)

Considering Germany's dependence on fossil fuels for heating as well as its rapid rise in renewable electricity, there is an opportunity to both enhance the direct role of renewables in heat generation and to pursue sector coupling, which would allow renewables-based electricity to be used more for heating. Heat pumps in buildings can provide localized electric heating, as can large-scale power-to-heat production in district heating systems. Large-scale electrification of heating can offer issues to the electricity grid by transferring energy demand to the power sector, but it can also bring opportunity for increasing total energy system efficiency through sector coupling. (IEA, 2020)

As part of the NAPE 2.0 (National Action Plan on Energy Efficiency), the government aims to incorporate a plan to decarbonize heating. The proposed NECP (National energy and climate plans) calls for renewable heat to double from 14% to 27% by 2030. Furthermore, the Climate Action Programme 2030 included numerous major decarbonization initiatives for the heating sector, including a CO2 tax and a ban on the use of oil-based boilers beginning in 2026. (IEA, 2020)

Incentives for energy efficiency and renewable heat in buildings

Germany's twofold strategy for decarbonizing the heating sector is to maximize energy efficiency improvements while growing the role of renewables at the same time. By 2030, the government hopes to reduce energy use in buildings by half and increase the share of renewables to 60-70% of total consumption. (IEA, 2020)

For new structures, standards are employed to a larger extent, including a minimum statutory level for renewable energy in new buildings. From 1 January 2016, new buildings must achieve a 25% reduction in primary energy usage and a 20% decrease in heat transfer losses. (BMWi, 2015)

Financial incentives are the key tools used by Germany to enhance efficiency and expand the use of renewables in the heating sector. The government launched the Energy Efficiency and Heat from Renewables Support Strategy from 2017 to 20 to restructure numerous support programs to target audiences more specifically on a thematic basis.

The focus areas include:
1) energy-efficient buildings,
2) energy efficiency in industry and commerce,
3) heating infrastructure,
4) saving electricity in private households.
Towards this end, the government has set up a one-stop shop where potential recipients can get information about the programs. (IEA, 2020)

The Renewable Energies Heat Act (EEWärmeG) went into force in 2009, with the goal of increasing the contribution of renewable energy in heating and cooling to 14% by 2020, which it is already on track to fulfill. It contains a requirement that a certain amount of heating for new buildings be provided by renewable energy. According to the government's 2015 progress report on the legislation, it has been beneficial in boosting renewables growth in the heating industry. (IEA, 2020)

Through the state-owned promotional bank, KfW, the government administers the CO2 Building Renovation Programme, which offers financial incentives for energy-efficient renovations like as low-interest loans, payback, and investment grants. To qualify for assistance, homeowners and other facilities must demonstrate that they exceed ENEV's legal energy efficiency criteria. (IEA, 2020)

The Market Incentive Programme (MAP) provides investment or repayment subsidies to augment low-interest loans for investments in renewable heating and cooling facilities such as solar thermal, heat pumps, geothermal, and biomass installations. The MAP receives around EUR 320 million in financing each year, with the majority of it going toward existing structures. The Federal Office for Economic Affairs and Export Control (BAFA) provides investment funds for smaller establishments such as houses. KfW provides low-interest loans and repayment grants for larger facilities, as well as heat networks and storage. (IEA, 2020)

In January 2016, the government also launched the Energy Efficiency Incentive Programme (APEE), which gives additional financial incentives for efficient ventilation and heating installations. In particular, the program gives incentives to replace inefficient oil and gas heating systems with more efficient ones. (IEA, 2020)

Lastly, in 2016, the government launched the Heating Optimisation Programme, a promotion scheme that will subsidize up to 30% of the costs of replacing heat pumps and engaging professionals to optimize heating system operation to increase efficiency even further. (IEA, 2020)

District heating

In comparison to other European countries, the use of district heating in Germany is minor. As a result, district heating accounts for a modest but significant portion of residential heat demand in Germany, and it is becoming more essential in metropolitan areas. Municipal utilities usually operate district heating systems. There are no regulations on the district heating market, and the prices are set by suppliers. (IEA, 2020)

Supporting a wider role for renewables in district heating networks demands lowering network operating temperatures, which are currently high (100°C to 120°C). As a result, the change to renewables will need to be accompanied by significant improvements in energy efficiency, such as insulation measures. (IEA, 2020)

Germany also encourages the development of advanced district heating systems. The government launched the Heating Network Systems 4.0 program in 2017, which offers investment grants for heating infrastructure with low temperatures (20°C to 95°C) and high renewable energy and waste heat shares. (IEA, 2020)

Heating systems have a natural storage capacity because, once an area is heated to the proper temperature, it can maintain that temperature even if the heating system is switched off for short periods of time. This is especially true for well-insulated structures. If electricity generation and heat production are effectively coupled, this intrinsic heat storage capacity might be exploited to enable variable renewables integration (for example, in reaction to a rapid drop in solar photovoltaic output, an electrified heat system could swiftly reduce its heat production to avoid the requirement for an increase in generation from natural gas plants). This natural storage capacity of heating systems can be supplemented with extra heat storage, particularly in district heating and co-generation systems that can heat and store enormous amounts of water. In a coupled heat and electricity system, improved heat storage can help with absorbing variable renewables, which can help with decarbonization. (IEA, 2020)

3.3.1.6. Adapting to climate change

Germany has already begun to feel the effects of climate change in the form of extreme weather events, such as a heat wave in 2018 that highlighted the harmful effects of climate change on agriculture. The average temperature in Germany in 2017 was 9.6°C, making it one of the eight warmest years since weather records began in 1881. In the last century, sea levels surrounding Germany have risen by 10 to 20 cm. The government predicts that extreme weather events such as heat waves and heavy rainfall have become more common and severe over the last 50 years. (BMU, 2016)

As a result, the population's health concerns are predicted to worsen, as are dangers to water management systems and transportation infrastructure systems. Weather changes will also have an impact on biodiversity, such as increasing the prevalence of invasive species and introducing new disease risks. Drought conditions are anticipated to have an impact on crops and yields in the agriculture and forestry sectors (however longer growing seasons may favour specific crops such as soybeans). Droughts will also have an impact on the transportation of products when river water levels are low, as well as the capacity to use water to cool thermal power plants. (IEA, 2020)

Germany has created an organisational and methodological framework for dealing with climate change adaptation in order to manage the effects of climate change. This includes scientific research programs, methods for involvement and consultation, and continuing reporting systems. (IEA, 2020)

The German Climate Change Adaption Strategy (DAS) was adopted by the federal government in 2008, outlining the aims and possibilities for adaptation techniques. According to the strategy, responding to the effects of climate change in the energy business is essentially the duty of the industry, with federal and state governments offering support. (KliVO, 2019)

The government formed the Interministerial Working Group on Climate Change Adaptation and the Federal/Länder Working Group on Climate Change Impacts in 2009. The Interministerial Working Group on Climate Change Adaptation, directed by the BMU, includes nearly all federal ministries. Monitoring reports are due every four years, vulnerability assessments every six years, and adaptation action plans and progress report every four years. The first adaptation process evaluation report is scheduled for 2019. (IEA, 2020)

The 2011 Adaptation Action Plan (APA I) featured tangible steps for all levels of society, from citizens to local, national, and international governments, to accomplish the DAS adaptation targets (BMU, 2011).
It was created with close collaboration from states, municipalities, academics, and civil society.

In 2015, the government issued the First Progress Report on the DAS, indicating that climate adaptation has become more systematically included in planning, particularly in agriculture, urban planning, and cross-sectoral projects. At the same time, the government issued a second Adaption Action Plan (APA II) and agreed to 140 of the DAS's binding adaptation actions. (IEA, 2020)

Six clusters of activities were outlined in the APA II:
1) water, 2) infrastructure, 3) land, 4) health, 5) economy and 6) special planning and civil protection. (Umweltbundesamt, 2019b)

The APA contains a priority area within the infrastructure cluster for the energy business, which comprises electricity, transportation, and production. The 2015 Progress Report assessed overall modest vulnerabilities, but also projected significant changes to the sector, particularly in the areas of heating and cooling demand, cooling water for thermal power plants, and power plant and energy production facility disruptions (BMU, 2016).
The APA II emphasizes the importance of focusing on power plants in order to avoid cooling water shortages and damage to generation infrastructure. (IEA, 2020)

However, climate change can have an impact on other aspects of the energy supply. Notably, historically low Rhine River water levels hindered the supply of petroleum goods by barge in 2018, driving increasing fuel costs. Future heatwaves may cause a return of low water levels, posing additional issues for fuel supplies. (IEA, 2020)

3.3.1.7. IEA Recommendations according to 2020 review

‘’The government of Germany should:

- Prepare policies and measures that are sufficient to attain national GHG emissions reduction targets and remove barriers for the effectiveness of these additional policies and measures.
- In the context of an overall review of price incentives (prices, taxes, levies) in all energy sectors (electricity, heating and cooling, transport), consider carbon pricing in sectors not covered by the EU ETS while considering distributional consequences and realistic time frames for phasing in these price signals supporting the energy transition.
- Concretely embed sector coupling in all energy and climate policies, including through enhanced co-operation within the federal administration and with regional administrations.
- Make more systematic use of ex post evaluation results to improve the effectiveness of existing policies and measures.’’ (IEA, 2020)

3.3.2. Renewable energy

Renewable energy is central to Germany's energy transition. Renewable energy has grown from a minor source to 14% of the total primary energy supply (TPES) and 14% of total final consumption (TFC) in recent decades. The most impressive increase has occurred in electricity generation, where renewable energy has increased from less than 5% in 1998 to 35% in 2018. Germany was a pioneer in developing rooftop solar photovoltaics (PV) and is also a world leader in biogas power, but wind power has dominated growth in recent years. (IEA, 2020)

While renewable energy is fast expanding in the power generation sector, it is lagging in other areas. Germany is falling short of its objective of 30% renewable energy in TFC by 2030 and needs a clear strategy for expanding renewables in transportation, buildings, and industry. One option would be to leverage rising renewable energy to decarbonize other sectors such as heating and transportation. However, progress in these sectors has been slow, which can be attributed in part to the present fuel and electricity pricing regimes, which act as a barrier to efficient sector coupling, particularly in heating and cooling. (IEA, 2020)

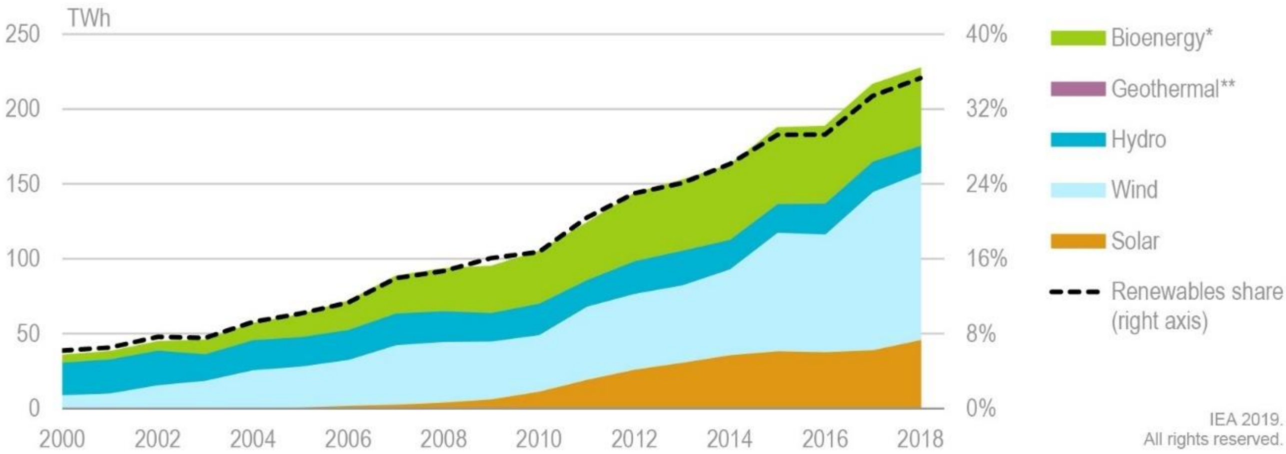
The ongoing phase-out of nuclear power and the projected phase-out of coal power will increase the importance of renewable electricity, putting additional strain on the power infrastructure. Germany will need to upgrade infrastructure to accommodate sustained growth in variable renewable energy, as well as establish policies that support more dependable and efficient system integration of these resources. (IEA, 2020)

3.3.2.1. Electricity from renewable energy

In recent decades, Germany has quickly grown its share of renewable energy in electricity generation, owing to substantial regulatory support. Renewable energy generated 35% of total electricity generation in 2018, up from 15% in 2008. (Figure 18).

Germany had a surge in PV installations, as well as distributed generating plants in the business sector, between 2009 and 2012. Following government involvement to manage subsidy costs, solar PV development has significantly slowed, and solar power generation has broadly stabilized since 2015 at around 40 terawatt-hours (TWh) (around 6% of total generation) but hit record levels of 46 TWh in 2018. Power production from bioenergy surged fast in the early 2000s but has since leveled off at slightly under 60 TWh (about 8% of total electricity generation). (IEA, 2020)

Figure 18: Renewable energy and waste in electricity generation, 2000-18



Renewable electricity has doubled in seven years and covers a third of total electricity generation in 2017, with wind power accounting for most of the growth in recent years.

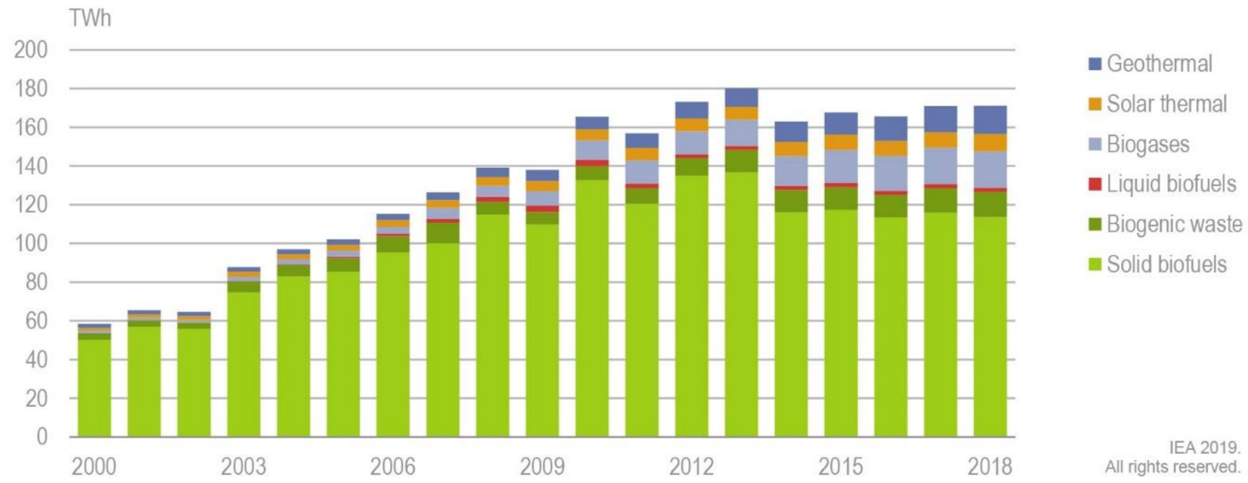
* *Bioenergy* includes solid primary biofuels, liquid biofuels, biogases, and renewable municipal waste.
** Not visible on this scale.
Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/.

3.3.2.2. Renewable heat

In Germany, the growth trajectory for renewable heat is considerably different from that of renewable power. While the final energy consumption for renewable heat generation nearly tripled between 2000 and 2010, it has since stopped (Figure 19). Renewable heat consumption is dominated by biomass fuels in various forms (solid, liquid, gaseous, and the biogenic fraction of waste), with solar and geothermal accounting for just around 13% of the total.

In 2018, renewable energy contributed 14.2% to final energy consumption for heating and cooling, meeting the EU 2020 target (European Commission 2009).

Figure 19: Final energy consumption for heat generation based on renewable energy sources, 2000-18



Renewable heat in Germany almost tripled between 2000 and 2010, but has remained relatively stable since then, with slight annual fluctuations.

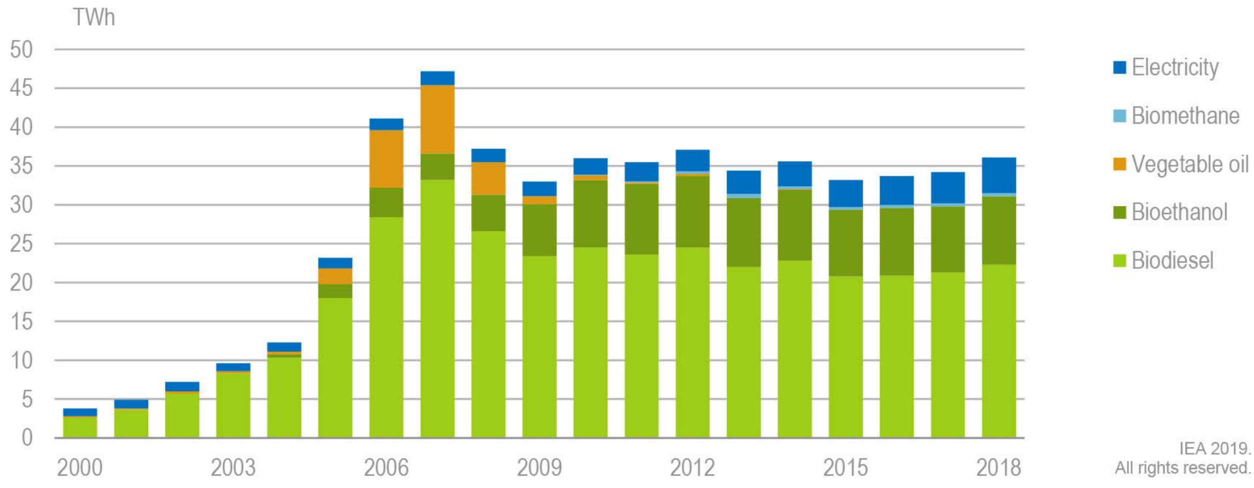
Source: BMWi (2019), "Development of renewable energy sources in Germany in the year 2018".

3.3.2.3. Renewable transport

Final energy consumption for transportation in Germany depending on renewable energy sources Between 2000 and 2007, it more than tenfolded, owing to the rapid increase of biofuels, particularly biodiesel. However, since 2008, the level of renewable energy use has remained essentially consistent, with the rise in renewable electricity accounting for the fall in liquid biofuels (Figure 20).
Despite Germany's tremendous biogas development, biomethane's contribution to the transportation sector has remained quite minimal. (IEA, 2020)

In 2018, renewables accounted for only 5.2% of total energy consumption in transportation. Even when the EU methodology is used, which allows for double counting of renewable electricity, the gap with the 10% EU target remains large, and Germany is certain to fail its 2020 targets. Much more aggressive legislative initiatives will be required in the future for Germany to accomplish a comprehensive decarbonization of its transportation industry. (IEA, 2020)

Figure 20: Final energy consumption for transport based on renewable energy sources, 2000-18



Final energy consumption for transport based on renewable energy sources grew more than tenfold between 2000 and 2007 but has remained basically stable since 2008.

Source: BMWi (2019), “Development of renewable energy sources in Germany in the year 2018”.

3.3.2.4. Institutions

The Federal Ministry for Economic Affairs and Energy (BMWi) has ultimate responsibility for renewable energy in Germany and is helped in this function by two state bodies that fall under its banner, namely the Federal Network Agency for Electricity, Gas, Telecommunications, Post, and Railway (Bundesnetzagentur) and the Federal Office for Economic Affairs and Export Control (BAFA), as well as units from the Federal Ministry for Economic Affairs and Export Control (BAFA). (IEA, 2020)

The Bundesnetzagentur, in accordance with the Renewable Energy Sources Act (EEG), publishes monthly the new renewable energy installations that have been entered into the core energy market data register and monitors the nationwide equalisation scheme process for financially supported renewable electricity among transmission system operators (TSOs) and distribution system operators (DSOs) on the one hand and electricity suppliers on the other. (IEA, 2020)

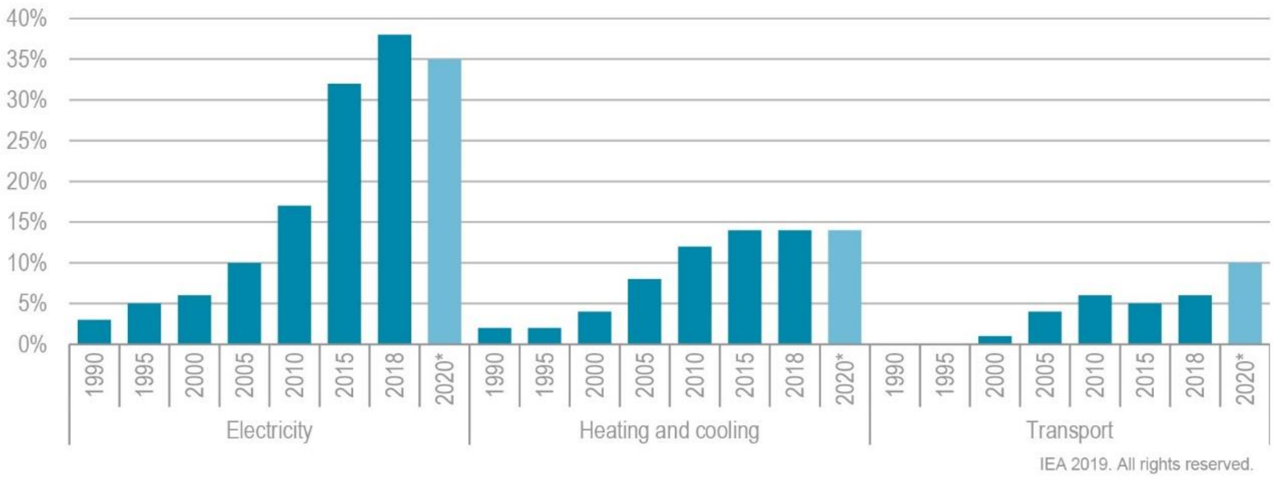
The BMWi coordinates renewable energy strategy within the federal government with all other relevant agencies, such as the Federal Ministry for Environment, Nature Conservation, Nuclear Safety, and Consumer Protection (BMUV), which controls the federal government's climate protection goals. (IEA, 2020)

3.3.2.5. Policies and measures

The primary policy initiatives and frameworks related to renewables deployment in Germany include particular policies promoting renewables deployment in the electricity, heat, and transportation sectors, as well as energy efficiency rules in the buildings sector and the more general energy and climate change policy framework. Germany has a well-developed set of short-, mid-, and long-term renewable energy and climate targets derived from EU requirements as well as national policies and legislation. (IEA, 2020)

Germany has made great progress in renewables, particularly in the electrical sector, since the targets were adopted. Renewables accounted for 15.5% of total final energy consumption in Germany in 2017. Germany already exceeded its indicative renewable power generation target in 2017, and the country is on course to meet its renewable heat target. (IEA, 2020)

Figure 21: Progress towards 2020 targets



Germany has achieved impressive progress toward its renewables targets in the electricity sector, but less so in heating and cooling and transport.

* 2020 Target.
Source: BMWi (2019), “Development of renewable energy sources in Germany in the year 2018”.

Germany has also set various long-term goals, which are summarized in (Table 1). The 2050 renewable objective of 60% renewables in total energy consumption and 80% renewable electricity in power supply was first approved in 2010 through the Energy Concept and was then enacted into law through the EEG 2012 revision.

Germany ratified the Coalition Agreement in March 2018, defining 65% renewables target for final consumption by 2030. This goal is supplemented by renewable electricity targets included in the EEG, which state that Germany's power supply will be mostly dependent on renewables by 2035, with shares ranging from 55% to 60%. (IEA, 2020)

Table 1: Targets and indicative trajectories of renewable energies in final energy consumption and electricity supply by year and policy

	Renewables in gross final Consumption of energy*			Renewables in electricity supply				
	2020	**2030**	**2050**	**2020**	**2025**	**2030**	**2035**	**2050**
NREAP	18%			35%				
2010 Energy Concept			60%					80%
2018 Coalition Agreement						65%		
NECP draft		30%				50-52.5%		

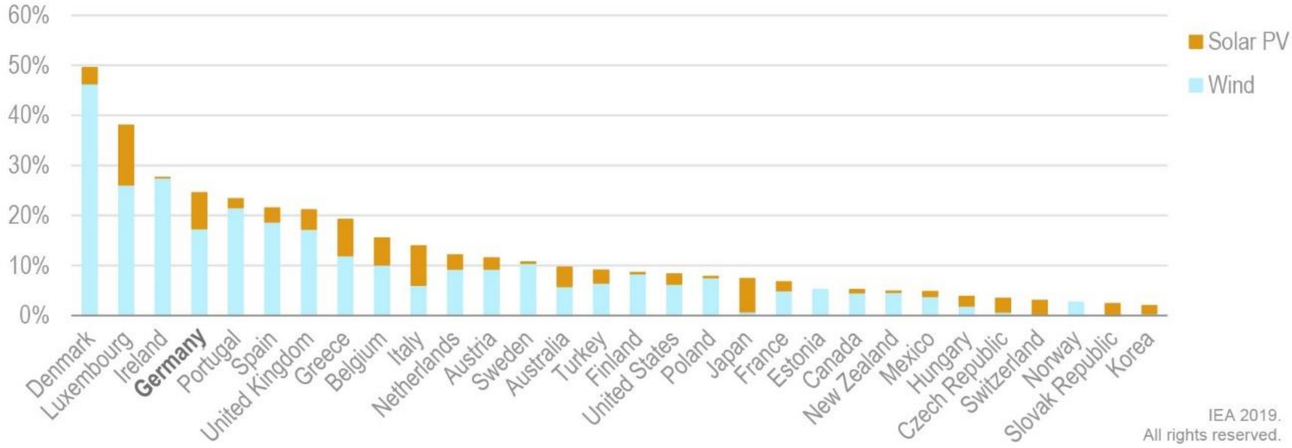
* Target/indicative target for the share of energy from renewable sources in gross final consumption of energy.
Notes: NREAP = National Renewable Energy Action Plan; NECP = National Energy and Climate Plan.
Sources: Based on NREAP, 2010 Energy Concept, 2018 Coalition Agreement, NECP.

In 2018, the combined wind and solar share in Germany was 25%. This is the fourth-highest share among IEA countries, just below Ireland (Figure 22). Such a high proportion of variable renewables necessitates a great amount of flexibility.

Hydropower-pumped storage systems supplement this. Given the scheduled nuclear phase-out and the planned progressive phase-out of coal by 2038, the flexibility requirements of a growing fraction of variable renewables will need to be closely monitored and reviewed in the future. (IEA, 2020)

According to the EEG, Germany's goal is to generate 40-45% of its electricity from renewable sources by 2025. The federal administration intends to expand the share of renewable energy in the electrical industry to 65% by 2030, according to the coalition agreement. This will necessitate the ongoing expansion of renewable energy consumption in an ambitious, efficient, better synchronized with grid development, and increasingly market-oriented manner. (IEA, 2020)

Figure 22: Share of solar and wind in electricity generation in IEA countries, 2018

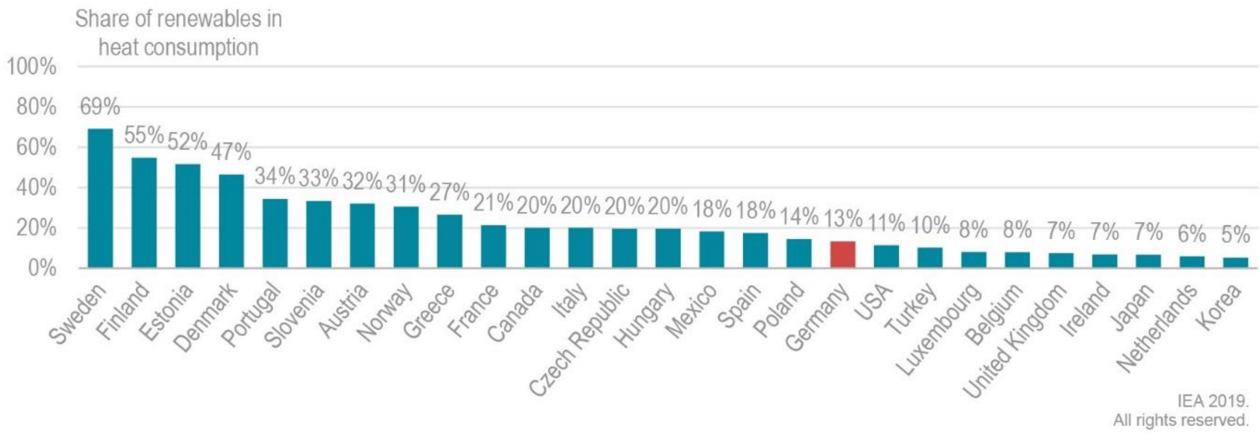


Germany has the fourth-highest share of variable renewables in electricity generation in the IEA.

Notes: For Luxembourg, domestic electricity generation only covers a small part of demand (most is imported). Data are provisional.
Source: IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/

Heating (and cooling) accounts for more than half of total final energy consumption and over 40% of carbon dioxide (CO2) emissions in Germany. The German heating industry is strongly reliant on fossil fuels, accounting for more than 80% of direct heat in the residential sector. It is worth noting that heating oil accounts for 25% of total heating costs. In district heating, which supplies 10% of heat demand in residential and commercial buildings, the share of renewables is limited (14%). (IEA, 2020)

Figure 23: Share of renewable energy sources in heating and cooling, IEA countries, 2017



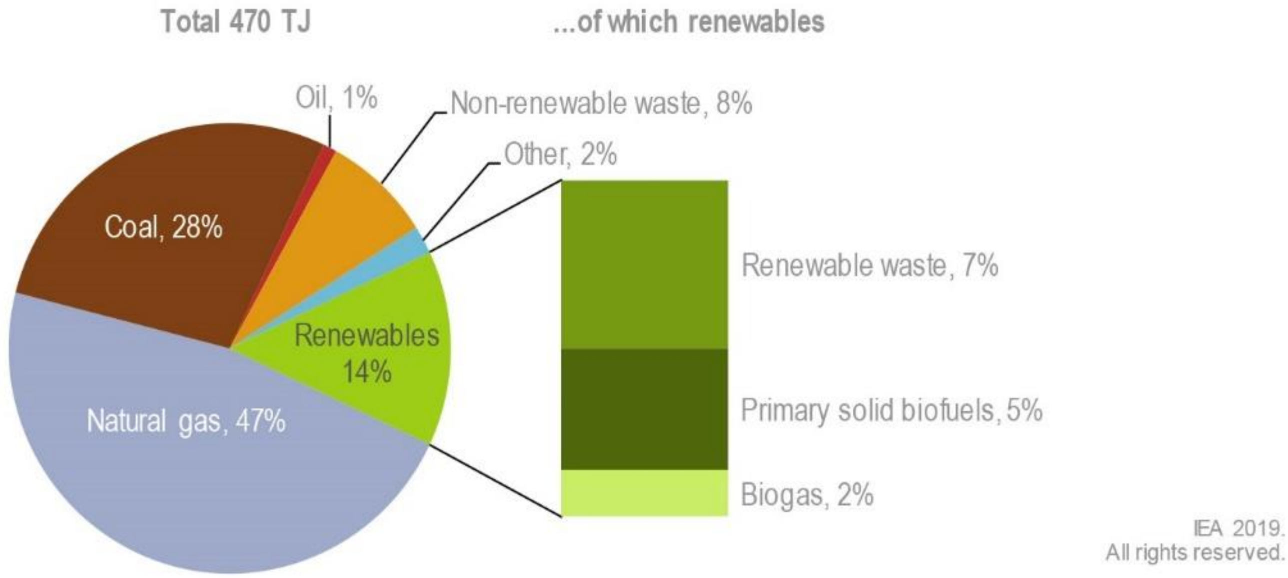
The share of renewable heat in Germany is close to the relevant 2020 EU RED target but is significantly lower than in many other IEA countries.

Sources: Eurostat (2019), SHARES 2017 detailed results for EU countries.
IEA (2019a), *World Energy Balances 2019*, www.iea.org/statistics/; IEA (2019d), *World Energy Outlook 2019* for non-EU countries.

Renewable energy can be supplied directly or indirectly in heating (and cooling). Bioenergy dominates direct use, either as solid biomass fuels or as biogas supplied into gas networks. Other renewable heat sources include geothermal and solar thermal, which accounted for around 13% of total renewable heat in 2018. (IEA, 2020)

In Germany, district heating accounts for just about 8% of total residential energy demand. While this is a low share in comparison to several other European countries, it is increasing due to urban expansion. District heating is used in more than 20% of new apartments. District heating is being examined because of its ability to integrate renewable energy and contribute to sector coupling. (IEA, 2020)

Figure 24: Fuel shares in district heating in Germany, 2017



District heating is expanding, particularly in new buildings, but energy supply is still dominated by fossil fuels.
Note: TJ = terajoule.

Sources: IEA (International Energy Agency) (2020), Germany Energy Policy Review, p.101
https://www.bmwk.de/Redaktion/DE/Downloads/G/germany-2020-energy-policy-review.pdf?__blob=publicationFile&v=4

3.3.2.6. IEA Recommendations according to 2020 review

‘’The government of Germany should:

- Develop a strong strategy supporting the use of renewables in transport, buildings, and industry in line with the 2030 targets. Propose measures that support innovation and competition across renewable fuels, including biogas, biomethane, advanced biofuels, and renewable hydrogen-based fuels and feedstocks.

- Remove the barriers that hinder efficient sector coupling by fostering a level playing field across end-use sectors, including by removing fossil fuel subsidies, introducing carbon pricing in non-ETS sectors, and rebalancing taxes, levies, and incentives, while fairly allocating costs and benefits across customer groups.

- Further enhance the overall system efficiency of the EEG by maximising the system value of renewables with market-based measures, aligning with other measures fostering system flexibility, and addressing social acceptance and permitting issues with stronger community involvement.

- Put a stronger focus on policies for distributed renewables, including regulatory frameworks aimed at a fair cost allocation of infrastructure (e.g., distribution grids, smart meters) that can enable both distributed renewable generation and flexibility resources such as demand-side response and storage.’’ (IEA, 2020)

3.3.3. Energy efficiency

Germany's energy intensity has decreased in recent decades, thanks in part to attempts to link its energy efficiency policy with its climate strategy. Despite the constant increase in GDP between 2000 and 2017, total final consumption (TFC) remained relatively stable, indicating a decoupling of economic growth and energy use. Meanwhile, TFC per capita has been constant. (IEA, 2020)

Reflecting the decade-long decline in energy intensity, Germany ranked 19th among International Energy Agency (IEA) member countries in terms of TFC per GDP in 2017, around 19% lower than the IEA average. However, per capita energy consumption in Germany was only 5% lower than the IEA average, and it was higher than the IEA median. (IEA, 2020)

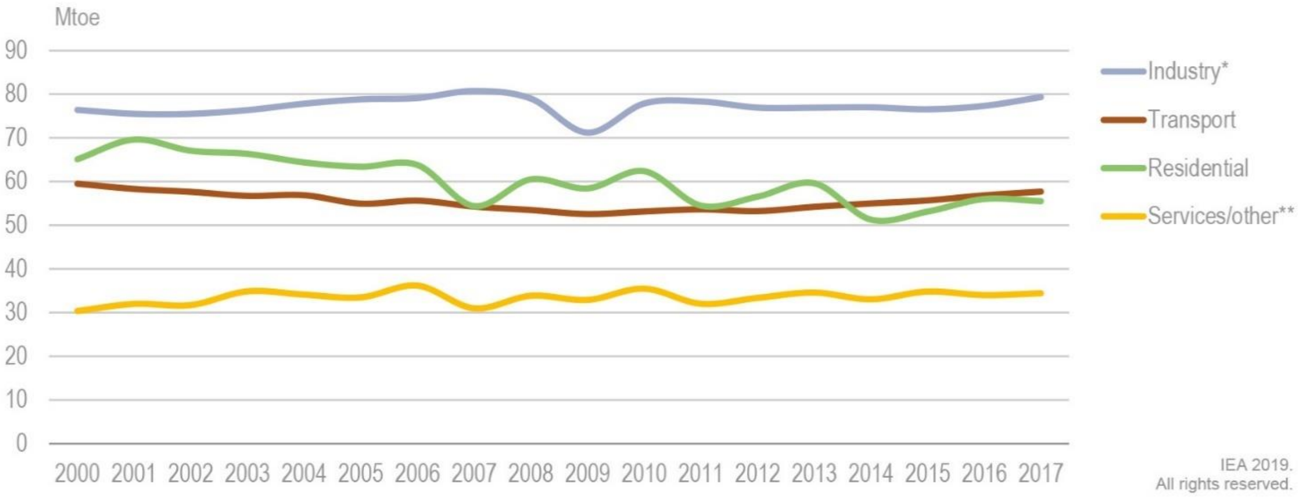
While Germany has reduced overall primary energy use by more than 10% since 2008, it is still on track to miss its 2010 Energy Concept targets of 20% reduction by 2020 and 50% reduction by 2050, both in comparison to 2008. The government must go forward by adopting more precise energy efficiency policies and regulatory frameworks for all sectors. (IEA, 2020)

3.3.3.1. Energy consumption by sector

In recent decades, Germany's energy usage has been largely steady. TFC was 227 million tonnes of oil equivalent (Mtoe) in 2017, 2% lower than in 2000 but 3% higher than in 2007. TFC fell substantially in 2009 due to a collapse in energy consumption in the industrial sector following the 2008 financial crisis, but rapidly rebounded to pre-crisis levels. (IEA, 2020)

With 35% of TFC in 2017, the industry sector is Germany's greatest energy consumer (Figure 25). The residential sector used to be the country's second-largest consumer, but it was eclipsed by the transportation industry in 2014. In 2017, transportation contributed for 25% of TFC, while the residential sector accounted for 24%. At 15%, the business sector has the smallest share of TFC. However, when the residential and commercial sectors are considered combined as representing structures, they account for the majority of energy use in Germany. (IEA, 2020)

Figure 25: Final energy consumption by sector, 2000-17



TFC is relatively stable for most sectors, with the exceptions of a drop in industry consumption after the financial crisis and fluctuating energy demand in buildings.

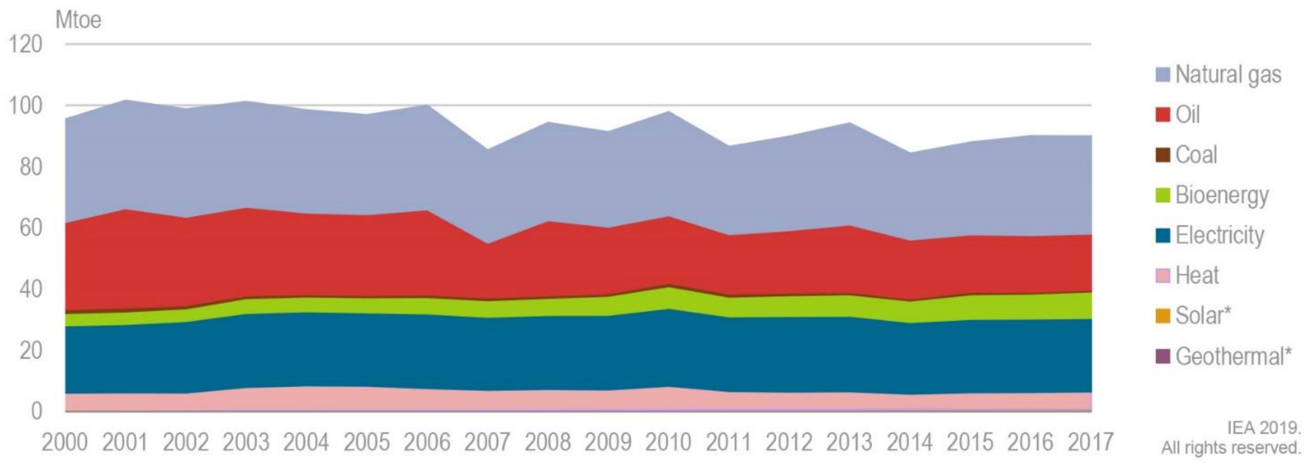
*Includes non-energy use.
**Includes commercial and public services, agriculture, forestry, and fishing.
Source: IEA (2019a), World Energy Balances 2019, www.iea.org/statistics.

Residential and commercial energy consumption

In 2017, the residential and commercial sectors consumed 90 Mtoe of TFC, accounting for 40% of total TFC consumption in the country. This is mostly energy consumption in buildings, primarily for heating, which varies with outdoor temperatures on a yearly basis (Figure 26). However, as buildings become more energy efficient, the long-term trend is toward decreased energy demand (though restorations of the relatively old building stock will be important to achieve incremental gains). The trend is most visible in the residential sector, where average energy demand was 6% lower over the five-year period 2013-17 than the previous five-year average. Because of the country's booming service sector, the commercial sector boosted its average energy usage by 2% over the same five-year period. Natural gas is the largest energy source in the residential and commercial sectors, accounting for 36% of total consumption, followed by electricity at 27% and oil at 21% (Figure 27). Direct use of biomass for heating has increased by 60% in a decade, and accounts for about 10% of total energy use in residential and commercial buildings. The share of district heating has decreased in the last decade to 6% of residential and commercial consumption in 2017. (IEA, 2020)

Like other European countries, more than 80% of energy consumption in residential buildings are used for space and water heating (Figure 27). The rest is mainly electric appliances and small shares for cooking and lighting. Natural gas is the main source for space and water heating, supplying around half the energy consumed. The rest is supplied by oil, biomass, and district heat. The energy intensity of residential space heating per floor area decreased by 7% between 2010 and 2016, indicating energy efficiency improvements from higher standards in new buildings and renovations. (IEA, 2018)

Figure 26: TFC in residential and commercial sectors by source, 2000-2017



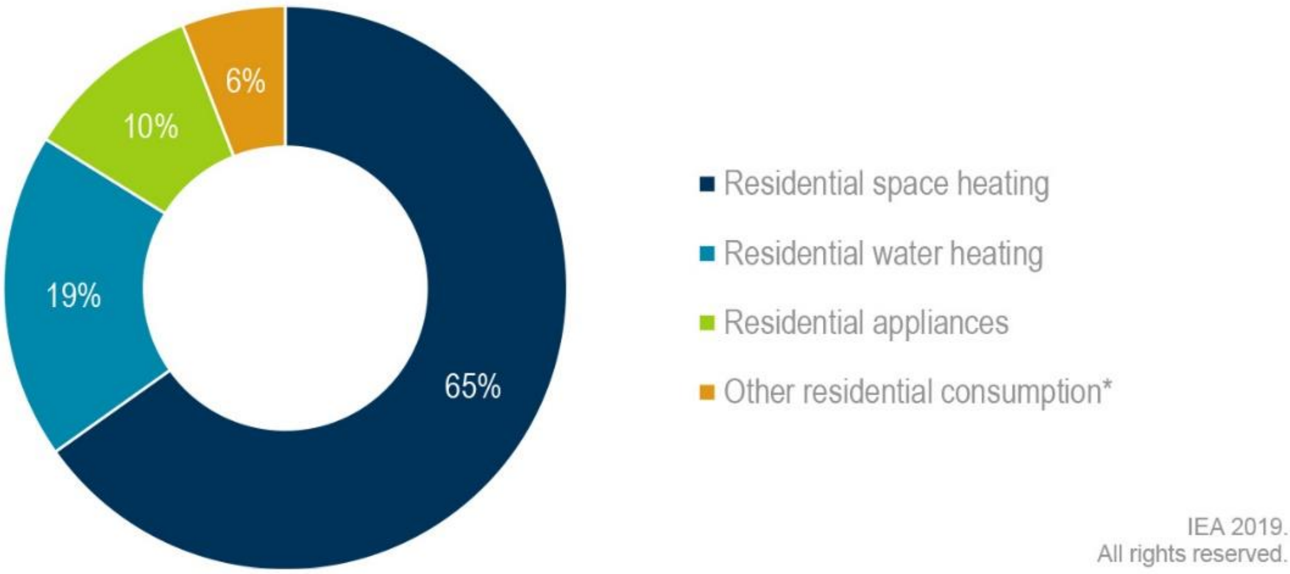
Residential and commercial energy demand has flattened to around 90 Mtoe, with natural gas, oil and electricity accounting for 83% of total energy consumption in the sectors.

*Not visible on this scale.

Note: The commercial sector includes commercial and public services, agriculture, forestry, and fishing.

Source: IEA (2019a), World Energy Balances 2019, www.iea.org/statistics.

Figure 27: Breakdown of TFC in the residential sector, 2017



Space and water heating accounts for over 80% of residential energy consumption, although energy demand for heating has decreased significantly from 2000.

*Other residential consumption includes energy for cooking, lighting, and space cooling.

Source: IEA (2019b), Energy Efficiency Indicators Highlights 2019, www.iea.org/statistics.

3.3.3.2. Institutions

Energy efficiency programs are primarily handled by the Federal Ministry of Economic Affairs and Energy (BMWi), while other ministries, such as the Federal Ministry of Environment, Nature Conservation, Nuclear Safety, and Consumer Protection (BMUV), are also involved when measures touch their respective coverage areas. The BMWi and the Federal Ministry of the Interior, Building and Community (BMI) both supervise building energy conservation concerns, while the Federal Ministry of Transport and Digital Infrastructure (BMVI) is in charge of transportation efficiency programs. The Federal Office for Economic Affairs and Export Control (BAFA) oversees a number of energy efficiency subsidy programs. (IEA, 2020)

The Länder (states) and municipalities in Germany have substantial authority to implement energy efficiency initiatives under the federal structure of government. The Federal Bureau for Energy Efficiency (BFEE) was formed in 2018 as part of an endeavor to improve collaboration and policy coordination between the federal government and the states. (IEA, 2020)

3.3.3.3. Energy efficiency policy

Germany's energy transition prioritizes energy efficiency, both to reduce greenhouse gas (GHG) emissions and to keep costs down for individuals and businesses. The German government, in particular, sees energy efficiency as a means of increasing German industry's global competitiveness. As a result, the 2010 Energy Concept established targets to reduce primary energy use by 20% by 2020 and 50% by 2050 compared to 2008 levels. BMU (2010)

In December 2014, the German government adopted the National Action Plan on Energy Efficiency (NAPE), which outlined a set of measures to help reduce energy consumption in line with the energy transition's targets. (BMWi, 2014)
The first area of focus of the NAPE is to provide consumers with information and advice on energy efficiency. The second area of focus is on promoting targeted investment in energy efficiency through incentives. The third focus area is to demand more action, including requiring large companies to conduct energy audits, and applying new standards for appliances and newly built buildings. (BMWi, 2019a)
The NAPE increased public financial support for energy efficiency measures to EUR 17 billion between 2016 and 2020. (BMWi, 2018)

Table 2: Energy efficiency targets of Germany's energy transition

Targets (from 2008 levels, except where noted)	2020	2050
Primary energy consumption	-20%	-50%
Electricity consumption	-10%	-25%
Primary energy consumption in building		-80%
Heat demand in buildings	-20%	
Energy consumption in transport (from 2005)	-10%	-40%

Source: Berlin Energy Transition Dialogue (2019), "Key facts about the energy transition in Germany", https://2019.energydialogue.berlin/wp-content/uploads/2019/04/betd_press_factsheet.pdf.

The Energy and Climate Fund (EKF), established by federal law in 2010 and financed through profits from permit auctions under the EU Emission Trading System (ETS), is one of the main sources of financing energy efficiency initiatives and programs in Germany. The programs vary from direct financial assistance to information, communication, and consulting services. In 2018, auction earnings contributed EUR 2.6 billion to the fund, which was supplemented by EUR 2.8 billion in federal government funding. The EKF provides up to EUR 500 million to energy-intensive enterprises to offset expenses associated with the EU ETS on electricity pricing, in addition to a wide range of energy saving measures addressing buildings, industry, towns, products and appliances, and transportation. (IEA, 2020)

Building sector

Through a combination of standards and financial incentives for both new and existing buildings, the Climate Action Plan 2050 aims to reduce energy consumption from buildings by 66-67% from 1990 to 2030. By decreasing primary energy demand from buildings by 80%, the government hopes to create a "virtually" climate neutral building stock by 2050. The German government published the Energy Efficiency Strategy for Buildings in November 2015, outlining a legislative framework for reaching energy transition targets in the building sector. (IEA, 2020)

Building standards

For new structures, standards are employed to a larger extent, including a minimum statutory level for renewable energy in new buildings. Germany has outlined a road map in its Energy Efficiency Approach for Buildings, which outlines a comprehensive strategy for this industry. Germany intends to make its building portfolio nearly carbon-neutral by 2050. To attain this goal, the Energy Efficiency Strategy for Buildings includes mandatory building rules, labeling schemes, low-interest loans for building renovations or new construction, investment grants, and consumer advising and consultancy services. (BMWi, 2015)

Information campaigns

The federal government provides a variety of energy efficiency advising services and information campaigns to individuals, businesses, and municipalities. Among these, the Deutschland Macht's Effizient (Germany Makes It Efficient) campaign has been a notable success story, providing, among other things, a free hotline, mostly to homes, to educate them about funding alternatives for energy efficiency improvements. (BMWi, 2019a)

Industry sector

Though Germany has energy efficiency standards for buildings and transportation, it does not specify separate targets for industry; instead, it has successfully used incentives and voluntary procedures. In terms of worldwide energy efficiency, German industry is now relatively efficient. (IEA, 2020)

Several incentive programs are in place to improve industrial energy efficiency. In 2019, a new subsidy scheme was created to encourage businesses to invest in energy efficiency. Funding is available for cross-sectoral technologies, renewable energy process heat, measurement, and control technology to be incorporated into an energy management system, and energy management software. Furthermore, the government provides financial support for enterprise-specific measures that improve the overall energy efficiency of the manufacturing process. This comprises efforts to avoid waste heat as well as steps for the first-time use (internally or externally) of waste heat; under this program, small and medium-sized firms (SMEs) benefit from higher financing rates. (IEA, 2020)

The federal government (headed by BMWi and BMU) formed an alliance with roughly 20 industry groups and organizations in December 2014 to develop nationwide energy efficiency networks. (BMWi, 2019f)
Energy efficiency networks are made up of 8 to 15 businesses that receive energy efficiency advice and suggestions from an energy expert. Based on the analysis, each organization sets an energy savings objective that is supported by an action plan. The coalition hopes to establish 500 networks by 2020 (BMWi, 2018). Through a controlled peer-to-peer procedure, the networks have assisted in driving efficiency improvements in industry.

Transport sector

Since 2011, the government has mandated car manufacturers and dealerships to attach labels with information on fuel consumption and CO2 emissions under the Ordinance on Energy Consumption Labelling for Passenger Cars (CarEnVKV). The labels compare CO2 efficiency with other vehicles using a color-coded scale, with rankings ranging from A+ (very efficient) to G (inefficient) (BMWi, 2019e). The labels also offer information about EV electricity consumption. The CarEnVKV is currently being amended to reflect the new methodology under the Worldwide Harmonized Light Vehicle Test Procedure - a change that is slated to take effect in the first quarter of 2020 - as a result of emissions cheating scandals in which automakers used unlawful defeat devices to pass emissions testing. (IEA, 2020)

Unlike many countries, Germany limits the speed of its highways only on certain sections.
Given that fuel efficiency drops precipitously as vehicle speed increases, actual efficiency might differ greatly from measured efficiency on German motorways, where cars frequently travel at high speeds. Most EU member states have speed restrictions ranging from 120 to 130 kilometers per hour (European Commission, 2019b).

3.3.3.4. IEA Recommendations according to 2020 review

‘’The government of Germany should:

Assign top priority to expediting the development of energy efficiency policy and regulatory frameworks for all sectors to enable necessary investments to close the gap on efficiency targets, define medium-term targets towards 2050 goals.

Reform and strengthen the measures targeting energy efficiency in buildings to increase the rate of renovation of existing buildings.

Accelerate and expand the smart meter roll-out to all households and enable the long-term digitalisation of the buildings sector to achieve energy savings and unlock flexibility of demand.

Ensure a level playing field among different fuel types to encourage the shift from inefficient fossil fuel boilers to more efficient heating systems, including renewables.

Update efficiency policy tools for industry to achieve more ambitious outcomes, including compulsory implementation of the identified energy savings opportunities from energy audits.

Adopt a more comprehensive approach to promote reduced energy demand in transportation, including stronger incentives for consumer uptake of EVs and promotion of public and multimodal transport options.’’ (IEA, 2020)

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4

BADEN-WÜRTTEMBERG INTEGRATED ENERGY AND CLIMATE PROTECTION CONCEPT

4.1. Overview

From 1901 to 2016, the average annual temperature in the region of today's state of Baden-Württemberg climbed by nearly 1K (from 8°C to 9°C), the largest increase since 1980. At the same time, the number of summer days with a daily maximum temperature of more than 25°C has increased since 1980, while the number of ice days (n 0°C) has declined. (Ministry of the Environment, Climate Protection and the Energy Sector Baden-Württemberg, 2012)

Projections for the future confirm this trend. In particular, the Rhine plain, where Mannheim is also located, will be affected by the increase in summer days and the associated increase in heat stress. At the same time, more frequent and longer periods of drought are to be expected in summer, which will further exacerbate the problem of heat stress.
In winter, on the other hand, larger amounts of precipitation are to be expected, which will locally lead to an increased risk of flooding. In addition, the rainfall will be more frequent as heavy rain (also in connection with storms and hail), which can lead to local flooding in spring/summer, especially on sealed or dried-out soils.
Spring and especially May 2018 broke many weather records and combined many of the aspects of climate change listed - according to the "Germany Weather Report in May 2018". (DWD, 2018)

In view of the rapidly advancing climate change, the state government of Baden-Württemberg has set itself ambitious goals to protect the climate. To achieve these goals, Baden-Württemberg has decided on an integrated energy and climate protection concept (IEKK) that names key goals, strategies, and measures.

In consideration of international, European, and national climate protection targets and measures (Detailed in Chapter 3 of this thesis under the heading 3.3.1.4), their goal is to reduce the overall total of greenhouse gas emissions in Baden-Württemberg by at least 42 percent by the year 2030. By the year 2050, the goal is to reduce emissions by 90 percent compared to total emissions for the year 1990.

4.2. Climate protection principles

According to the Integriertes Energie- und Klimaschutzkonzept Baden-Württemberg (IEKK), there are five fundamentals for climate protection:

1. Savings and efficiency
2. Renewable energy
3. Infrastructure modernization
4. Research and Development
5. Participation, and dialogue

1. Savings and efficiency

A sustainable energy supply based on renewable energies is only possible if energy is used more efficiently at the same time. As a result, the potential for energy efficiency and energy savings in all sectors is to be realized, resulting in a significant reduction in energy consumption in Baden-Württemberg. (IEKK, 2014)

The building stock has the highest potential for energy savings. This potential has not yet been completely realized. Older buildings, in particular, must be energetically restored in order to dramatically increase their energy efficiency. For budgetary considerations, this should be done concurrently with the ongoing maintenance, renewal, and repair work on the building envelope and technology. (IEKK, 2014)

Significant amounts of electrical energy can be saved in the power supply sector, for example, by employing energy-efficient household appliances and energy-saving construction and lighting equipment.
The transportation industry also has enormous potential in terms of avoiding and changing transportation services to more efficient modes of transportation, as well as the usage of climate-friendly driving.
Furthermore, the employment of more efficient technologies and the conservation of energy and raw materials are required not just in the energy sector, but also in agriculture and forestry, waste and sewage management, and industrial production in order to meet the IEKK's goals. (IEKK, 2014)

2. Use of renewable energy

Renewable energies and renewable raw materials are the backbone of future supply. The accelerated expansion of renewable energies (RE) is therefore a decisive component of energy policy for the state.

Energy production based on renewable energy sources reduces greenhouse gases and at the same time reduces dependence on energy imports. The share of renewable energies in the energy supply in Baden-Württemberg is increasing from year to year. The growth dynamic – especially in the electricity sector – is impressive. In 2011, nearly 19% of gross electricity generation in the country came from renewable energy sources.

The greatest increases are necessary for Baden-Württemberg in the next few years in wind energy use and photovoltaics. So far, these technologies have contributed relatively little to electricity generation in the country. In the long term, wind and sun will be the main sources of electricity generation from renewable energies. In 2050, renewable energy sources should make the dominant contribution to electricity generation with an 86% share. (IEKK, 2014)

A switch to renewable energy sources is also necessary in heat supply. In contrast to the electricity sector, the shares of renewable energies and their annual growth rates are still rather low. Since the dominant use of biomass is reaching its limits, solar collectors, as well as environmental heat and geothermal energy, must grow significantly. (IEKK, 2014)

In the transport sector, so far, the strategy for switching to renewable energy sources has been based on adding fuels that produce from biomass. The assessment of the associated climate protection effects and the further expansion strategy for biofuels are currently being discussed controversially at various levels. (IEKK, 2014)

3. Infrastructure modernization

The rapid increase in weather-dependent electricity supply from wind and solar energy also requires a significant increase in energy storage capacities in the medium to long term. Several technologies are available for this purpose, which convert the excess electricity into other usable forms of energy. More energy storage is required. The potential of heating networks is often underestimated. (IEKK, 2014)

Modernization of energy networks is also required. Electricity and gas national transportation channels must be expanded to avoid congestion. The expansion and conversion of regional distribution grids is also critical for the incorporation of renewable energies. The renewable energy generation systems are usually connected decentrally at this level. (IEKK, 2014)

Simultaneously, grids must become "more intelligent" beyond purely quantitative expansion in order to synchronize energy use and energy supply. This involves the technical data connection of many producing units as well as their cooperative control when energy balancing is required. The infrastructure for such "virtual power plants" to be built, ideally as an open platform with a large number of market participants. This also applies to negative control energy, such as the short-term shutdown of power-intensive activities or the management of cooling energy based on the supply of electricity. (IEKK, 2014)

Action is also required in the municipal and district heating networks. Heat networks should be established in areas where there is a supply of environmentally friendly heat and a matching heat demand. Existing heating networks will be energy-efficiently optimized.

Feeding in renewable energy sources like solar thermal energy, geothermal energy, industrial waste heat, or wastewater heat can be very efficient if both the heating network and the accepting structure to be fed are set to a low temperature. (IEKK, 2014)

There are also considerable modifications to the infrastructure in the transportation sector, land usage, and waste and recycling management in order to meet the criteria of climate protection. (IEKK, 2014)

4. Research and Development

The development and application of renewable energies, as well as a rise in energy efficiency, are critical components of the energy transition. The research and development of essential energy technologies is critical to achieving the aims of the energy transition. The state's universities and non-university research institutions contribute significantly to realizing these objectives.

In the energy sector, Baden-Württemberg already has a diverse, internationally competitive, and significant research landscape. This affects both universities and non-university research institutions. Baden-Württemberg is well positioned in research. (IEKK, 2014)

Baden-Württemberg has, in particular with the Karlsruhe Institute of Technology (KIT), the Helmholtz Institute for Electrochemical Energy Storage in Ulm, the Universities of Stuttgart and Ulm, the Centre for Solar Energy and Hydrogen Research Baden-Württemberg (ZSW) and the Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg for research into solar energy have powerful research facilities that cover the entire spectrum of energy research. (IEKK, 2014)

Research has the potential to accelerate the transition of energy supply away from fossil fuels and nuclear energy and toward renewable energies. It also provides the required foundation for Baden-Württemberg's medium-sized economy to play a leading international role in the new energy industry in the coming years and decades. (IEKK, 2014)

5. participation and dialogue

The state of Baden-Württemberg thrives on public spirit. This also applies to future energy and climate policy. The state relies on the willingness of society to shape the energy transition together. To this end, they want to seek dialogue with all interested groups and actively support models for citizen participation.

To tackle the energy transition together with the citizens and to shape it in dialogue, the state is carrying out a broad-based information and dialogue initiative entitled "Energiewende – machen wir’’ The aim is to present the elements of the energy transition and their interrelationships objectively and to motivate people to take part. Campaign elements include On-site events with the various target groups of the energy transition (citizens, industry and business, nature conservation associations, energy suppliers, etc.) and the ‘’50-80-90 ist das Maß fürs Land’’ measure. (T.Breining, 2013)

Regional " Kompetenzzentren Energie" were also established with state subsidies in all four regional councils to provide unbureaucratic advise to potential investors and project developers, regional associations and planning authorities, but also to citizens and citizens' initiatives. The state government will accompany and support these competency centres vigorously. (IEKK, 2014)

4.3. The areas of action

1. Electricity
2. Heat
3. Transport
4. Land use
5. Material flows

1. Electricity

The state first concern is a reliable, uninterruptible power source. Safe and risk-free power generating, and distribution technologies must. A reliable supply also involves contemporary infrastructure with adequate generating, storage, and grid capacities. Reduced reliance on energy imports through targeted reductions in power demand and transition to renewable energies ultimately contribute to supply security. (IEKK, 2014)

According to the target in the federal government's energy concept, a trend reversal should be achieved in the development of electricity consumption. (BMU, 2010)

They are working on these federal German objectives and scenarios for Baden-Württemberg. According to this, gross power usage is anticipated to fall by 14% by 2050 when compared to 2010. The assumption is that in the future, systems based outside of the country will cover 20% or more of total electricity requirements. (IEKK, 2014)

The share of nuclear energy in electricity generation in the state was planned to fall from 48% in 2010 to 18% in 2020 and will no longer contribute at all from 2023 when the ‘‘Neckarwestheim II’’ reactor is shuts down. (IEKK, 2014)

In contrast, the share of renewable energies in electricity consumption was expected to increase from 14% to 36% in 2020 and to 89% in 2050. This considers that the electricity imported to Baden-Württemberg will also increasingly come from renewable sources. (IEKK, 2014)

Since the potential of hydropower and bioenergy is naturally limited and electricity generation from geothermal energy is unlikely to make any major contributions, the growth is based primarily on the expansion of wind power and photovoltaic systems. However, an essential task of the necessary change in the power supply is also to synchronize the energy demand with the weather-dependent fluctuating power generation from wind power and solar radiation through flexible generation, storage, and controllable loads. The security of supply must be always guaranteed. (IEKK, 2014)

For this, efficient and flexible power plants needed that supplement the renewable energies and can react as quickly as possible to fluctuations in wind or solar power. The market has only offered insufficient economic incentives for investing in such systems so far. The state government will not permit any development where security of supply would be jeopardized by a lack of capacity to stabilize the power grid. That's why the state advocate for appropriate Framework conditions, e.g., in the form of a capacity market, that give investors security in flexible gas power plants. (IEKK, 2014)

In addition, the demand for electricity is to be kept as flexible as possible and adapted to variable power generation by means of time-based control of the needs in industry, trade, commerce, and households. At the end of this transformation process there is a new, intelligent energy system that optimally networks power generation, consumption control and storage. (IEKK, 2014)

2. Heat

The long-term goal is to make the heat supply in Baden-Württemberg climate-neutral by 2050. To be able to achieve this goal, today's heat requirements, especially in the building sector, must be consistently reduced. The greatest potential for a sustainable heat supply in the country lies in saving energy and using it more efficiently.
Saving energy by reducing demand (sufficiency) and increasing efficiency when providing energy (efficiency) is therefore the top priority. (IEKK, 2014)

However, efficiency and sufficiency are not always found together. The specific heating requirement per square meter of living space has fallen significantly in recent years due to higher energy standards in the building sector. On the other hand, today the individual takes up more square meters of living space than in the past. The gain in efficiency is thus consumed again (rebound effect).

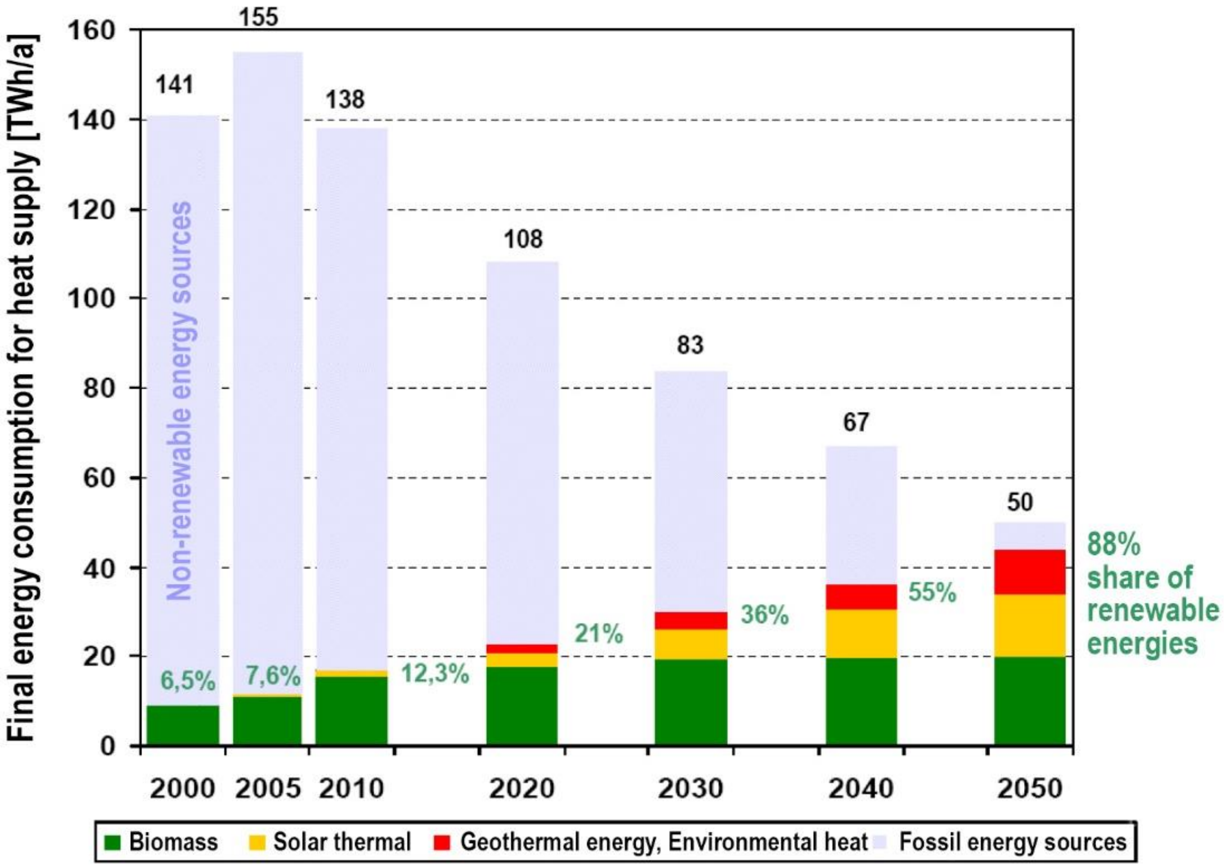
The outstanding importance of energy-efficient building renovation is also considered in the federal government's energy concept. At the same time, in practice, an effective and ambitious framework is required at the federal level to be able to achieve the goals, especially when it comes to reducing the heat requirements of buildings. (IEKK, 2014)

Even after extensive energetic modernization, there will still be a residual heat requirement for space heating and hot water preparation. This demand should then be covered based on renewable energies.

To transition to renewable energy, a country's potential must be utilized consistently, and infrastructure must be aligned and maximized properly. Switching to renewable energies is not only vital for climate conservation, but it can also make financial sense. In contrast to today's heat supply technologies, such as oil or gas boilers, the costs of a heat supply based on renewable energy are considerably easier to calculate in the long run when using solar thermal systems. This is because future variable fuel costs will be substantially lower, and no one can anticipate future price developments with any certainty. The early investments and system upkeep are then largely responsible for future energy expenses.

To specify the objectives of the federal government's energy concept, key energy policy scenarios were developed which assume a very significant drop in energy requirements for heating buildings in the future for the area of heat supply. Based on the federal German scenarios, the future developments in final energy consumption were transferred to Baden-Württemberg. (J.Nitsch, 2012)
According to this, the use of fuel for heat supply (excluding the use of electricity for heating purposes) will fall 66% by 2050. At the same time, the share of renewable energies in the heat supply can be increased to 88% by 2050. (Figure 28)

Figure 28: Possible development of heat supply according to ZSW report 2011



Source: ZSW/Nitsch: Gutachten zur Vorbereitung eines Klimaschutzgesetzes, Stuttgart, Dezember 2011

3. Transport

The Council of Ministers of the State of Baden-Württemberg decided on February 7, 2012, that the transport sector in Baden-Württemberg should emit 20% to 25% less carbon dioxide in 2020 compared to 1990. The country's climate protection law provides for a 90% reduction in CO2 emissions across all sectors by 2050. (IEKK, 2014)

The targets for reducing emissions and pollution in traffic can only be achieved through many individual steps and changes. The goal is a new culture of mobility. Many mobility needs can be met with little or no traffic, be it through new communication technologies or through local supply. The transport required in the future should be comfortable, affordable, environmentally friendly, and intelligently networked. (IEKK, 2014)

From the point of view of the state government, mobility is an indispensable part of the quality of life of the population and a basic requirement for an efficient economy. A needs-based transport infrastructure is necessary to handle commuter traffic and transport. In addition, logistics and the mobility economy are important sectors for technical, social, and cultural innovations. Baden-Württemberg has the opportunity to create models that can be marketed on a global scale and are sustainable at the same time. Products and services for sustainable mobility can become competitive and location factors. (IEKK, 2014)

4. Land use

Baden-Württemberg's agriculture can significantly further reduce its greenhouse gas emissions. This applies not only to the climate gases methane (CH4) and nitrous oxide (N2O) considered in the balance presented here, but also to other emissions that occur during land cultivation or the production of fertilizers and pesticides and are balanced elsewhere will. One possible approach to this is the expansion of organic farming in Baden-Württemberg. (IEKK, 2014)

In addition, methane and nitrous oxide can be effectively reduced by optimizing the storage and application of manure. An increase in the efficiency of the use of mineral fertilizers and a reduction in nitrogen balance surpluses in crop production also led to a significant reduction in the amount of nitrous oxide. (IEKK, 2014)

A more efficient and therefore more climate-friendly milk and beef production must also be achieved, whereby the overall system of milk and meat production and not just the individual animal performance must be in the foreground. Efficient, climate-friendly milk and meat production in conjunction with further measures can result in a reduction to 3.121 million t CO2equ by 2050. (IEKK, 2014)

Climate change and the tasks of sustainable agriculture:

Hardly any other area is as badly affected by climate change as agriculture. The level of yield and the quality of the harvested products are significantly influenced by temperature and precipitation. Agriculture is therefore forced to adapt to climate change. However, agriculture can also make a significant contribution to climate protection by lowering its energy consumption, reducing production-related greenhouse gas emissions, using resources even more efficiently and providing raw materials for energy production.

The main task of multifunctional agriculture is still to ensure food security. In plant and animal production, in addition to climate protection, the requirements of protecting soil, water and biodiversity as well as animal welfare must also be considered. (IEKK, 2014)

Forestry: Concrete steps for climate protection:

Sustainable management is decisive for the preservation and expansion of the storage capacity of the forest.

In Baden-Württemberg, the public forest has been managed in a near-natural way - e.g., with targeted promotion of mixed forests that are as low-risk as possible, with conscious renunciation of higher timber yields, with soil-conserving timber harvesting methods, regeneration with site-specific tree species and extensive renunciation of clear-cutting during timber harvesting. The conservation and the standards for this sustainable management are regulated in the state forest law, their implementation is ensured by the forest administration. (IEKK, 2014)

Another strategic focus of the state government is reducing the use of cement and steel by increasing the use of local wood as a building material.
The energetic use of wood as a raw material can make a significant contribution to climate protection if it is carefully planned and considers the complex interactions of sustainable forest use. Energetic measures such as efficient power generation and heat supply through a central wood-burning system with local heating make a significant contribution to climate protection, because only as much CO2 is released as was previously removed from the atmosphere and the use of fossil fuels for energy production is avoided. (IEKK, 2014)

Finally, suitable forest areas in windy locations are to be developed so that wind energy can become a mainstay of the country's energy supply in the long term. The use of wind energy in the forest should make an appropriate contribution to the goal of wind energy generation in Baden-Württemberg, as stated in the cabinet decision of February 7, 2012. (IEKK, 2014)

5. Material flows

The increasing global demand for consumer goods is leading to increasing pressure on the environment and competition for resources. Important resources such as metals or phosphates are used to drive economic growth as if they were unlimited - this is not sustainable in the long term. (IEKK, 2014)

Around to accelerate the move to renewable raw materials, new applications for renewable raw materials must be researched and developed and introduced to the market.
Improved recycling and the use of waste also play an important role. In the areas whose emissions have the greatest impact on climate change, the IEKK pursues the following goals and strategies:

Cement/building materials:

In cement production, by reducing the proportion of clinker in the cement, a reduction in process-related CO2 emissions is possible and is the goal. Various methods are being researched worldwide to further minimize carbon dioxide emissions in cement production. The extent to which these efforts will be successful cannot be estimated, that's why the IEKK assumes a further reduction in carbon dioxide emissions from the cement industry can only be achieved by capturing the CO2 in the production process and subsequent storage or recycling of carbon dioxide (e.g., power-to-gas, CO2 binding in cement¸ CCS). The IEKK assumes that a 50% reduction in emissions from the cement industry (-1.05 million t CO2) can be achieved by 2050 using appropriate technologies. (IEKK, 2014)

The importance of innovative processes for further reducing CO2 emissions from the cement industry is made clear by the fact that without such processes the cement industry would cause almost a third of Baden-Württemberg's greenhouse gas emissions in 2050. For example, the development of "Celitement" at the Karlsruhe Institute of Technology should be mentioned. "Celitement" is a cement whose production is not only energy-saving and resource-saving, but also saves up to 50% CO2 emissions. (IEKK, 2014)

Despite the positive development in cement production, an attempt must be made to further reduce the production of cement with high carbon dioxide emissions on the one hand and to replace the building material wherever possible with less climate-relevant and renewable materials on the other. Therefore, the importance of wood as a domestic, renewable raw material for the construction industry should be further promoted. (IEKK, 2014)

Waste and recycling management, wastewater management:

The aim of the policy is to close material cycles as far as possible. This not only protects our natural basis of life but also secures valuable raw materials for the local economy.

However, significant amounts of waste will continue to exist for the foreseeable future. As much of this as possible should be recycled in high quality. The disposal of waste must be limited to what is necessary, for example, to remove pollutants. When it comes to the disposal of residual waste from households, thermal treatment is the case. The cessation of landfilling municipal waste has already paved the way for a drastic reduction in methane emissions from landfills. (IEKK, 2014)

In wastewater management, an important goal is to further minimize methane emissions. The connection of further buildings to the sewage system contributes to this, which prevents methane leakage from septic tanks. In more sewage treatment plants than before, the digester gases are to be used to operate combined heat and power plants; where combined heat and power plants already exist, the escape of methane into the environment should be minimized through modernization. (GMI, 2013)

The co-incineration of sewage sludge in cement and coal-fired power plants in Baden Württemberg contributes to climate and resource protection in two ways. On the one hand, valuable fuels are saved and, on the other hand, the co-incineration of the sewage sludge, which is considered climate-neutral, also contributes to the reduction of CO2. In the long term, the resources from the wastewater should be used even better. (IEKK, 2014)

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5

MUNICIPAL CLIMATE ADAPTATION IN LAND-USE PLANING IN THE PILOT PROJECT OF THE SPINELLI SITE / GREEN CORRIDOR NORTH-EAST DEVELOPMENT IN MANNHEIM

5.1. Overview

Climate change is not only a global, continental, or regional phenomenon, it also takes place on a local scale as humans change land use and thus the physical properties of the land surface, which significantly affect those of the near-surface atmosphere.

Because there is nearly always forests in Baden-Württemberg (with a high proportion of beech) without human intervention (Müller T 1992), the cool inner forest climate is what would determine the natural climate. The climate is already changing noticeably because of the city, its buildings, sealing, waste heat from vehicles and apartments, etc. It is leading to significantly warmer conditions "heat island effect".

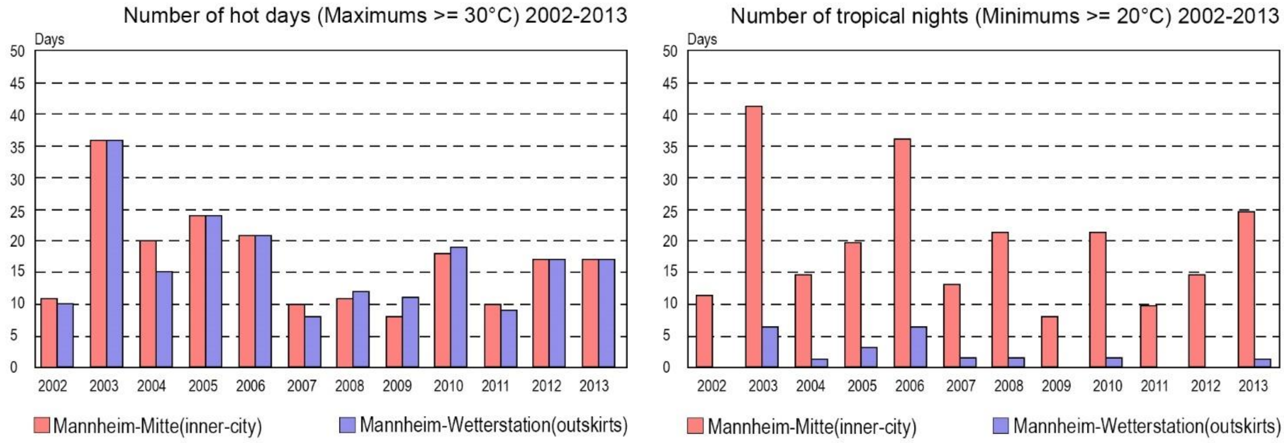
The currently existing urban overheating is now accompanied by another effect: global climate change. According to the models and forecasts for Baden-Württemberg more summer days, hot days and tropical nights will determine summertime in the future. The urban effect of overheating therefore does not seem to be reflected in the forecasts - but must be considered separately. (Ministry of the Environment, Climate Protection, and the Energy Sector Baden-Württemberg, 2012)

For the city of Mannheim, the Ökoplana office examined the heat island phenomenon and the associated heat stress situations “hot days” and “tropical nights” in more detail.
The data from two stations were compared, with one representing the inner-city situation (Mannheim-Mitte, Reichskanzler-Müller-Strasse) and the other a situation on the outskirts of the city (Mannheim weather station, MA-Vogelstang).

No clear difference or trend in the number of hot days (Tmax >= 30 °C) could be determined over the years 2002–2013. However, the increasing stress in inner-city areas can be clearly observed due to an increased number of tropical nights, which is 5 to 10 times higher than in the outskirts of the city (Figure 29).

The nocturnal overheating that is generally found in cities can be mitigated when there is little wind at night, primarily via so-called corridor winds (UHI circulation) (Kuttler 2009).
If the topography is suitable, the overheated rising air in the city can lead to an influx of cooler air from surrounding areas. It is therefore even more important to have uninterrupted green corridors and areas where cold air is produced in the inner-city area to counteract the trend of overheating at night.

Figure 29: Heat Island effect: comparison of the number of hot days and tropical nights in inner-city and outskirt areas.



Mannheim in the years 2002-2013. (Source: Office Ökoplana)
Source: Deutscher Wetterdienst, LUBW Baden-Württemberg: Values edited

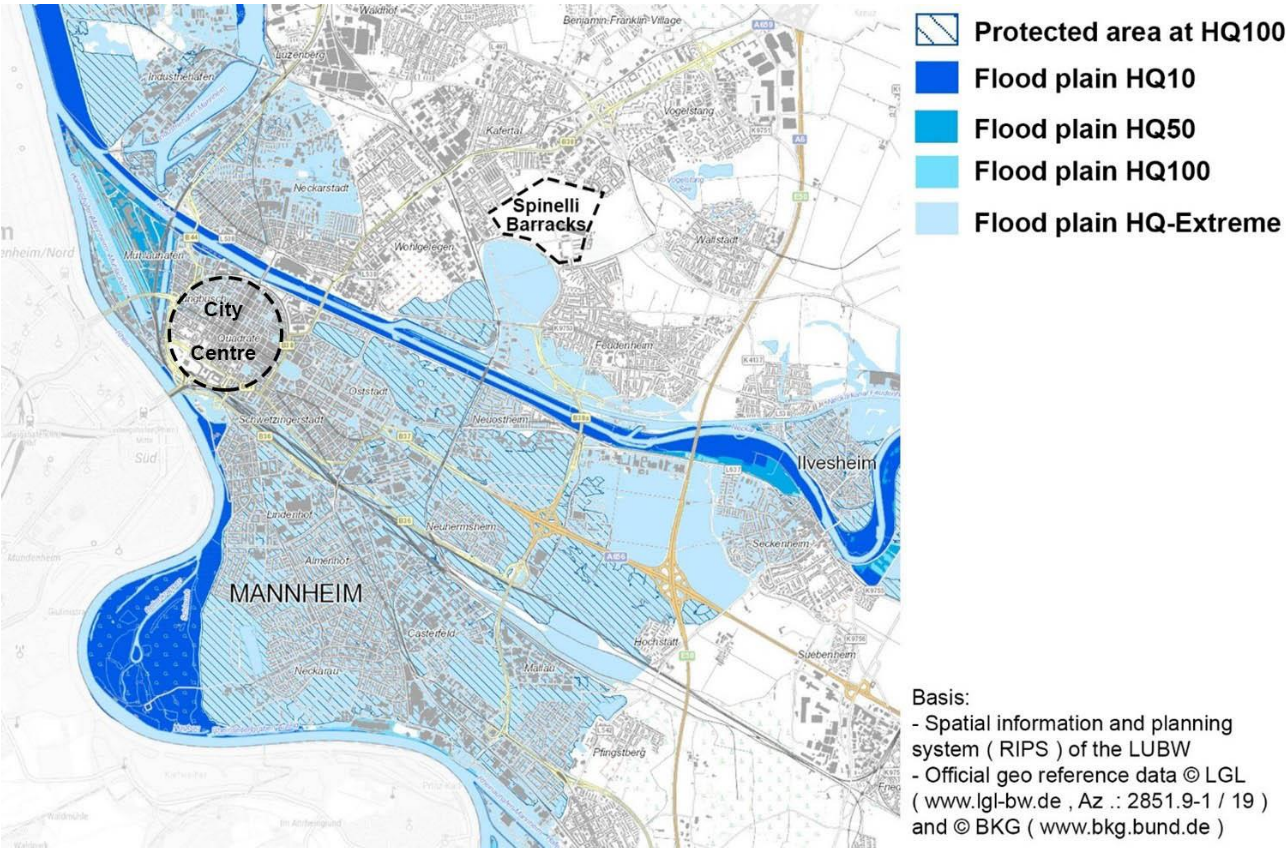
Conversion areas as an opportunity to improve the urban climate

The concept of conversion describes the conversion of former military areas into subsequent civil uses designated. In the Rhine-Neckar metropolitan region, more than 500 ha of former military areas have been redeveloped and abandoned between 2007 and 2014 and are now being used for civilian purposes.

Some of the conversion areas are in the city centre or, as in the case of Spinelli Barracks, within green breaks between built-up parts of the city.
The vacancy of these areas offers valuable opportunities for urban inner development. However, it should be noted that many of the places are contaminated as a result of military use, which can have a negative impact on proposed following uses.

Another data provides information about the flood risk of the site and adjacent areas, as assessed by the State Institute for Measurements and Nature Conservation (LUBW, 2018). The area is slightly elevated compared to the southern and partly western areas (Figure 30). The further use of such areas depends on many factors such as the location in the city area or the city's needs. However, due to urban overheating on the one hand and the increased heat problems to be expected because of climate change on the other hand, large outdoor and cooling areas “cold air production areas” in cities are becoming increasingly important. From the climate adaptation point of view, the goal should therefore be not to ‘’completely’’ build on these areas, but to develop them as open and recreational areas if necessary.

Figure 30: Overview of the location of the Spinelli Barracks conversion area opposite downtown Mannheim, using the example of the flood risk assessment map of the State Institute for Measurement and Nature Conservation (LUBW).



Source: KLIMOPASS–KomKlim Abschlussbericht, (2018), p.12

5.2 Climate protection versus climate adaptation

Climate protection and climate adaptation stand for two different approaches in the scientific and political context to take climate change into account.

Climate protection means the reduction of climate-relevant emissions.
Climate protection concepts should contain the topics of saving greenhouse gases, energy efficiency and the use of renewable energies.
They include the areas of space management, own properties, municipal procurement, IT and data centres, street lighting, private households and the areas of industry, commerce, trade, and services as well as renewable energies, mobility, wastewater and waste (Nationale Klimaschutz Initiative, 2017)

Climate adaptation is an adaptation to the consequences of current and future climate change. It is about “improving resilience to climate change in such a way that its consequences can be managed” (Commission of the European Communities 2009).

At the federal level, the topic was processed as a German adaptation strategy (Federal Government 2008) and in the form of an adaptation action plan.

In the municipal and especially urban context, there are diverse fields of adaptation, such as human health (especially thermal comfort), water balance and water management, construction, and urban planning.
The primer on urban climate offers practical standards for urban development., for example, "a systematic creation of ventilation corridors that ensure the deepest possible penetration of fresh air from the surrounding area into the city centre" and "increasing the proportion of urban green spaces" to counteract the urban heat island effect (Reuter et al. 2012, p.69f)

From the descriptions, it is clear how extensive and cross-sectional the task of climate protection is as well as adaptation, and its predictable the huge new task the municipalities will have to cope with in the future.

As of November 2016, an additional staff position within the administration responsible for climate protection management was funded by the federal government in Baden-Württemberg in a total of 24 cities, three municipalities, two district towns, ten districts and the Rhein-Neckar Region Association (Deutsches Institut für Urbanistik, 2016).

The conversion was embedded in Department 61 (Urban Planning) in Mannheim as an internal "Project Group Conversion." The topic of climate adaptation is in the division 67 “Environment and Green Spaces."
A so-called climate control centre was integrated, which initially dealt mainly with climate protection issues, but now also represents more and more climate adaptation issues.

This department had conducted an internal workshop initiated by the climate control centre (an informal instrument of the procedural/structural type), and the result was made available to the project. (KLIMOPASS, 2018)
The workshop is part of the work to create a guide that will include both climate protection and climate adaptation issues.
Based on the motto ‘’ Leitfaden für klima- und umweltgerechte Stadtentwicklung’’ (Guidelines for climate-friendly and environmentally friendly urban development), five relevant planning phases developed together with their paramount planning and control instruments (Table 3).

Table 3: The five relevant planning phases

Phase	Designation	Brief description	Instruments
1	Urban development planning	Among other things, examination of the general conditions of the location; Query of planning requirements, initial inventory and situation analysis on site, clarification of planning objectives, examination of alternatives, and planning information.	– framework plan – Open space concept 2030 – Model spatial order – Urban climate analysis – Clean air plan
2	Urbanistic design phase	Among other things, evaluation of the location, urban dimension of planning, concrete objectives, planning and case variants, (final) setting of priorities, competitions, planning information.	– competitions (Urban development and open space planning) – climate report
3	Land-use planning	Among other things, legally binding determinations, in the B-plan.	– development plan (superordinate) – Green space plan, environmental report – Tree protection statute – Greening statute
4	contractual regulations	e.g., public law contracts, urban planning Contracts, private law contracts. However, this is true. only if the city owns the property to be built on area is.	– Urban planning contract - Purchase contract
5	implementation and control	E.g., construction inspection, success control of the planning, if necessary Certification, user advice etc.	– Certification

Source: KLIMOPASS–KomKlim Abschlussbericht, (2018), p.18

5.3. The Pilot project: Spinelli barracks in Mannheim

In terms of planning law, the area is a particular area in the conversion process. It differs from the usual areas of urban development by its large area. The new development and redesign of these conversion areas are particularly relevant to the structure of the city Character, which is why the planning is based on more comprehensive and longer-term aspects to deal with the topic. To process these questions, in Mannheim in the field of Urban planning temporarily the special units "Project Group Conversion" and the "BUGA Society" launched as relevant actors. (KLIMOPASS, 2018)

The area of the pilot project, with a total of 80 ha is in the middle of what is currently the most continuous and therefore most important green corridor in terms of its climate-ecological balancing and relief effect: the Northeast green corridor. (Figure 31)

In contrast to many other inner-city conversion areas (e.g., in Heidelberg) the vacated area should not be developed as building land or only to a small extent. The central part of the area will instead be integrated into the existing green area as open space. The current Barracks development is the final "stopper" that needs to be opened to make the green corridor continuous from the outside areas into the city centre, and specialists have evaluated its urban climatic efficacy to optimise. (Ökoplana 2013)

Expert opinion is a mandatory prerequisite for the issues in the subsequent planning and politics to accurately portray the procedure. Because analogy findings, even if they have a high level of plausibility, have less influence and argumentation force when compared to other interests.

In every land use plan, superordinate laws and planning works must be observed. These are set out below in relation to the planning of the pilot project is therefore briefly presented. spatial planning requirements State level are based on the Baden-Württemberg State Planning Act of 22 October 2008.

The planning instrument is the state development plan (LEP), which is “the framework-setting, integrative overall concept for the spatial order and development of the country” (LEP, 2002).

For Baden-Wuerttemberg the 2002 version currently applies. The city of Mannheim is part of the Rhine-Neckar conurbation and classified as a metropolitan location. These so-called regional centres are intended to Guarantee the supply of "highly qualified and specialized facilities and jobs". These goals always compete with other goals, such as climate adaptation.

The goals and Principles of the state development plans are set out in the respective regional plans in terms of subject matter and space concretized. The ‘’Einheitliche Regionalplan Rhein-Neckar, (2012)’’ (Uniform Regional Plan Rhine-Neckar) applies to

Mannheim. Climate protection and air pollution control are specifically addressed and discussed at this level for the first time.

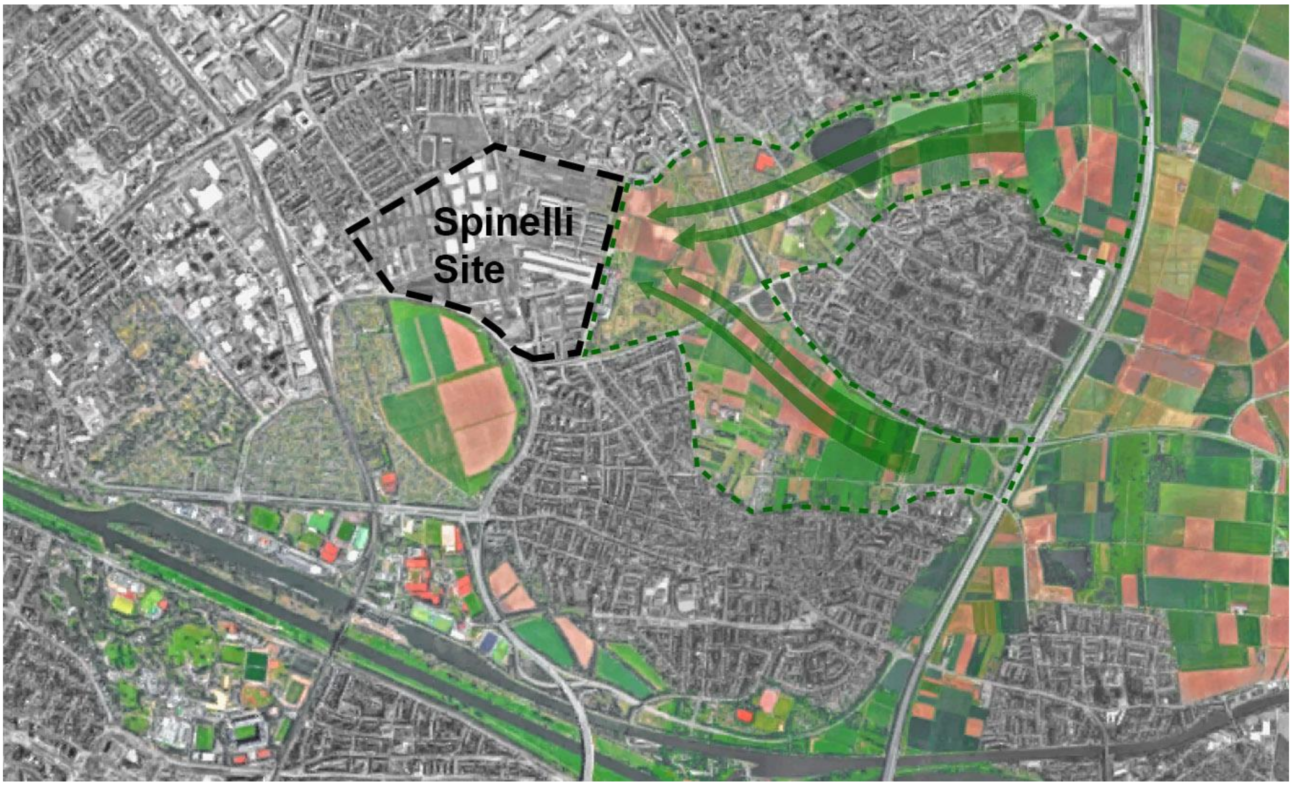
There are the following principles:

a. Secure the cold and fresh air origin sites, as well as the cold and fresh air outflow pathways, and restore them as needed.

b. A rationale aspect of regional green corridors/green breaks is the compensation of urban climatic loads in open spaces that are essential from a climate-ecological standpoint. These open spaces are created by buildings and other structures. Measures that can obstruct the generation or transport of fresh and cold air must be avoided (explanatory map of nature, landscape, and environment).

c. In climatically valuable areas, care should be taken to ensure that systems emitting disruptive emissions do not obstruct the path of air currents close to the ground or pollute them with pollutants. However, unlike the regional plan's goals, there are no binding conditions for compliance.

Figure 31: Conversion area which allows the continuation of the cold air flow and fresh air of the earth's surface from outside areas.



Source: Google Earth, Map data 2022,
Modified by author.

The Spinelli Barracks inner-city conversion area is only to be partially developed as building land. The central area of the vacated area, on the other hand, will be integrated into the existing green corridor as an open space. The municipality has decided to include them in a federal garden show BUGA 2023. (KLIMOPASS, 2018)

Through this planning

1- A newly created cold air generation area in the vicinity of the city centre,
2- Further develop the cold air channel from the north-east towards the city centre,
3- Created a continuous green corridor from the north-east towards the city centre,
4- An existing open space pattern is continuously networked.

5.4. Strategies to identifying climate adaptation options

Determination of the local climate and the impact of planned development

A suitable climate adaptation strategy must be tailored to the local, climatic, and ecological conditions. Therefore, these must be specified in the planning process. To determine suitable adjustment options, the following aspects of the Spinelli surface and environment were clarified in advance. (KLIMOPASS, 2018)

Table 4: Overview of the climatic-ecological parameters considered for determining the local climate.

Characteristics	Basis for	Expression at Spinelli Park and consequences
Bioclimate	Assessment of the recent, thermal stress situation of people on site and the effect of the expected climate change.	Mannheim lies in the long-term average in very frequent thermal stress. The expected increase in temperature due to climate change will exacerbate the problem. Source: Bioclimate map of Germany, German Weather Service
Terrain structure and relief	Assessment of the cold air situation (mountain-valley system ...) and the drainage situation ("water flows to the lowest point"), especially in heavy rainfall.	Largely flat, recently a slight drop from the planned building area in the direction of the green corridor (< 1%) very sensitive cold air currents. Largely flat terrain is ideal for infiltration. Any terrain modelling requires precise consideration, especially for heavy rainfall.
Ventilation situation, wind characteristics	Assessment of the circulation situation for the residents (fresh air, cooling "from outside").	Prevailing wind direction: south to southwest. Due to the use of land, there are sometimes significant local differences. Assessment of the ventilation of urban development: moderate to poor (Ökoplana 2013). A priority goal should therefore be to improve the ventilation situation.
Climatic balancing rooms, cold air situation	Are there climatic compensation rooms in the area/accessible on foot? Could (did) the open spaces have a positive effect on the planned construction area?	Due to the location on the planned north-east green corridor, the ventilation situation and cold air effect for the adjacent, existing and planned buildings can be significantly improved (Ökoplana 2013). The aim is therefore to create the highest possible fresh/cold air permeability. 2013).
Geology and floor	Can accumulating precipitation water be seeped away on site or are other solutions necessary? In the case of military areas: (where) are there any contaminated sites?	Soil material capable of percolation is to be expected in the entire area. River sediments, typically sand and gravel sands from the Pleistocene, are covered with fine sands/loams possible, partly loess. Source: The City of Mannheim, water study.
Groundwater	Can rainwater be infiltrated without any problems (GW not too high)? What is the irrigation situation of the vegetation, is there a supply via groundwater/capillary water?	The average depth of the groundwater is 9.80 - 13.00 m Source: City of Mannheim, water study. Infiltration is therefore possible without any problems. There is no natural water access underground for the vegetation → evaporation processes for cooling must be promoted via above-ground water supply.
Flood risk	Assessment of the recent flood risk. If heavy rain with higher water volumes occurs more frequently due to climate change, this could increase the risk of flooding from overflowing watercourses.	The LUBW flood risk assessment map currently indicates for the extreme case (HQextrem) no risk of flooding for the Spinelli Barracks area, although the floodplain would be affected. Source: (LUBW 2018)

Source: KLIMOPASS–KomKlim Abschlussbericht, (2018), p.27

A necessary basis for assessing the recent situation was the preparatory work of the Ökoplana office.
These related both to the overall urban area (city climate analysis 2010) and specifically to the Spinelli Barracks area.
An overview of the climate-ecological parameters to be considered Table 4 shows the determination of the local climate.
Table 5 give an overview and content of the climate-ecological analyses and reports for the Spinelli Barracks.

The following statements were made about the local climate in Mannheim (Ökoplana 2013):

- The average number of days with heat stress is currently at the top of Baden-Württemberg with 35.1-37.5.

- Forecasts indicate an increase of 11–15 additional hot days (>30 °C) and 25–30 by 2055 additional summer days (>25 °C).

- The city centre is clearly overheated, on the outskirts (MA-Vogelstang) it is over 4.5 K cooler in the Summer.

- Average wind speed is 2.0–3.0 m/s) ventilation is moderate to poor. Higher wind speeds, especially in winter and the transitional seasons.

- High heat loads in summer due to high air temperatures combined with low ground level ventilation.

- Frequent inversion weather conditions (> 225 days/year) with increased air pollution and fog formation. Fresh air is then only supplied via green corridors.

Table 5: Overview and content of the climate-ecological analyses and reports for the Spinelli Barracks area, commissioned by the City of Mannheim.

Document	Short description	Topic, Reviews, or Recommendations
Urban climate analysis Manheim (Ökoplana 2010)	Part of the overall urban climate atlas 2010. The focus was on the city centre and barracks areas. Climate-ecological basis for the award of the competition "Green corridor north-east and Federal Garden Show 2023".	Evaluation of the bioclimatic conditions within the building, determination of thermal stress zones based on the building structure, calculation of the bioclimatic stress. Determination and evaluation of cold air production areas, evaluation of the thermal compensation capacity.
Climate report Mannheim green corridor Northeast / Spinelli Barracks + Federal Horticultural Show 2023 (Ökoplana 2013)	Examination of the spatial concept for climate issues. Investigation and presentation of the climatic-ecological functional processes in the green corridor north-east / Spinelli Barracks; Evaluation of possible land use changes in the Spinelli Barracks area; Evaluation of the planning concept.	Recommendations: breaching the Spinelli Barracks flow dynamic barrier; demolition of the barracks halls; Space between Käfertal / ImRott and the remaining Spinelli development of at least 450m; no trees/shrubs perpendicular to the course of the green belt; car-free green belt; no larger buildings in the central green area; Minimization of the additional thermal load of the planned new construction through appropriate measures; Specific recommendations for the climate-ecologically optimized execution of the Käfertal-Süd rounding off.
Supplementary climate Report I (Ökoplana 2016a)	In-depth climate-ecological examination of the winning design for landscape and open space planning by the office of RMP Stephan Lenzen landscape architects (local cold air movements, flow dynamics, thermal conditions).	The planning draft by RMP implements the climate-ecological objectives very well. Open space and green structures strengthen the function of the green corridor as a channel for cold air and fresh air; Rounding off Käfertal-Süd offers bioclimatically favorable residential developments without seriously burdening existing buildings.
Variant check (Ökoplana 2016b)	Investigation of the effect of planning variants on cold airflow. The city of Mannheim submitted the following scenarios for examination: a) RMP planning draft without underground hall; b) Planning draft RMP without U-Hall and planned peripheral development "Im Rott" along the Anna-Sammet; c) Planning draft RMP without U-Hall, without peripheral development "Im Rott" and commercial area Talstraße.	U-Hall as a flow obstacle: demolition without simultaneous demolition of the commercial buildings is not relevant from a climate-ecological point of view; Fragmentation of the U-Hall significantly reduces the negative impact. No peripheral development south of Anna-Sammet-Str. only of minor importance for the local cold air situation, their development parallel to the flow has a positive effect.
Climate report on current planning draft (Ökoplana 2016c)	Update the report from 2016 based on the updated planning draft of the RMP office. The city of Mannheim also submitted the following scenarios for examination: a) the current RMP planning draft without U-hall fragments and green courtyard, b) as a and additionally without development in the "Am Wingertsbuckel" area.	In both scenarios of the city of Mannheim, the local cold air productivity and flow rate increase in the areas without buildings (remaining the front buildings at the Grünhof continue to have a flow-impeding effect). General recommendation: Climate adaptation measures to summer heatwaves in Käfertal-Süd (new building) based on a multifunctional modular principle; for example, the Use of intensive green roofs, targeted tree planting, or the use of water.

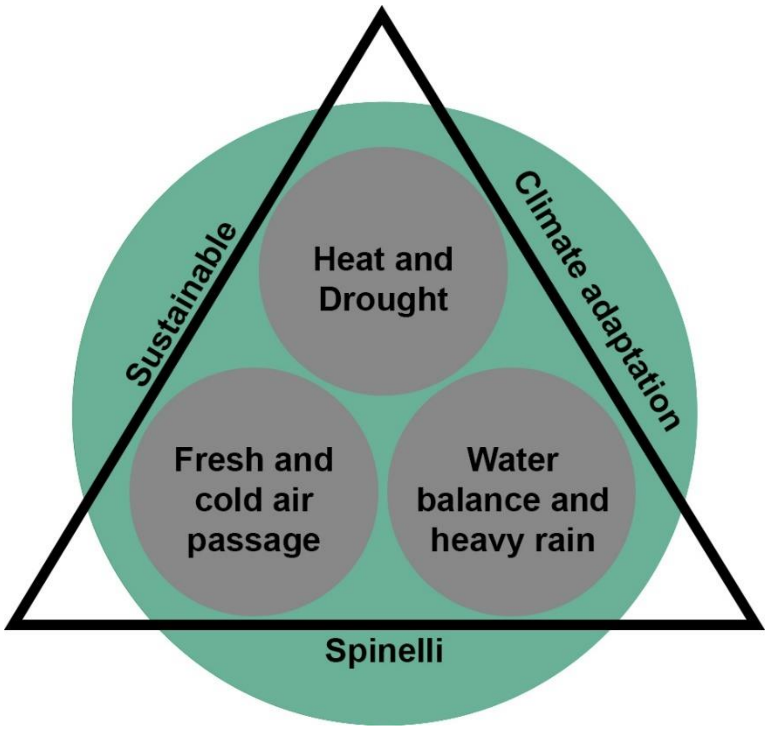
Climate report on current planning draft (Ökoplana 2017a)	Update of the report from 2016 based on the updated planning draft of the office RMP (master plan draft) with concrete use of space; Comparison of the planning case (Spinelli Barracks) with the planning case (continuous green corridor & land use). Focus: cold air, ventilation conditions, temperature distribution (2m).	The planning draft strengthens the function of the green corridor as cold air and fresh air path; Rounding off Käfertal-Süd offers climatically favorable residential developments without seriously burdening existing buildings. Recommendation: Climate adaptation measures to summer heatwaves in Käfertal-Süd (new building) based on a multifunctional modular principle; Use of, for example, intensive green roofs, targeted tree planting, or the use of water.
Climate-ecological brief statement (Ökoplana 2017b)	Examination of the climate-ecological impact of two planning variants of a school located in the TV Käfertal sports area in comparison to the current master plan (report from 05/31/2017).	Additional aerodynamic and thermal loads due to new construction; Recommendation: minimize alternative location or barrier effect and heat radiation of the buildings (optimize building location and size; minimize tree planting, sealing, greening of buildings, light colors)
Climate-ecological opinion on inventory plan Green corridor north-east (Ökoplana 2017c)	Examination of the RMP green corridor design from 2017 with partial preservation of existing paved areas and individual building elements on the Spinelli site.	Remaining large areas of in-situ concrete reduce the favorable cooling effect of the green belt; solitary fragments are of secondary importance. Recommendation: Removal of the in-situ concrete between U-Halle and Anna-Sammet-Strasse, and greening of the ballasted track bed.
Brief statement climate-ecological effects of open space design in Auweiher area (Ökoplana 2018)	Examination of the RMP draft of 2018 for the development of a naturally designed body of water. Recommendations of the climate report from October 25th, 2013, for the development of a near-natural body of water are included.	Improvement of the "cold air production", habitable areas thermally relieved. pond worms cold air to a negligible extent. The cold air obstacle effect of the groups of trees is not serious. Recommendation: no further extension of the wooded areas.

Source: KLIMOPASS–KomKlim Abschlussbericht, (2018), p.29

5.5. Determination of climatic adaptation fields in the project area

Climate change affects different locations in different ways, with varied repercussions for action. This, like all cross-sectional tasks, presents difficulties for the territorially organized municipal administration. Furthermore, comments on medium-term (2022-2050) and even longer-term (2071-2100) changes in individual fields of action (e.g., temperature, wind, precipitation) and parameters (mean values, extreme values) can be anticipated with varying degrees of certainty. This is not discussed in depth in the recommendations for action, but it is considered.

Figure 32: graphically summarizes the adjustment areas relevant to the Spinelli Barracks area.



Components of a sustainable, planned adaptation to climate change for the planning area Spinelli Barracks.
Source: KLIMOPASS–KomKlim Abschlussbericht, (2018), p.104
Graphic: D. Böhnke

Summer overheating and dryness

According to the climate forecasts, a significant increase in temperature and an extension of the hot spells in summer is expected in future.
The prolonging of hot spells causes the drought to worsen and the cooling via latent heat flows ("evaporation losses") to decrease. The result is an increase in the number of days with bioclimatic/medical meteorological stress on people.

Measures must consider both the conditions of the temperature increase with predominant insolation during the day and those with predominant radiation and cooling at night.
The urban and landscape planning response to this challenge must therefore aim to reduce the heating of the ground-level atmosphere due to summer radiation and to promote nocturnal cooling. (KLIMOPASS, 2018)

According to KLIMOPASS report, the reduction in warming can be achieved through following measures:

- Promote evaporation processes in open spaces, especially during dry periods. This contributes to the cooling of the air, as the energy required for evaporation is extracted from the evaporating surfaces and, above them, also from the surrounding air. This means that the focus is on water availability in the dry heat waves of future summers. The high energy and maintenance costs of artificial bodies of water (fountains, etc.) make it sensible to first look for near-natural solutions.

- The better the growth and health of the trees, the better they fulfil their cooling function through shading and transpiration. Therefore, the dimensions of the planting pits should be as generous as possible, and the availability of water should be guaranteed by local storage systems. In addition, tree species appropriate to the location should be used.

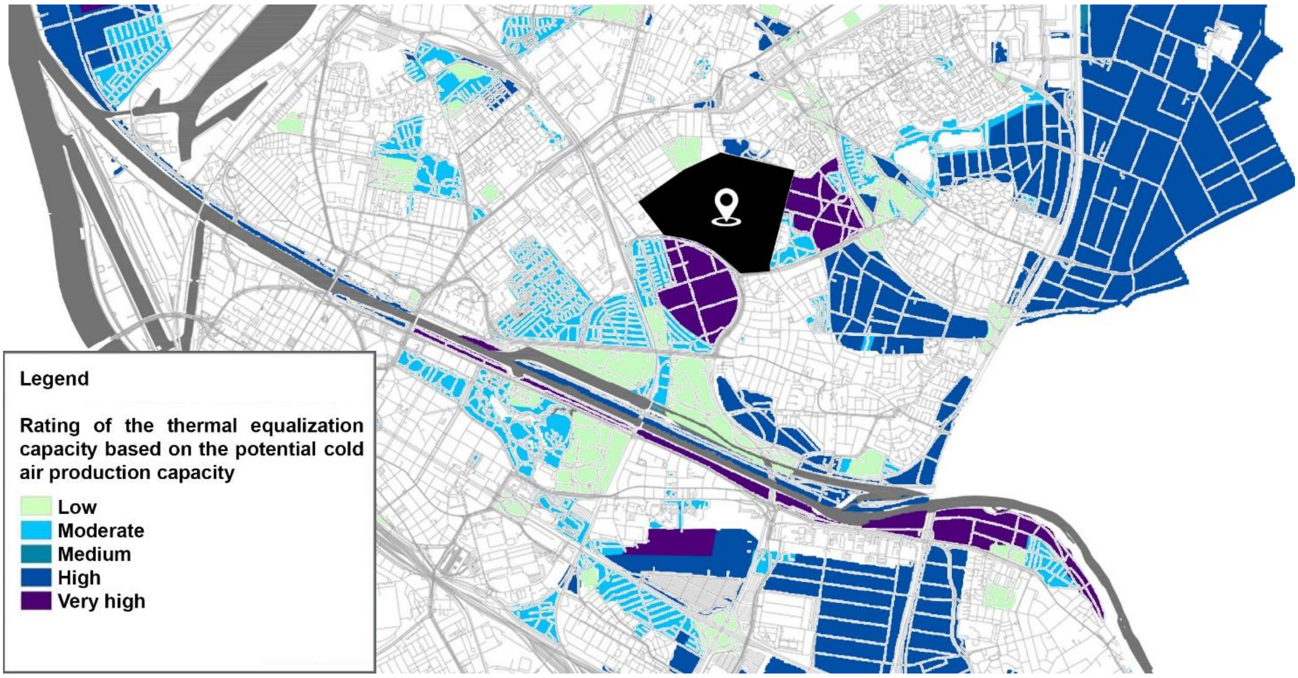
- Avoidance of multiple reflections of the radiation in the street space (climatological: within the UCL-Urban Canopy Layer). The radiation reflected from light-coloured materials must not be directed onto the opposite facade or the street surface, as otherwise the positive effect of the reduction in absorption would be cancelled out in total. It is best to reflect into the upper hemisphere and - if not possible - onto vegetation, which converts the energy gains through evaporation and thus not into sensible heat.

Promotion of urban climate compensation

As a result of the deconstruction of the Spinelli Barracks, the area where cold air originates is expanded to cover the former barracks area, and the entrance of fresh and cold air from the surrounding areas is encouraged.

Since the urban heat island is particularly noticeable at night through reduced cooling in Mannheim, the promotion of nocturnal cooling is a primary goal of climate adaptation to reduce the night-time heat stress of residents to a less health-relevant level in the future. (KLIMOPASS, 2018)

Figure 33: Thermal balance capacity based on potential cold air production capacity.



Source of data on map: Stadtklimaanalyse Mannheim 2010, Ökoplana Karte 12,
Graphic by Author.

The nocturnal cooling is of fundamental importance for the bioclimatic situation (the "well-being of the city dweller"). According to KLIMOPASS report, the cooling can be promoted by:

- The long-wave (thermal) radiation in the upper hemisphere, supported by evapotranspiration (evaporation of plant surfaces and soil), (evaporating) surfaces with low heat storage capacity and low thermal conductivity (e.g., meadows) cool down faster, the so-called "cold air production".

- In order to generate new "cold air production zones" in the planning area, it was a climatically sound measure to demolish the existing hall and barracks buildings ("remove the plug") and unseal as many huge spaces as possible in favour of the nearby structures along the green belt.

- Because cold air near the ground is heavier than warm air, horizontal pressure gradients form, which, if powerful enough, can induce air motions. These are the so-called corridor winds, which can theoretically enter from open regions near the ground (below the ridge level of buildings) into built-up areas if impediments are not present and the temperature and hence pressure differential is significant enough.

- The flow-physical roughness of the flow surface also influences the range of this very feeble air movement. Buildings, trees, and plants make it harder for corridor breezes to penetrate densely populated places. These corridor winds are the most significant local air movements on the northeast green belt's edge. As a result, they are critical in the Käfertal-Süd planning area for the climate-friendly implementation of the urban design.

- The corridor winds must reach the inside block since there are essential outdoor lounges and resident bedrooms that are aired at night for cooling. As a result, no tall trees should be planned in the fresh air axes towards Spinelli Park.

- On the open spaces of the northeast green corridor, the weak, near-ground (> 20 m thickness) cold air outflow is to be preserved and, if possible, intensified by removing obstacles to the flow, but in any case, not building them. Achieving a low level of surface roughness on the surfaces through which flow occurs and the width of the discharge path is decisive.

- Increasing the availability of water at the site is one of the answers to the question of how to react to the expected longer periods of heat in the summer in planning precautions.

Local water balance and heavy rain

Climate change is expected to lead to more frequent and longer winter precipitation, and higher summer precipitation.

The new development zones in the Käfertal-Süd and on the Wingertsbuckel (neighborhood districts) should address not only flood protection but also water supply on site and groundwater enrichment. Measures and construction methods that collect, store (and utilise) (extra) rainfall and/or allow it to leak away locally rather than releasing it through the sewage system should therefore be pursued. (KLIMOPASS, 2018)

These measures increase the availability of water on the site, and this water becomes thermally effective directly, via the ground or via vegetation during the summer heat wave. The evaporation of 1L of water under normal conditions requires about 2.3 MJ of energy, which is withdrawn from the evaporating surface. (Engineering ToolBox, 2003)

The goal is thus not to drain the rainwater as rapidly as possible, but to keep it at the site so that it can be used for cooling reasons, among other things, during hot periods.
This can be accomplished by modifying the soil's horizon structure such that soil water can rise vertically through the core pores (so-called capillary water). This potential is particularly good with loess soils, but it is usually physically impossible to make them. The northeast green belt has a long vertical distance to groundwater, which reduces the volume of capillary rising water. (KLIMOPASS, 2018)

The "Guideline for municipal heavy rain risk management in Baden-Württemberg" published by the LUBW (Koch et al. 2016) provides a good overview of the topic for municipalities.

Due to the damage events recorded in recent years, municipalities are generally and urgently recommended to develop a municipal heavy rain risk concept.

For the Mannheim area, the recorded heavy rain events between 1980 and 2016 are 20–40 mm with a precipitation duration of 1–30 min and are thus in one of the lower ranges in a nationwide comparison (Koch et al. 2016).

Heavy rain events are rain events in which large amounts of precipitation occur in a short period of time - which are usually above the design limits of the sewer networks.
As a result, these flooding episodes are not limited to bodies of water and can occur everywhere. Rainwater then drains off above ground via roads, walkways, or cuttings in the landscape, might gather in local depressions, and cause damage in open spaces (soil erosion) as well as surrounding buildings and infrastructure, especially in built-up regions with a high degree of sealing. Even with a flooding depth of 5-10 cm, water penetration can cause a variety of building damage if building openings (e.g., basement windows) are designed too low. (Koch et al. 2016)

Because Mannheim is built partly on porous, sandy soil, precipitation may be effectively channelled away locally. This can be accomplished in a highly cost-effective and low-maintenance manner, for example, by planting (planted) hollows in the open spaces between residential structures.

5.6. Concept catalogue

The selection was narrowed down from a wide number of measures to those that are administratively significant in the design and land use planning process as well as the framework plan of the specific project, here the pilot project (e.g., can be determined in the development plan), and secondarily are climatically relevant for the adjustment regions determined in the project. The most important adaptation measures under these two elements are given in the concept catalog, which does not pretend to be exhaustive. This step of concretization aims to concretize and coordinate the diffuse concept of "climate adaptation" among diverse players both inside administration and in the early stages of involvement, as well as to communicate about it in a goal-oriented manner. (KLIMOPASS, 2018)

The concepts catalogue defines the climate-related adaptation measures and provides explanations for the planner, special information for implementation in the Spinelli conversion region, the type of fixing, etc.

The scientific description of the particular measurements is originally retained in the concept catalog in order to build a link to prior reports and guidance. All of these measures were then re-examined from the standpoint of planning practice and transferred as an example to the planning practice system. The outcome is depicted in a summary table (Table 6).

Table 6: A systematized overview of climate adaptation regions, goals, and ways to attain those goals. [M = measure no. in the concept catalogue*]

Area	Target	Brief explanation	Measures to achieve goals
Heat and dryness	Minimize resealing. [M1]	The less surface is sealed, the less it heats up ambient air	Reuse of areas that have already been sealed
			Limit the traffic area to a minimum
			Water-permeable coverings [M13]
			Number of floor / building height
	Natural water balance create	As much water as possible! seep away or be stored (in the ground) in the area	Water-permeable coverings [M13]
			Flat or trough infiltration [M14]
			Natural irrigation (tree trench, lake storage trough) [M7]
	Shading in public spaces, parking lots, and buildings	shading reduces surface brightening, reduces the perceived temperature considerably. Buildings also have this effect.	Adapted tree planting [M2]
			Façade greening [M4]
			Building position / height
			Technical solutions (e.g., pergola, roofing of parking lots/bus stops)
	Intensive greening of the outdoor areas	Plant stocks heat up less than (partially) sealed surfaces, facades, etc., the heat stress felt by humans decreases.	Creating green areas
			Façade greening [M4]
			Adapted tree planting [M2]
			Roof greening [M3]
			Irrigation (tree trench, storage trough) [M7]
	Increase in perspiration	The ambient air is cooled by the evaporation of water from plants and moist surfaces (e.g., ground). The more water that remains in the area, the more that can be evaporated.	Adapted tree planting [M2]
			Facade greening [M4]
			Creating green areas
			Roof greening [M3]
			Natural irrigation (tree trench, storage trough) [M7]
			Water-permeable coverings [M13]
			Surface or trough infiltration [M14]
	Avoidance of multiple reflection [M6]	Reduces Radiation Exposure & Heating	Adapted tree planting [M2]
			Facade greening [M4]
	Increase albedo [M5]	Reduces the Warming Feeling Temp. Day and night	Light colours and building materials on facades / walls
			Light colours and building materials on public streets, (parking) spaces, etc.
maintain/ development/ creation of cold air ducts and cold air origin areas. [M10]	Creation of green and open spaces	Cold air develops on green and open spaces; if these are open, cold/fresh air can flow through them largely unhindered.	Reducing the structural density.
			Demolition and unsealing [M9]
			Creating green areas.
			Adjusted arrangement, type selection and growth form of the trees planting [M2]
	Sufficient settlement ventilation [M11; M12]	The settlement is to be developed in such a way that cold and fresh air can enter or flow through it as unhindered as possible.	Adjusted building position / plot area that can be built on.
			Adjusted routing of the streets and paths.
			Adjusted arrangement, type selection and growth form of the tree plantings.

heavy rain	Increase infiltration capacity in the area	Every area in the planning area that is capable of water infiltration or retention reduces the amount of water that may accumulate and thus the risk of flooding.	Area or trough infiltration [M14]
			Multifunctional area [M15]
			Creating green areas.
			Water-permeable coverings [M13]
	Retention basin		Border green roofs [M3]
			Multifunctional area [M15]
	Flood protection	The measures serve the targeted drainage and introduction of rainwater runoff in less endangered areas	Creating an adapted terrain topography [M17]
			Creating an adapted street topography [M16]
			Accompanying measures (ground floor height, road top edges, etc.) [M18]
			Multifunctional surface [M15]
			Surface or trough infiltration [M14]

Source: KLIMOPASS–KomKlim Abschlussbericht, (2018), p.47

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6

MANNHEIM AND SPINELLI SITE ANALYSIS

6.1. Mannheim geographical location

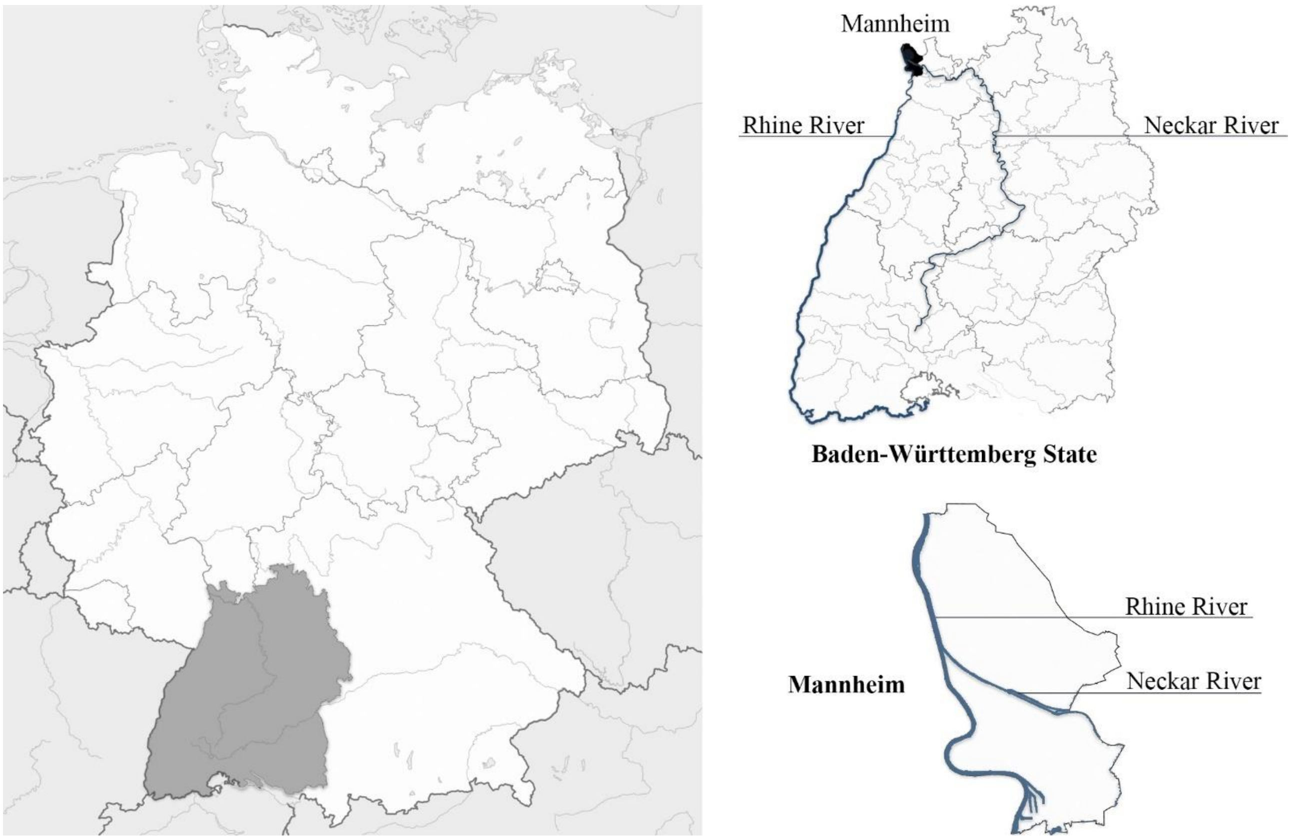
Mannheim is the 3rd largest city in the state of Baden-Württemberg, southwestern Germany, with a population of around 310,000 inhabitants. (Stadtmarketing Mannheim)

Mannheim is located at the convergence of the Neckar and Rhine rivers in the Upper Rhine lowlands. The city is positioned on the right bank of the Rhine River, facing Ludwigshafen, and the Neckar River enters the Rhine after having been controlled through a canal system. (Britannica, 2018)

In comparison to other areas in Germany, Mannheim has a higher level of humidity in the summer, contributing to a greater heat index. Snow is uncommon, even in the winter season. Rainfall mainly takes place during thunderstorms that happen in the afternoons during the warm season, with approximately 40 to 50 thunderstorm days annually. ("Mannheim," Wikipedia, 2022)

The climate in Mannheim is characterized by mild differences between high and low temperatures, and there is a sufficient amount of rainfall throughout the year. According to the Köppen Climate Classification, the climate in this region is classified as "Cfb", which represents a Marine West Coast Climate or an Oceanic climate. (Weatherbase)

Figure 34: Geographical location



Source: https://en.wikipedia.org/wiki/Mannheim#/media/File:Germany_adm_location_map.svg
Redrawn and modified by author.

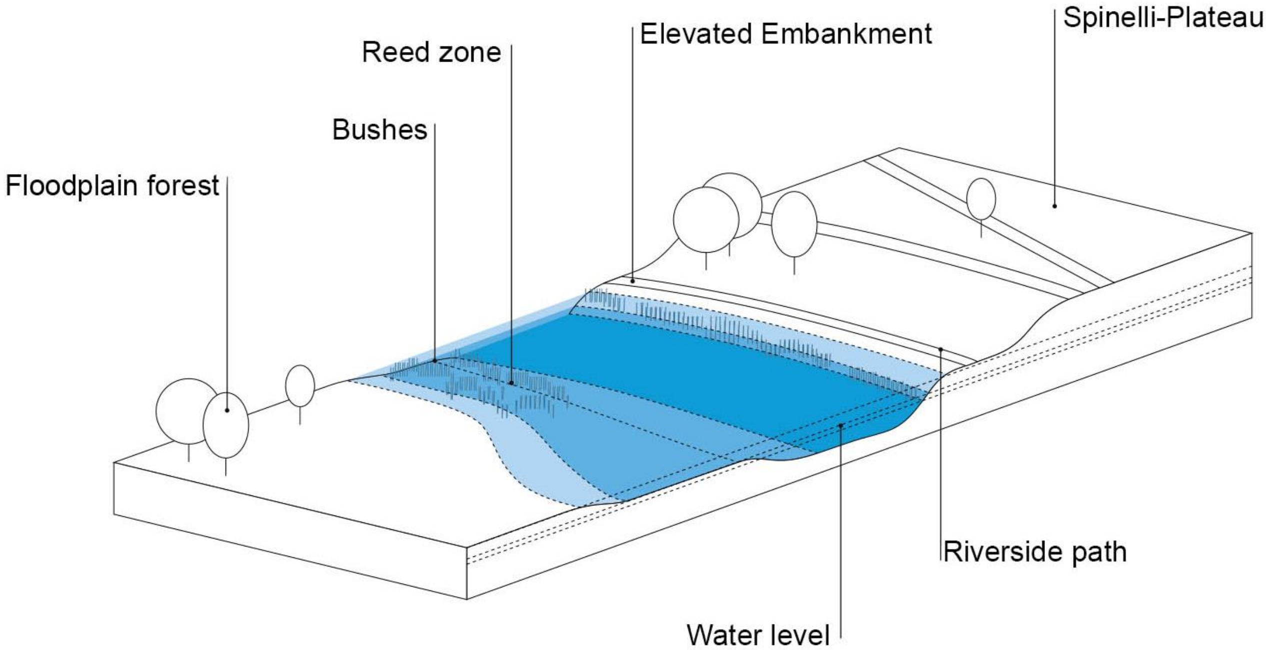
6.2. Mannheim and Spinelli site background

The city has been constantly changing. Particularly large changes took place at the beginning of the 20th century after the First World War. When settlement houses were built, some of which were given to war invalids on a pension basis. Civil servants who had been injured in the war and who had been expelled from Elsass-Lothringen initially settled here. (Rahmenplan Spinelli, 2018)

Geological history

Geological history has had a lasting impact on the Mannheim cityscape where the north-east green corridor is.
The difference in height between the Feudenheimer Au and the Spinelli site (Figure 35) was caused by the fact that an arm of the Neckar once ran there (Figure 36), which has dug into the soil of today's Au for centuries.

Figure 35: Different level between Feudenheimer Au and Spinelli

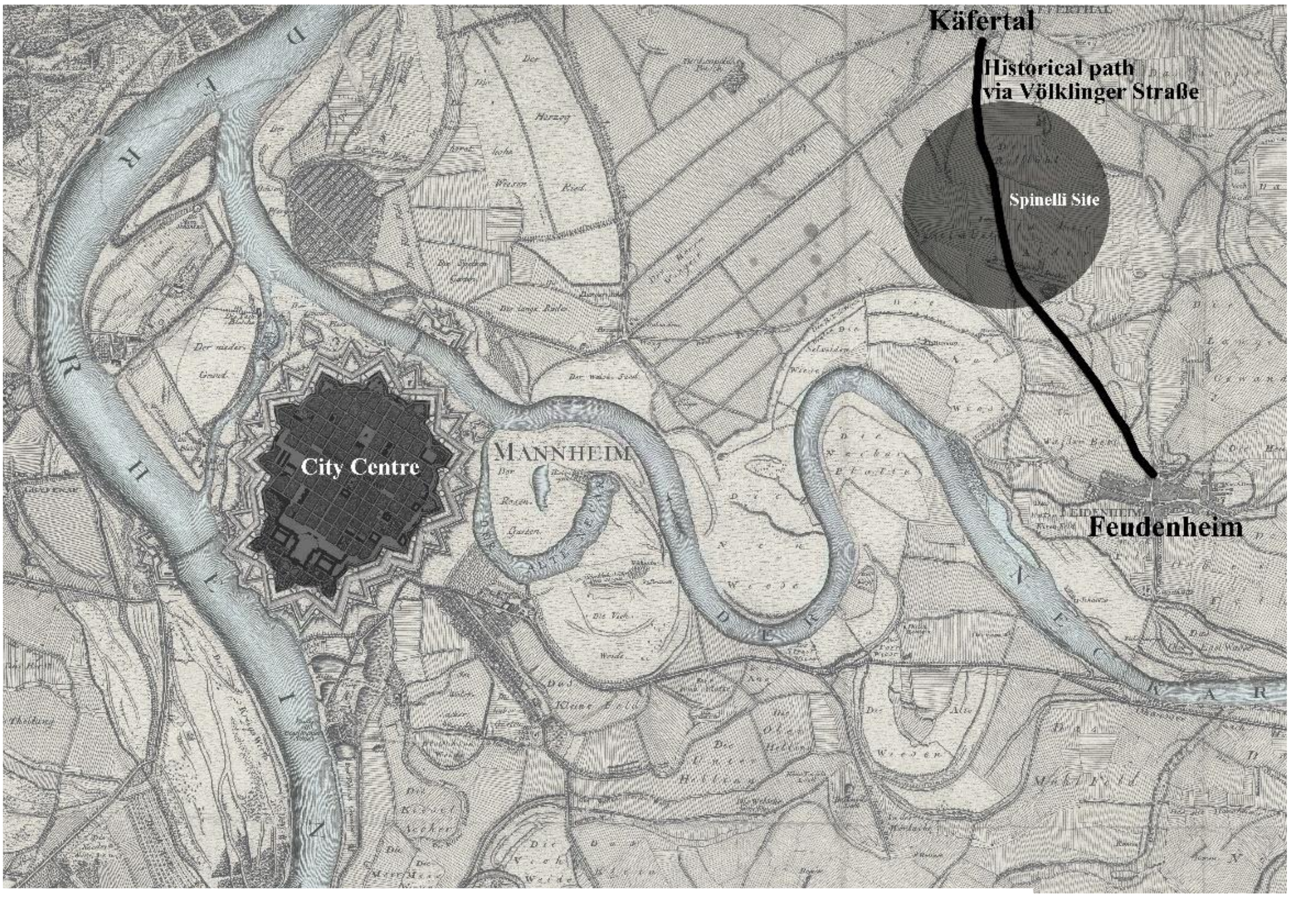


Source: Rahmenplan Spinelli, Page 24.
https://www.mannheim.de/sites/default/files/2020-01/spinelli_rahmenplan.pdf

When developing the green corridor, it is essential to work out these and other historical features as part of the open space planning and thus make them tangible. (Rahmenplan Spinelli, 2018)
As part of the urban development, a historical path connection was interrupted by the construction of the barracks (Figure 37). This connection can be seen in maps from the early 19th century and was an important path connection even then (Figure 36). (Rahmenplan Spinelli, Page 29).

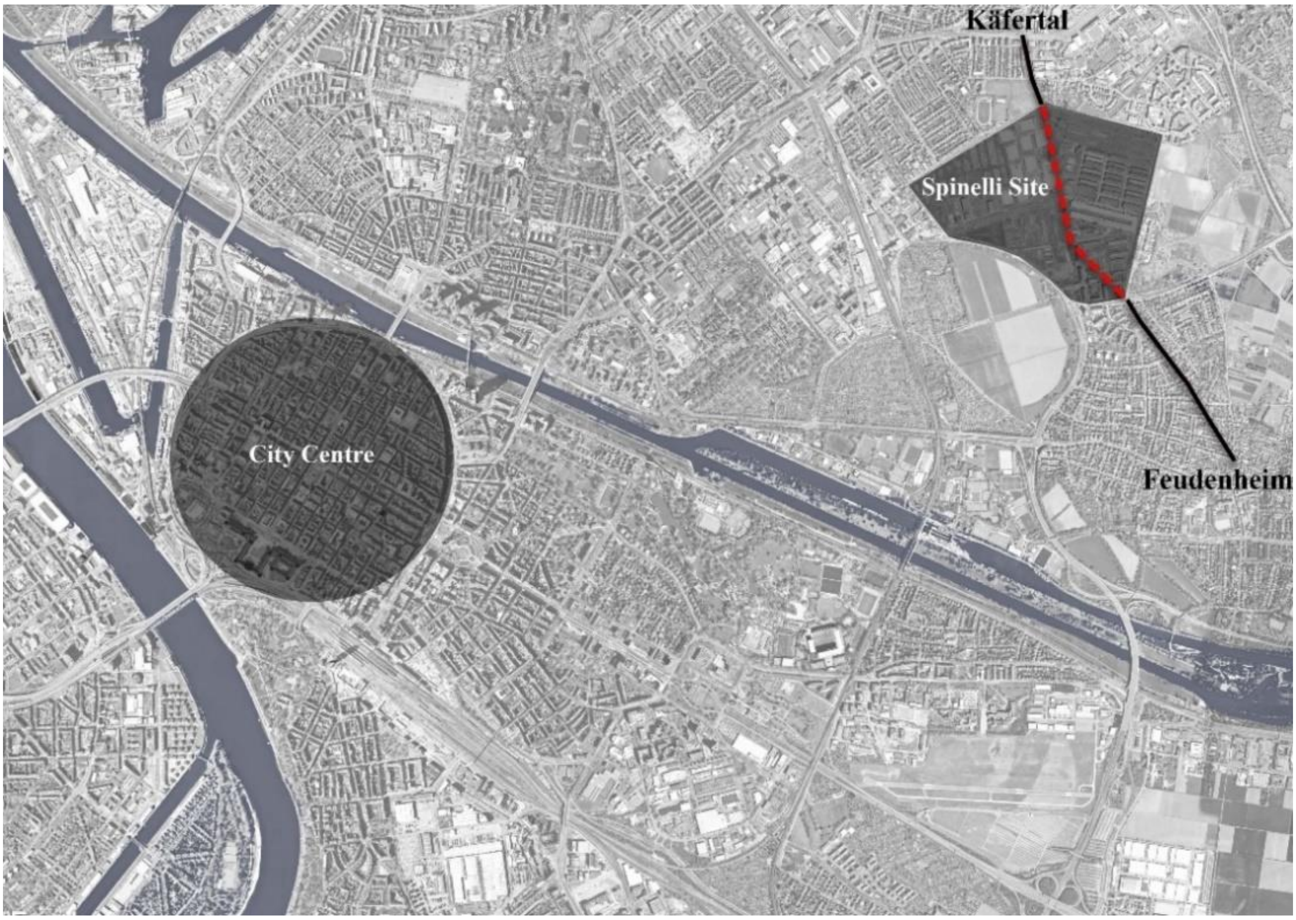
Also, the urban development around the Neckar River changed the natural flow of the river which had been once very winding before it was straightened.

Figure 36: Mannheim 1780, Historical path (Völklinger Straße) connection between Käfertal and Feudenheim.



Source: Heidelberg University Library,
https://digi.ub.uni-heidelberg.de/diglit/mannheim1780/0008.
Edited by author.

Figure 37: Mannheim 2022, Interruption of the historical path connection (Völklinger Straße) between Käfertal and Feudenheim.



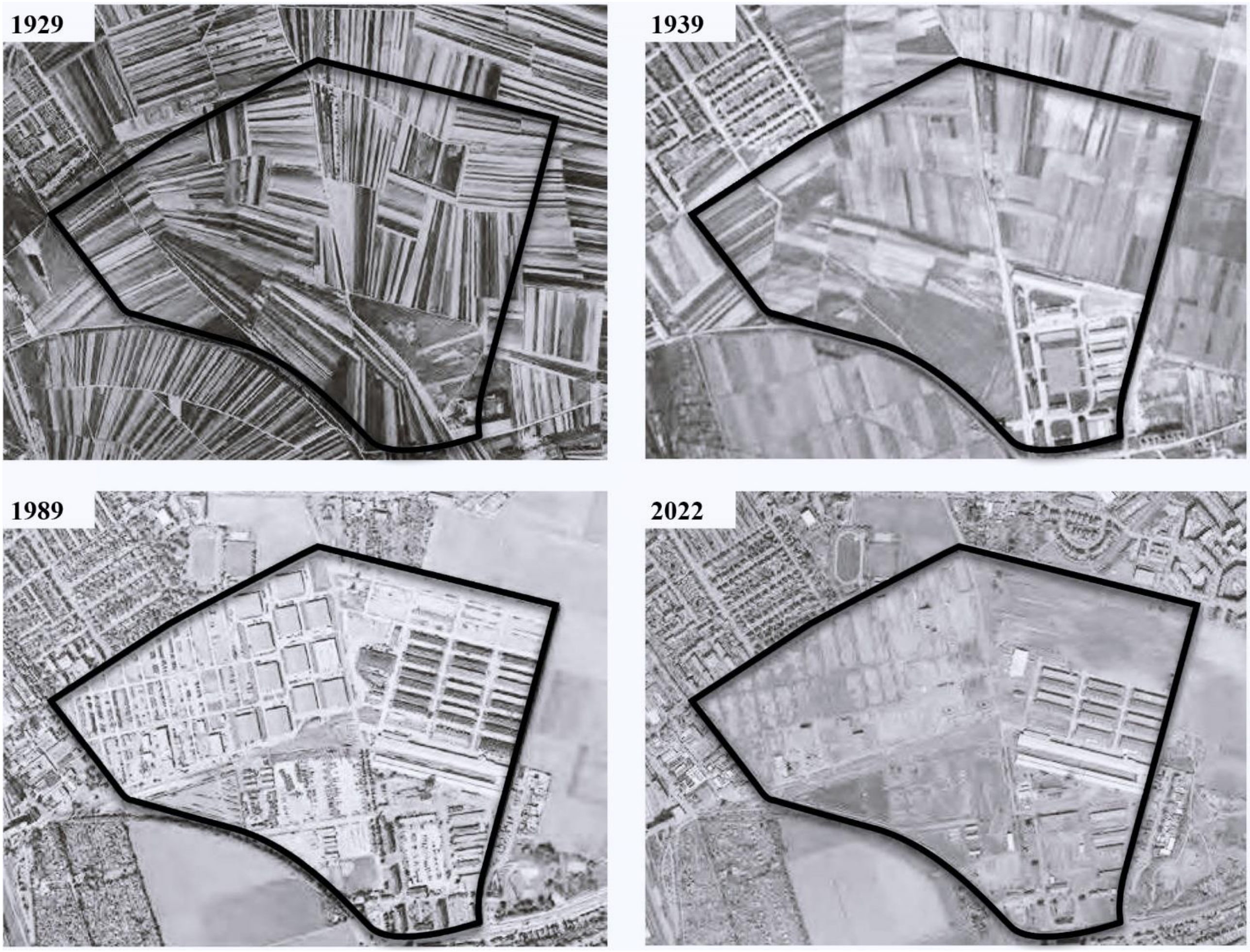
Source: Google Earth.
Edited by author.

Military history

In many ways, Mannheim has been shaped by its military-historical background. The significant preserved square city structure is directly related to this. When the Nazi regime came to power in the Second World War, many barracks were built. These are located both on the periphery and in the inner areas of the city. (Rahmenplan Spinelli, 2018).

The later Spinelli Barracks were built by the Wehrmacht in 1938 and used as pioneer barracks. After the Second World War, the US Army took over all military areas and gradually expanded them according to their needs. They used the area as a logistics and storage centre. (Rahmenplan Spinelli, 2018).

Figure 38: Pioneer Barracks and later Spinelli Barracks 1929 —2013



Source: Rahmenplan Spinelli, Page 26.
https://www.mannheim.de/sites/default/files/2020-01/spinelli_rahmenplan.pdf

6.3. Mannheim meteorology

Overview

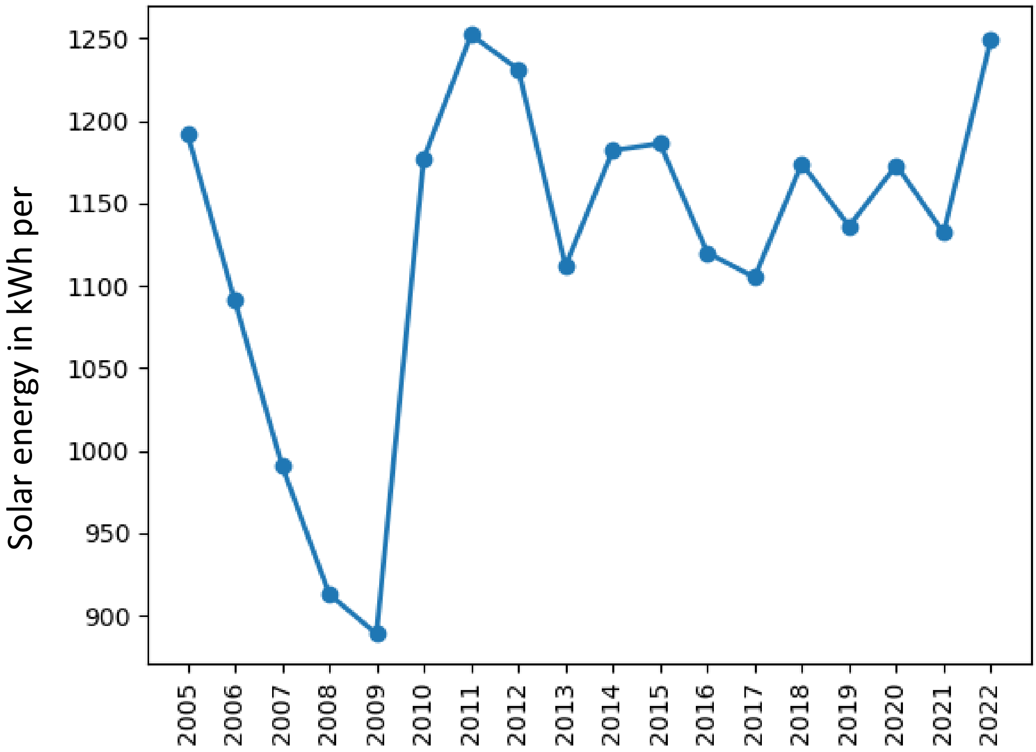
According to the Weatherbase website, Mannheim has a climate characterized by moderate temperatures and ample precipitation throughout the year. The area is located in the poleward region of the western continents, beyond the subtropical anticyclone. This location experiences the mid-latitude westerlies and frontal cyclones all year round, which leads to precipitation totals that vary somewhat but generally range from 500 to 2500mm per year, with local totals exceeding 5000mm in areas where onshore winds meet mountain ranges. The rainfall is frequent and reliable, with many areas having over 150 days of precipitation per year, although it is often of low intensity. The climate is characterized by mild winter temperatures and moderate summer temperatures, with frequent fog in autumn and winter, but infrequent thunderstorms. The Köppen Climate Classification for this climate is "Cfb". (Marine West Coast Climate). (Weatherbase, Mannheim)

Solar radiation

From 2010 to 2022 Mannheim received between 1100 and 1250 kWh of sunlight per square meter on an average year (Figure 39), and as much as 200 kWh per square meter during a summer month (Figure 40). There are between 1,530 and 2,070 hours of sunshine per year which results in a solar capacity factor of 20% on average.

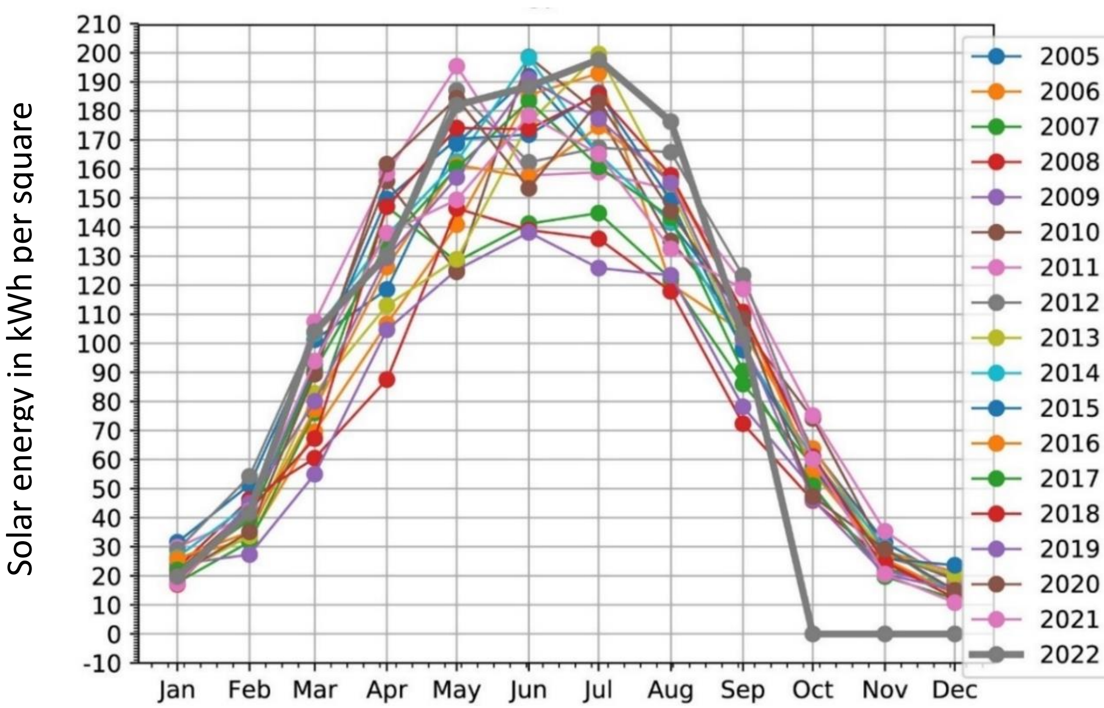
To be more specific, in 2022 Mannheim received 1.15 MWh of sunlight per square meter from 1895 hours of sunshine. On average, 5 hours of sunshine per day, which results in a solar capacity factor of 21.6%

Figure 39: Solar energy from 2005



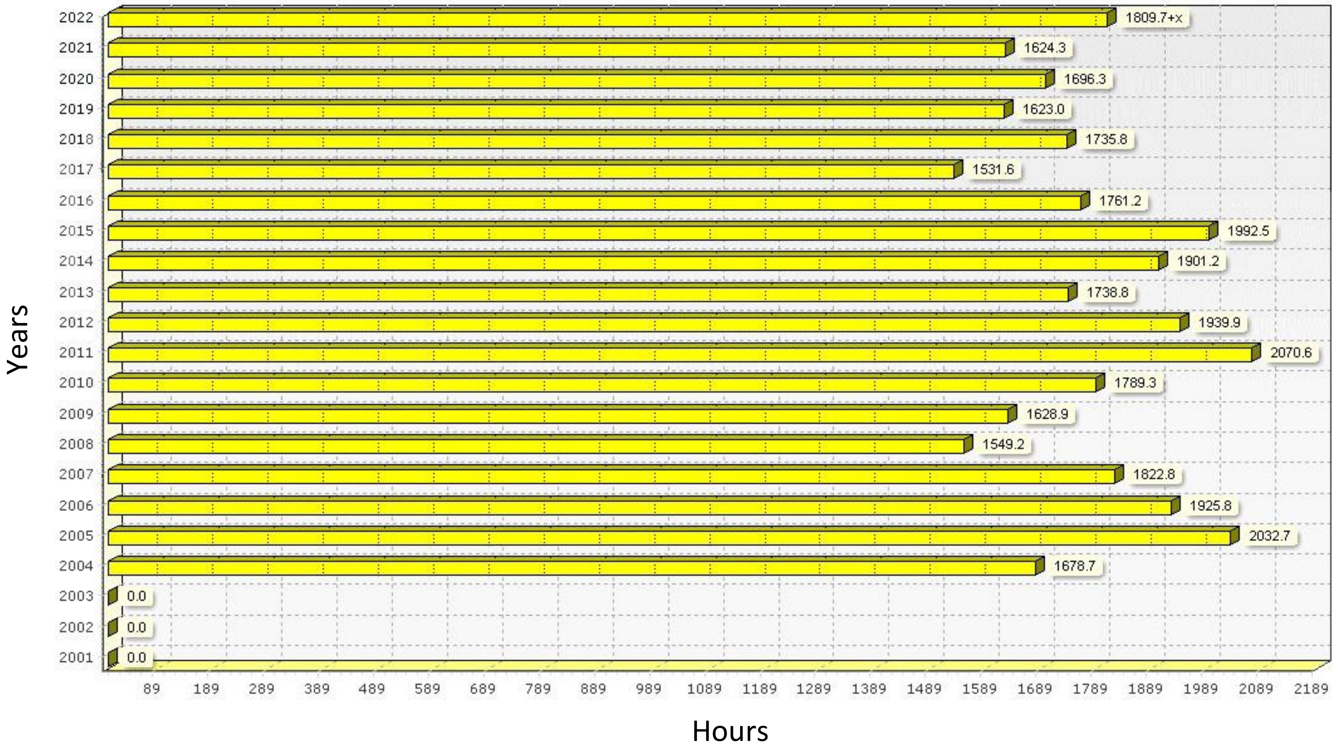
The kWh per m² is calculated from the sum of the daily solar radiation values in W/m² and displayed here graphically.
Source: www.Mannheim-wetter.info 10/01/2023

Figure 40: Solar energy in different months



The kWh per m² is calculated from the sum of the daily solar radiation values in W/m² and displayed here graphically.
Source: www.Mannheim-wetter.info 10/01/2023

Figure 41: Sunshine hours from 2001



Source: www.Mannheim-wetter.info 10/01/2023

Let's say we have 5 solar panels, each rated at 400 W. In this case, the maximum capacity of the photovoltaic system would be 2000 W (2 kW).

This is the maximum solar power the system can produce. Due to the capacity factor, the system will, however, always generate less than 2 kW of power.

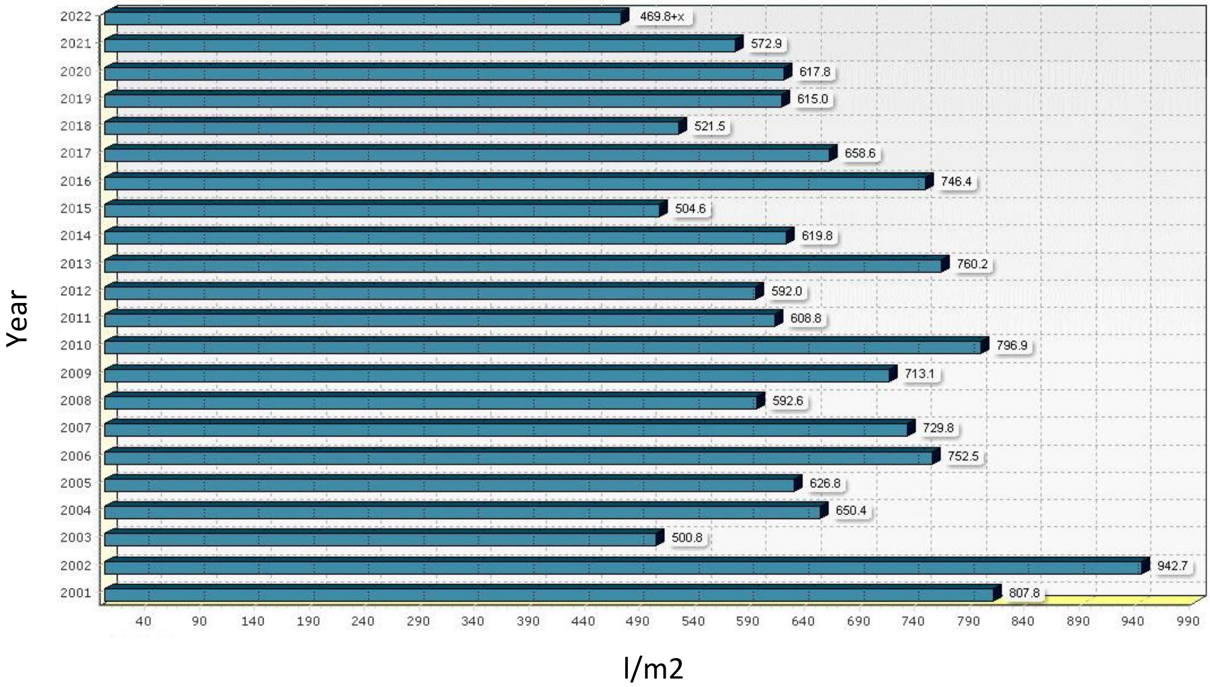
Due to the 20% solar capacity factor of Mannheim, we are able to generate 400 Watts by multiplying 2000 W by 0.20.

To equal one solar panel nameplate capacity, we need 5 solar panels. Therefore, low capacity factors are a major problem in solar technology and it should be integrated with other renewables to be more efficient.

Precipitation

Mannheim receives between 500 and 950 litters per square meter each year.
The annual amount of precipitation is around 550 – 650 mm, with the months of May to July having the highest levels of precipitation (Figure 42). During these months, showers and thunderstorms are more frequent due to the high intensity of solar radiation and the resulting convection with cloud formation. (Mannheim wetter)

Figure 42: Precipitation (l/m2) from 2001

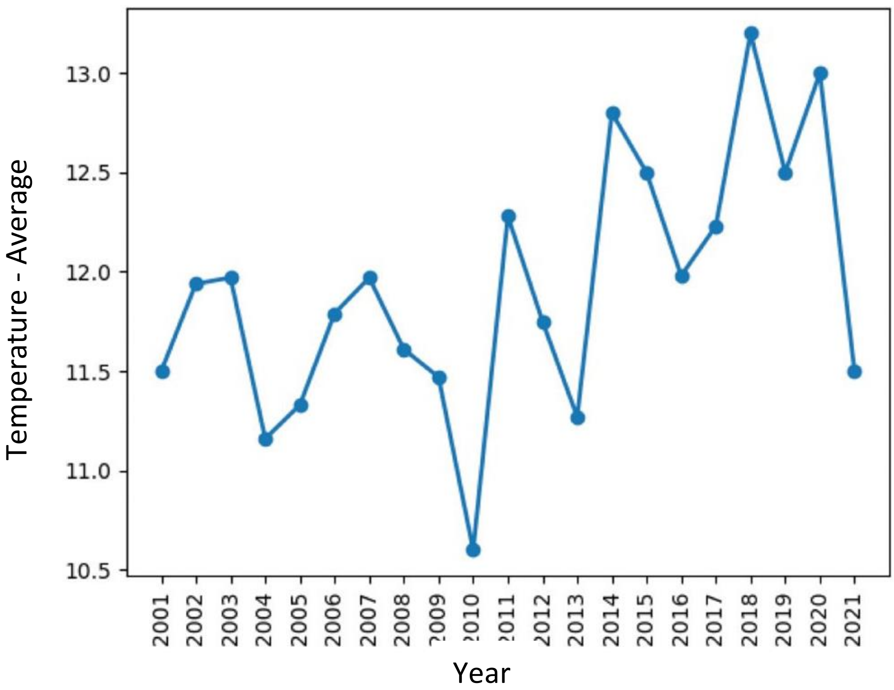


Source: www.Mannheim-wetter.info 31/10/2022

Air mean temperature

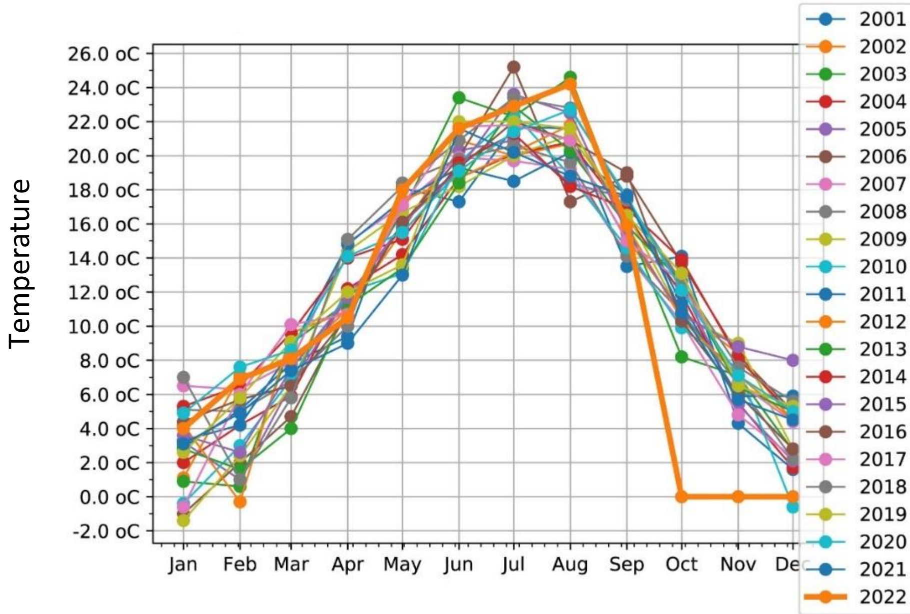
Mannheim's average temperature is between 10.5 and 13.5 C. Average winter temperatures are between 0 and 6 degrees Celsius with summer temperatures rising to between 20 and 24 degrees Celsius.

Figure 43: Average temperature from 2001



Source: www.Mannheim-wetter.info 31/10/2022

Figure 44: Average temperature in different months

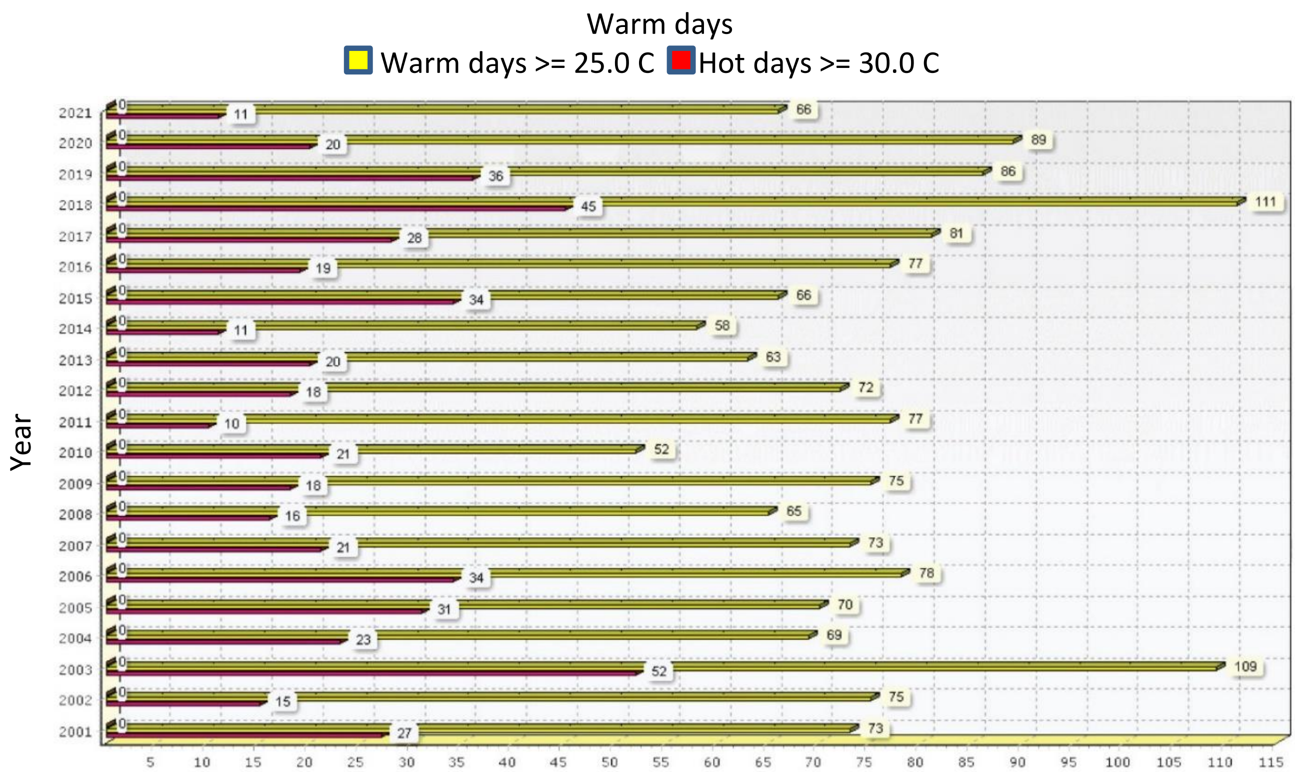


Source: www.Mannheim-wetter.info 31/10/202

Temperature extremes

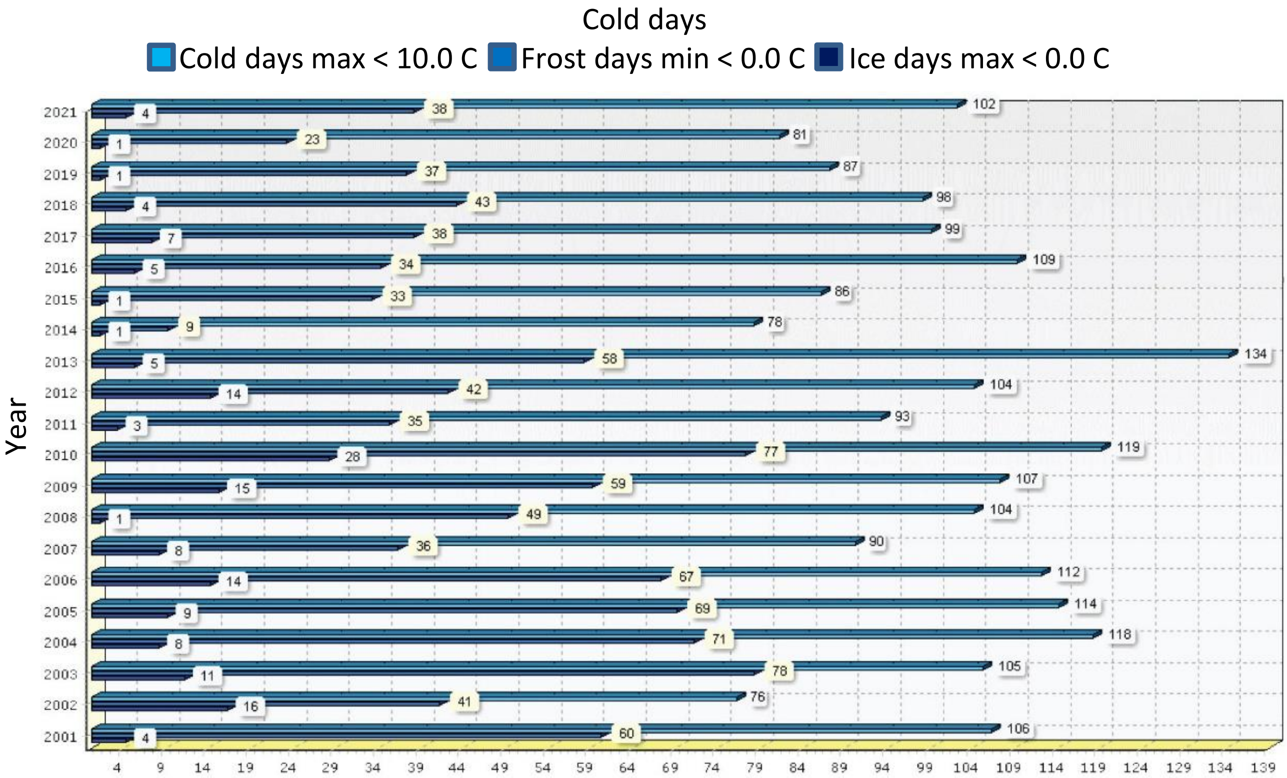
According to weatherbase website ''The highest recorded temperature in Mannheim is 99.0°F (37.2°C), which was recorded in July. The lowest recorded temperature in Mannheim is 1.0°F (-17.2°C), which was recorded in January''.

Figure 45: Number of extreme hot days



Source: www.Mannheim-wetter.info 31/10/2022

Figure 46: Number of extreme cold days



Source: www.Mannheim-wetter.info 31/10/2022

6.4. Urban system

Mannheim's urban system is based on a rectangular grid pattern that is divided into large blocks, each of which is further divided into smaller blocks. The blocks are separated by roads and streets, which makes it easier for people to get around the city and access different parts of it. This grid pattern makes it easy to navigate the city, even for those who are unfamiliar with the area.

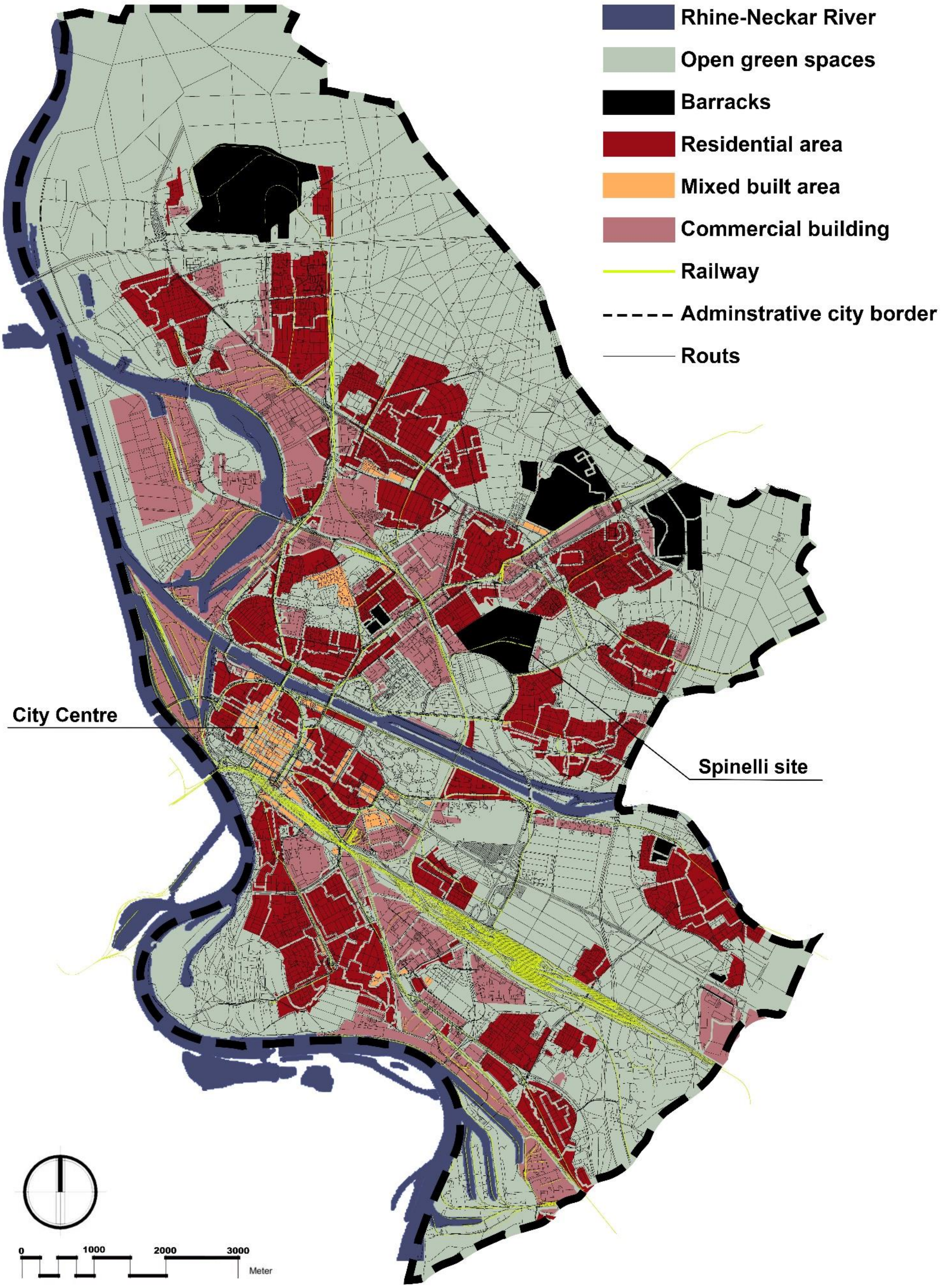
One of the key features of the Mannheim urban system is the use of parks and green spaces throughout the city. These parks provide a respite from the hustle and bustle of the city and serve as a source of recreation and relaxation for residents. They also help to regulate the temperature in the city, providing shade and cooling during hot weather, and helping to reduce air pollution.

The Mannheim urban system is an innovative concept that has helped shape the city into a modern, efficient, and liable place. Its grid-like structure, use of parks and green spaces, and well-developed transportation network make it a model for other cities to follow. By following these principles, other cities can improve the quality of life for their residents and make their cities more sustainable and efficient in the long term.

Figure 47: City centre grid pattern

Source: Prepared by author (Base map: Google earth)

Figure 48: Urban system and land use

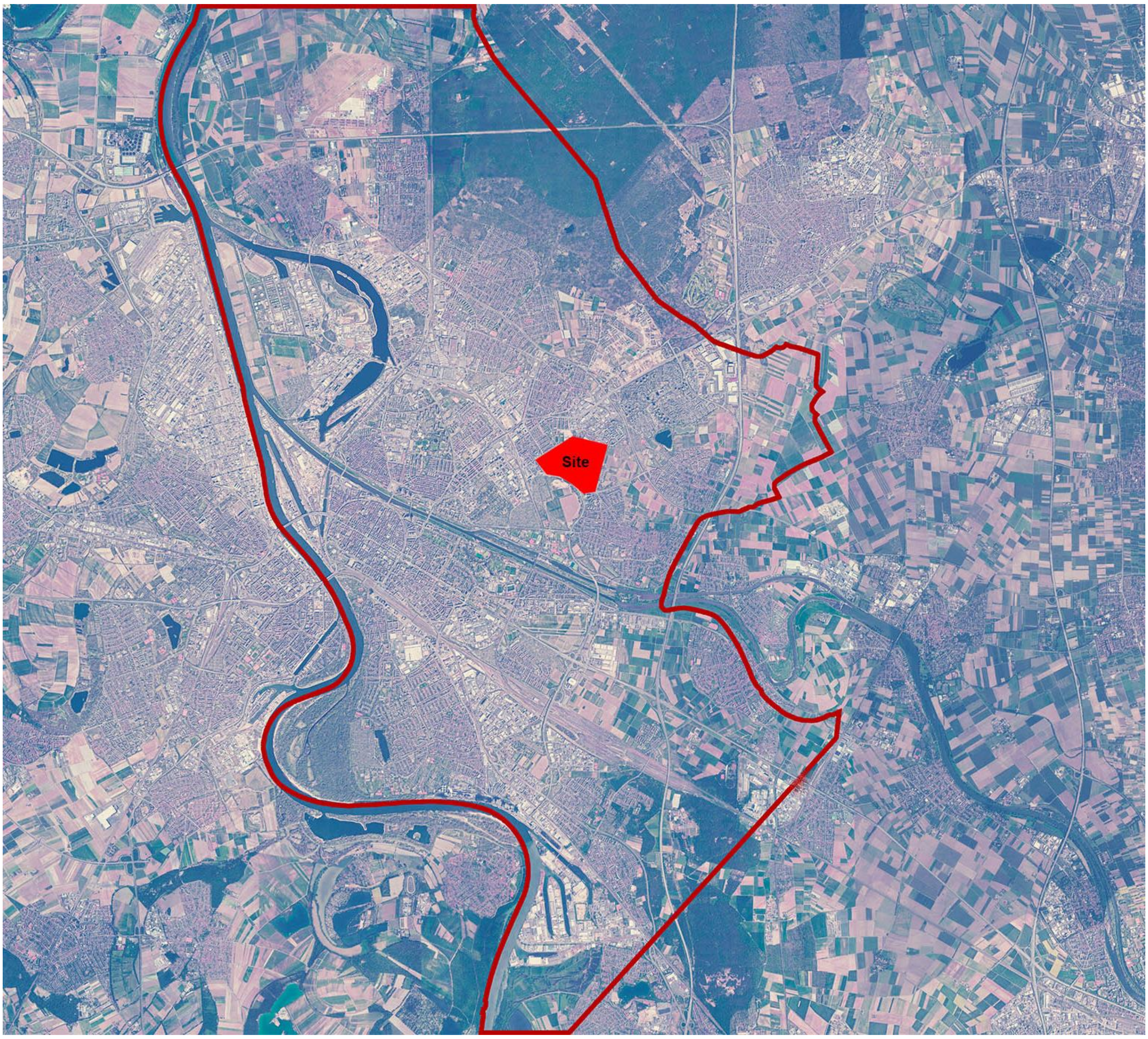


Source: Prepared by author based on data available on the https://www.gis-mannheim.de/. (Bodenrichtwertkarten Der Stadt Mannheim, n.d.)

6.5. Urban climate

The WMO (World Meteorological Organization) defines the urban climate as "the climate modified by interactions with buildings and their effects".
The urban climate that characterizes a settlement area is made up of many independent microclimates, which are caused by the different land uses and ultimately form the climate in the living environment of people.

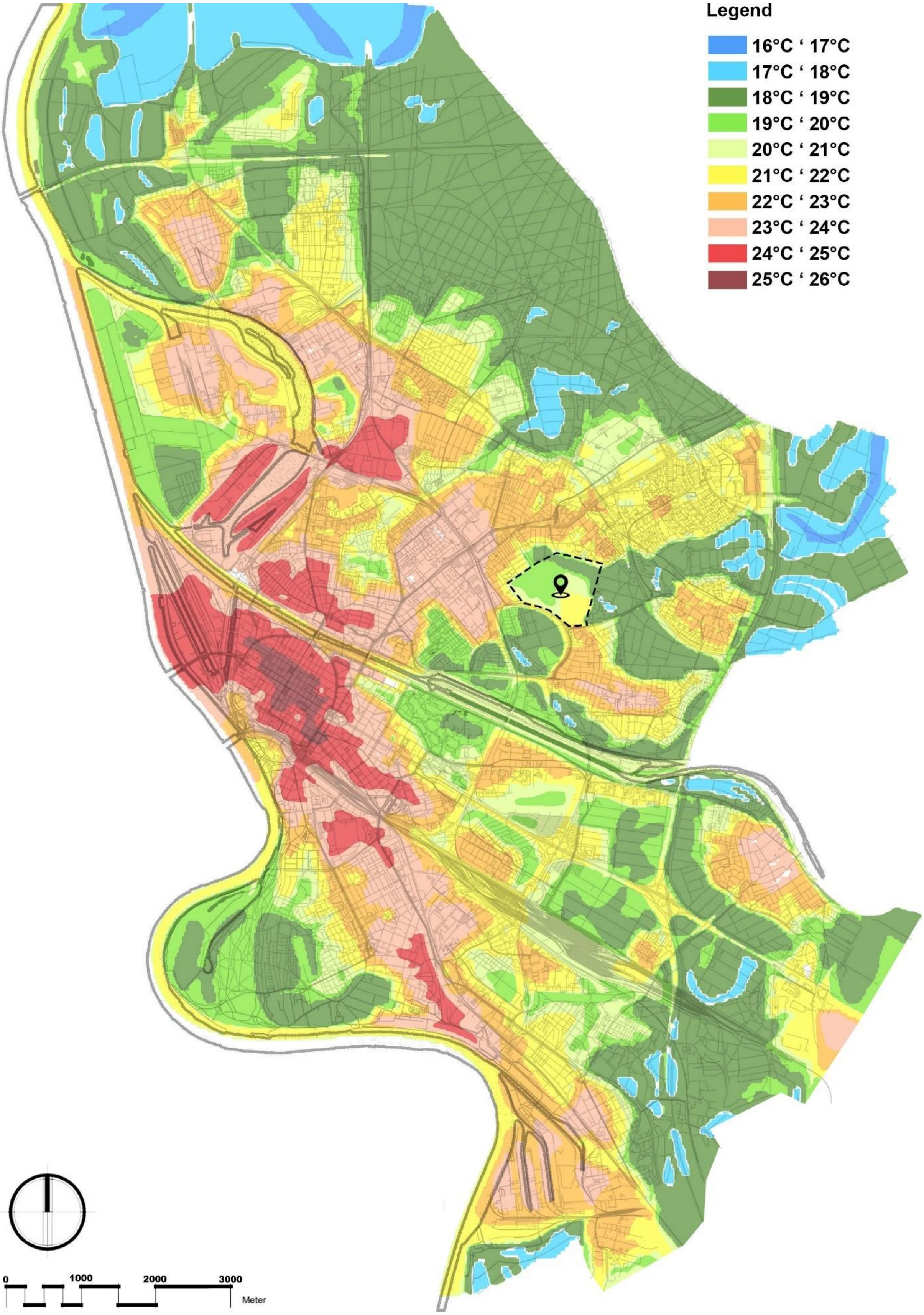
Figure 49: Mannheim climate analysis territory (Administrative border)



Data source: Google Earth.
Edited by Author.

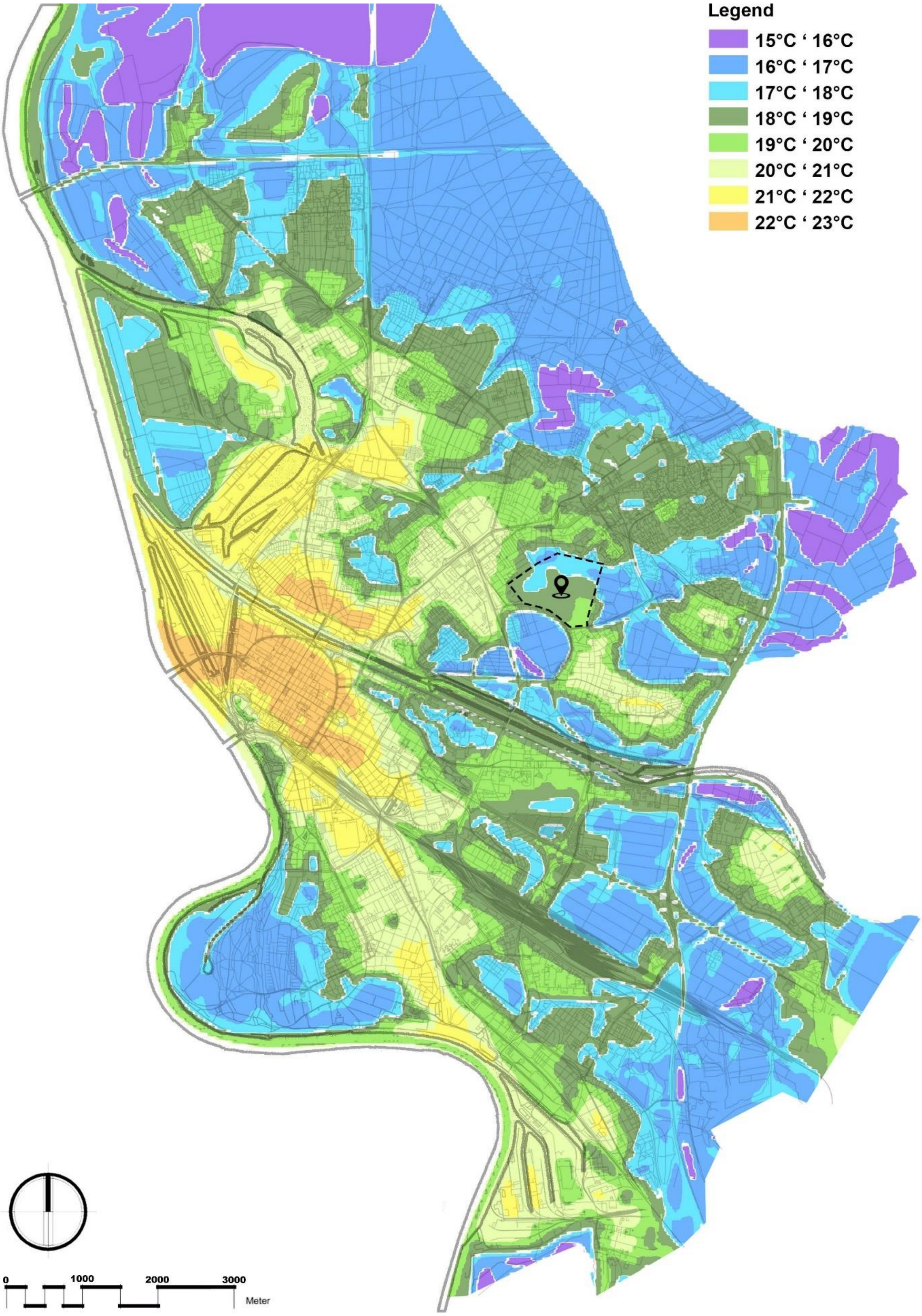
The urban heat island is particularly noticeable at night (Figure 48,49) through reduced cooling in Mannheim, the promotion of nocturnal cooling is the municipality's primary goal of climate adaptation (chapter 5) to reduce the night-time heat stress of residents to a less health-relevant level in the future.

Figure 50: Isotherm map, 11 p.m.



Data source: https://www.gis-mannheim.de/mannheim/
Map redrawn by Author.

Figure 51: Isotherm map, 5 a.m.



Data source: https://www.gis-mannheim.de/mannheim/
Map redrawn by Author.

Figure 50 shows the individual station locations with the main wind directions of the local winds/cold air currents close to the ground.

During low-wind radiation weather circumstances, pronounced temperature differences between open land and built-up regions stimulate the creation of local air currents, which manifest as detectable currents over colder open expanses heading towards the centers of overheating (Corridor winds).

The intensity of these local currents is determined by the temperature difference between outdoors and built-up areas (pressure equalization between higher air pressure in the cooler outdoors and lower air pressure in the warmer built-up areas) and the surface condition (soil roughness) of the place where it originates.

For the city of Mannheim, such local currents are of particular importance in the thermal/air hygiene conditions.The thickness of these compensating currents varies between a few meters and several decametres. The mostly thrust-like currents reach speeds of approx. 0.5 - 1.5 m/s. If these local currents interact with regional currents of a greater range, the air exchange around the built-up area will be intensified. (ÖKOPLANA 2010)

In the north-eastern part of the city (districts of Feudenheim, Wallstadt, and Vogelstang), wind directions accumulate during radiation nights (stations DWD-Mannheim-Vogelstang, Wallstadt-Kirche, Brunnenpfad, Mudauer-Ring, Wallstadt-Schule).
In these vicinities, local equalizing currents between cool open land and warm built-up areas are noticeable, with the free zones between Wallstadt and Vogelstang (Vogelstang lakes) and between Feudenheim and Wallstadt representing important cold air channels (green corridor north-east).
They form climatic-ecologically significant connecting axes in the direction of Feudenheimer Au/Sellweiden/Neckarvorland - interrupted by the development of the Spinelli Barracks. (ÖKOPLANA 2010)

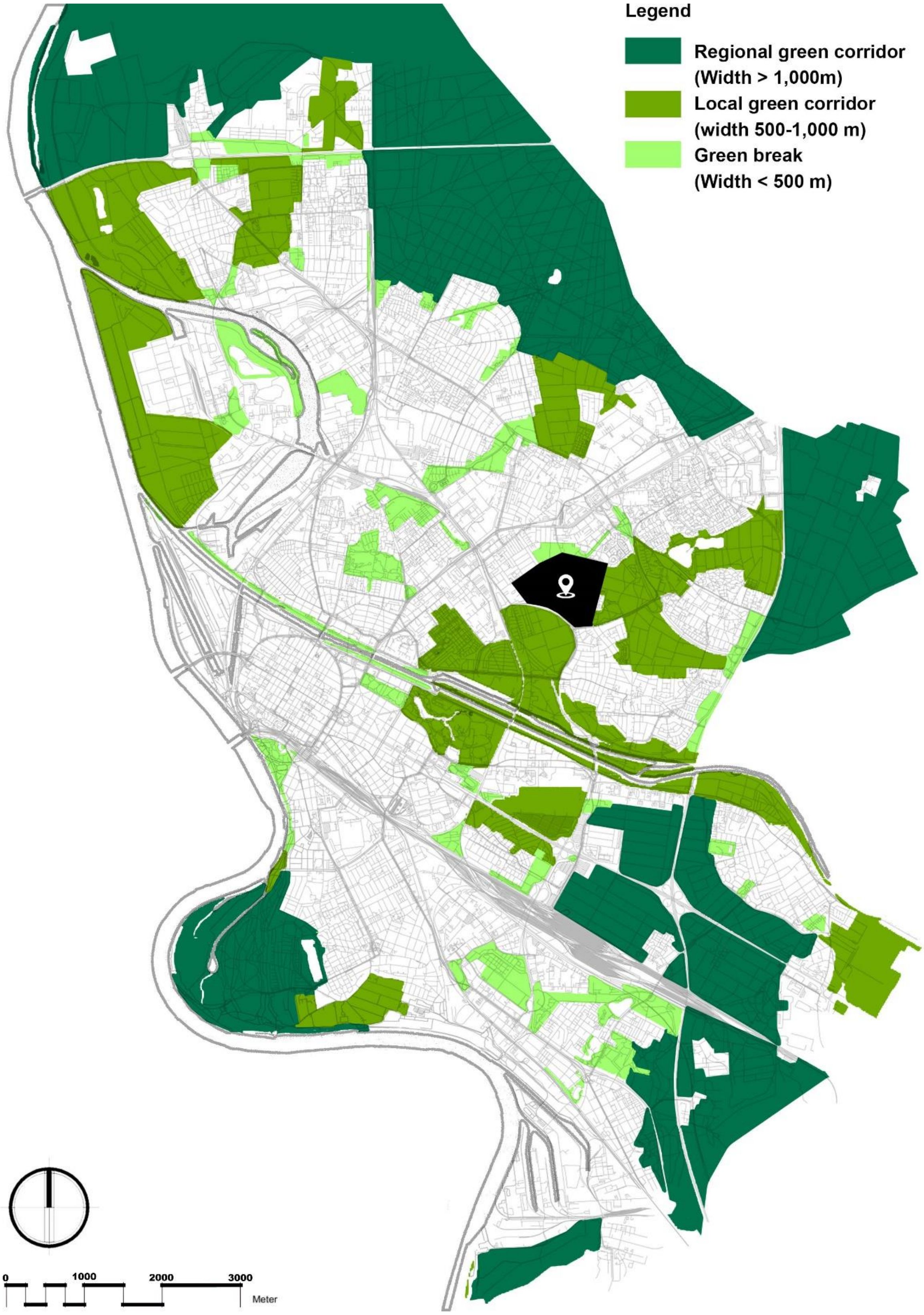
Figure 52: Local main wind direction of the cold air movement

Data source: Stadtklimaanalyse Mannheim 2010, Ökoplana Karte 09,
https://www.mannheim.de/sites/default/files/page/74508/stadtklimaanalyse_ma2010_bericht.pdf
Map redrawn by Author.

Figure 51 describes the channel characteristics of the larger climate-ecological compensation areas.
Regional green corridors that have interfaces to the compensation potential of neighbouring towns and communities should have a minimum width of 1,000 m. From a regional planning point of view, minimum widths of 400 - 500 m are required for cold air transport paths that are defined as local green corridors (ministry for regional planning, building and urban planning, 1979).

Accordingly, open spaces with a width of fewer than 500 m are defined as green breaks. If they have a spatial connection to larger open spaces, they still form essential cold air currents (passive effect) in the inner-city effect structure. Their active effect (cold air production) is limited since the heat aura of the adjacent effective areas weakens the cold air production. (Stadtklimaanalyse Mannheim 2010)

Figure 53: Channel character of larger climate-ecological compensation areas.



Data source: Stadtklimaanalyse Mannheim 2010, Ökoplana Karte 14,
https://www.mannheim.de/sites/default/files/page/74508/stadtklimaanalyse_ma2010_bericht.pdf
Map redrawn by Author.

The climate function "cold air production" is particularly pronounced during nocturnal radiation conditions over areas with good cooling possibilities (low elevation of the horizon, high evaporation capacity). Thus, for example, agriculturally used areas and meadows/green areas with a small number of trees are highly active areas where cold air is produced. Due to their low surface roughness, their suitability as a cold air transport path can also be rated as very good. (Stadtklimaanalyse Mannheim 2010)

The climate function "fresh air generation" primarily applies to forest areas or larger coherent, dense stands of trees. In forest stands, cold air can develop, especially during nights with little wind, which has fresh air quality due to the filter effect on dust. In comparison to the open areas, however, the forest shows a strong attenuation of all climatic elements. The reason for this is the reduction in radiation during the day and the reduced radiation during the night. (Stadtklimaanalyse Mannheim 2010)

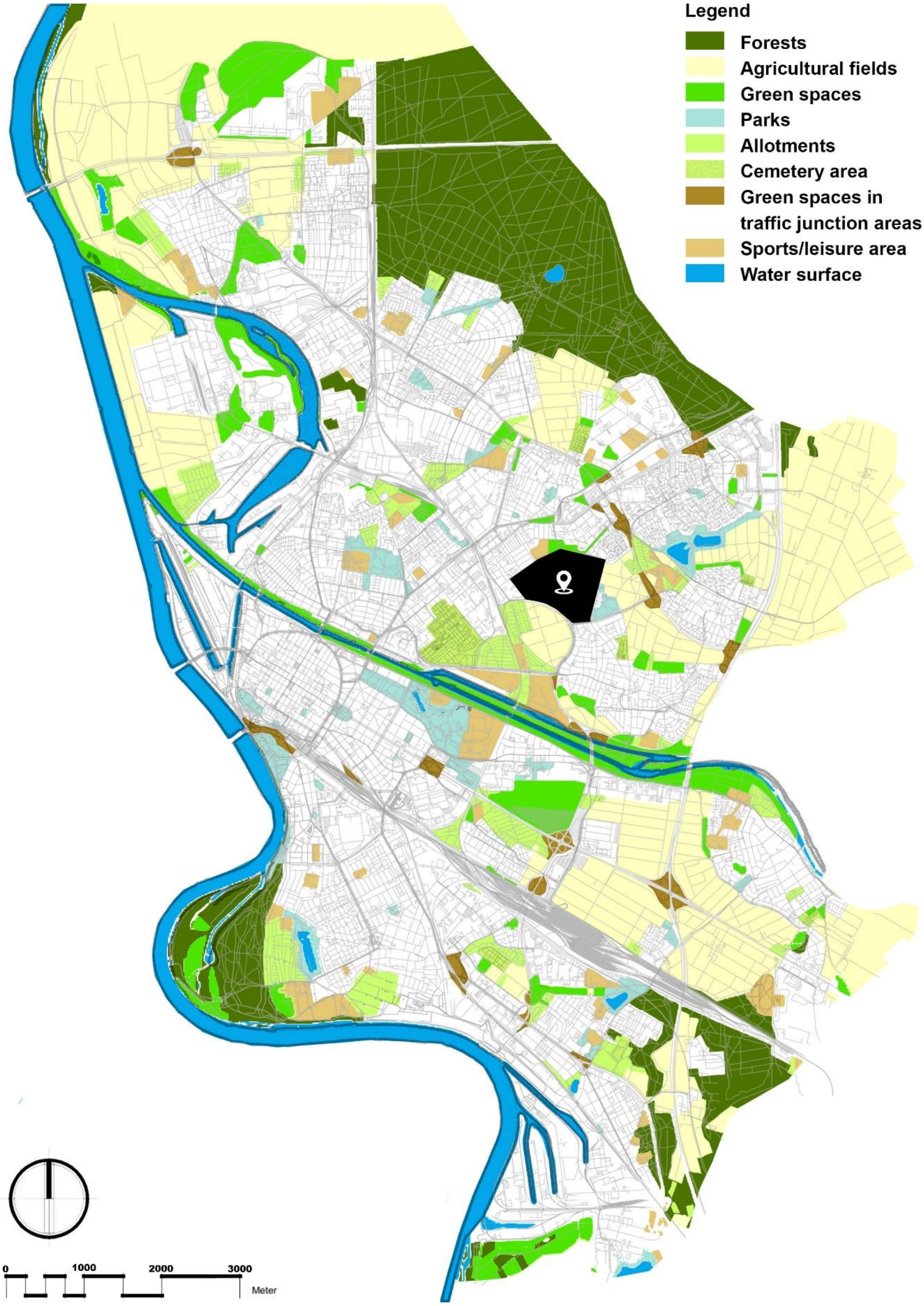
The open space potential has an area of approx. 8,072 ha (approx. 57% of the city area). Table 7 documents the individual types of use (Figure 52) and their area sizes.

Table 7: Climate Ecological compensation areas in the city of Mannheim, use, and size

Use	Area size [ha]	% Share in the total city area
Forest area	1.974,75	13.62
Agricultural area	3.367,18	23.23
Green space	789,60	2.83
Park	267,90	5.44
Allotments	425,73	2.93
Cemetery area	86,90	0.6
Green spaces in traffic junction areas	90,88	0.63
Sports/leisure area	343,46	2.37
Water surface	726,00	5.01
Total	**8,072.4**	**56.66**

Source: Stadtklimaanalyse Mannheim 2010, Ökoplana Page 57,
https://www.mannheim.de/sites/default/files/page/74508/stadtklimaanalyse_ma2010_bericht.pdf

Figure 54: Climate-ecological compensation spaces and their use.



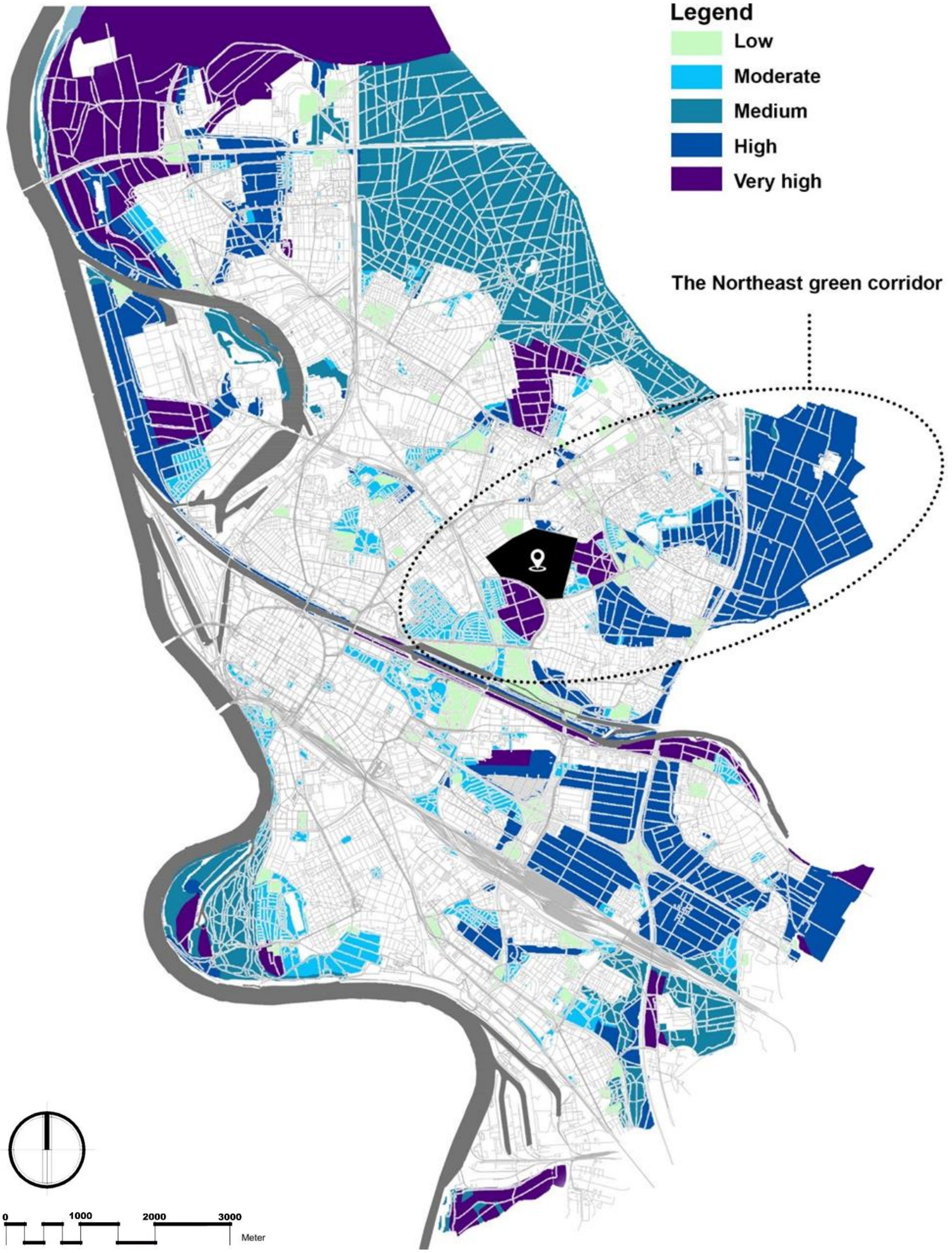
Data source: Stadtklimaanalyse Mannheim 2010, Ökoplana Karte 11,
https://www.mannheim.de/sites/default/files/page/74508/stadtklimaanalyse_ma2010_bericht.pdf
Map redrawn by Author.

Table 8: Climate-ecological compensation areas and the evaluation of their thermal compensation capacity (Figure 53)

Use	Area size [ha]	Cold air production rate in $m^3/m^2 \cdot h$	Valuation
Forest area	1.974,75	9	Medium
Agricultural area	3.367,18	12 - 15	High - Very high
Green space	789,60	9 - 15	Medium - very high
Park	267,90	6	Moderate
Allotments	425,73	6	Moderate
Cemetery area	86,90	6	Moderate
Green spaces in traffic junction areas	90,88	3	Low
Sports/leisure area	343,46	3 - 6	Low - Moderate
Water surface	726,00	0	Low

Source: Stadtklimaanalyse Mannheim 2010, Ökoplana Page 60,
https://www.mannheim.de/sites/default/files/page/74508/stadtklimaanalyse_ma2010_bericht.pdf

Figure 55: Thermal compensation capacity basis of the potential cold air production capacity.



Data source: Stadtklimaanalyse Mannheim 2010, Ökoplana Karte 12, https://www.mannheim.de/sites/default/files/page/74508/stadtklimaanalyse_ma2010_bericht.pdf
Map redrawn by Author.

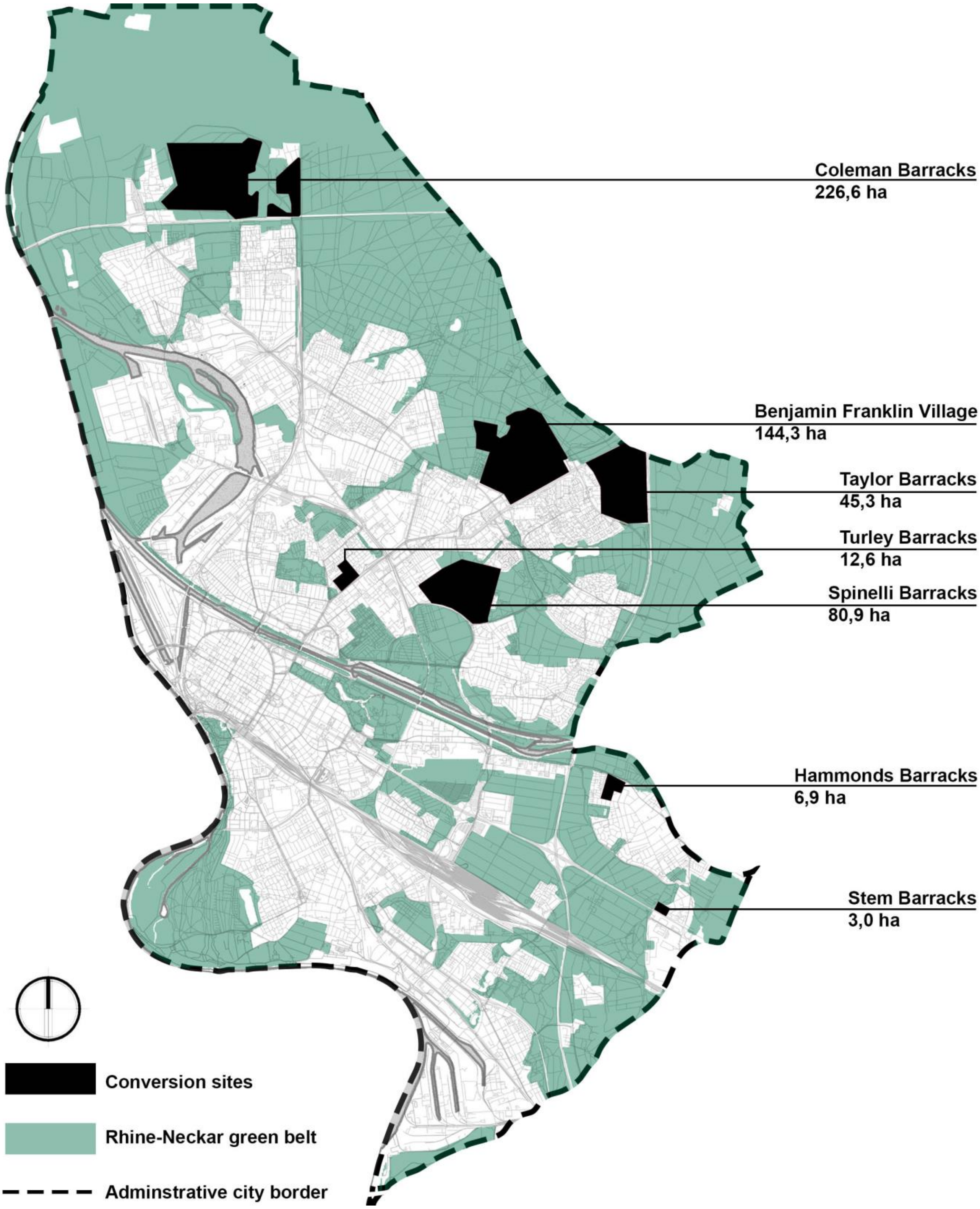
6.6. Rhein-Neckar green belt

The conversion of 500 hectares of land previously used for military purposes (Figure 54), combined with the evolving needs of the city due to urban and environmental issues, is the main challenge facing the city of Mannheim. Mannheim sees the "Open Spaces" left behind by the military as a chance to transform the city in an economically, ecologically, and demographically responsive way. The city is taking an ambitious approach to these processes. By hosting a Federal Garden Show in 2023, the city of Mannheim hopes to drive the conversion process and promote further urban and open space development. The aim is to connect open spaces, create diverse and appealing public spaces, and secure them permanently. Essentially, the goal is to create urbanity through the design of "Open Spaces" by recognizing and utilizing these spaces both physically and conceptually.

The BUGA is seen as a driving force for integrated city and regional development. Federal garden shows, which have been held in Germany since the 1950s, are recognized as exceptional cultural events in horticulture. They have led to the creation of large parks and inner-city green spaces that provide ecological and cultural benefits.

The Federal Garden Show (BUGA) will give a strong boost to the city development process. With the slogan "Mannheim connects," it will not produce an isolated park but will shape public spaces with their own unique characteristics and traits, where exchange and connection are core goals both for the city ecology and culture. With the conversion areas, Mannheim has a great potential for developing fresh air and climatically effective zones that have a city-wide impact. Thus, the utilization and preservation of these areas as green and public spaces is one of the overarching future tasks of Mannheim's city development.

Figure 56: Unused areas that were previously used for military purposes within the Rhine-Neckar green belt.



Source: Prepared by Author according to data available in the feasibility study of green corridor rhine-neckar river.

The green belt serves multiple functions:

- Social: Providing close-by open spaces for recreation and personal development
- Ecological: Creating and preserving habitats for wildlife and vegetation, and connecting/preventing traffic through proximity to residential areas and good accessibility
- Climatic: Generating and guiding fresh air.

The potential of conversion areas is crucial for focusing the study area on northern Mannheim. The reuse of former military sites is the central future task for Mannheim.
Here, waste is not seen as emptiness, but as an opportunity: "Open Space".
These areas are seen as valuable for long-term sustainability and play a crucial role in addressing open space deficiencies. The objective is to take advantage of these areas and turn them into networking opportunities.
Along with the conversion areas, there are already substantial open spaces located between the Rhine and Neckar that offer a diverse range of landscapes on a small scale and great natural diversity (Figure 57). These spaces have unique spatial and functional properties, leading to the distinction of different types of open spaces. This diversity presents an opportunity to create a large green belt composed of various open spaces with different qualities and atmospheres, appealing to a broad range of users. (Machbarkeitsstudie, 2013)

Figure 57: Identification of the types of open spaces in the greenbelt

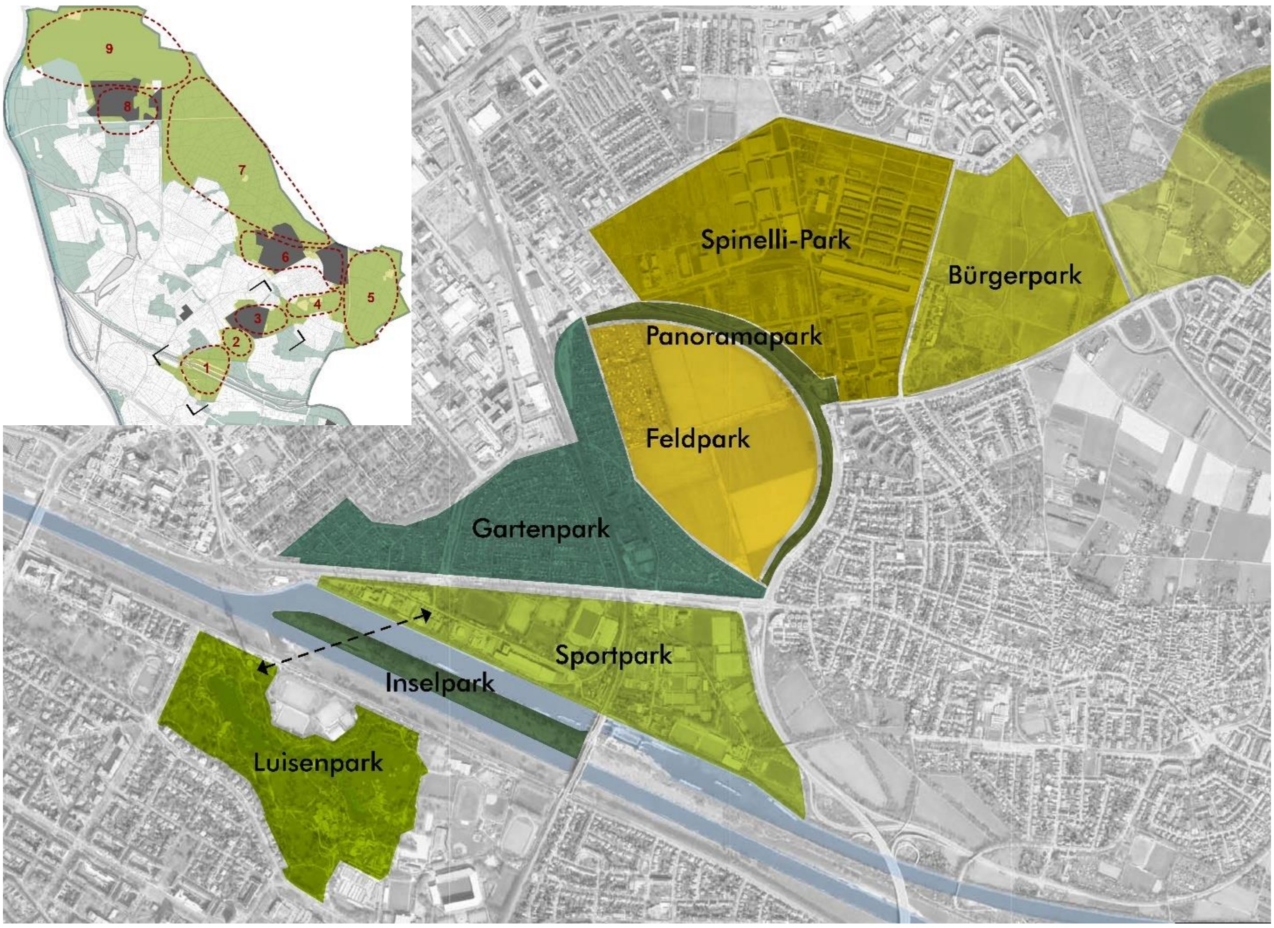
1-Open spaces close to the city center on the Neckar. Shore - Neckar
2-Feudenheimer Au. Expanse - old shore
3 Spinelli Barracks. sand dunes – freedom – movement
4 Vogelstang lakes. Lakes - recreation
5-Strasseheimer Feldflur. field - apple chamber
6 Franklin & Taylor Barracks. Heterogeneity - urbanity
7-Käfertal Forest. forest – human – water away
8- Coleman Barracks. Intersection - old shore - dry
9-Markgrafen-Acker/Sandtorfer Bruch. Width - Bank of the RhineRhine - Sand peat fracture

Source: Prepared by Author according to data available in the feasibility study of green corridor rhine-neckar river.

6.6. Green corridor Rhine-Neckar

The initiation of the overarching greenway in the city centre begins with the creation of a park sequence stretching from Luisenpark to Spinelli. Luisenpark serves as the starting point for the Luisenpark-Spinelli Park sequence and the initiation of the overarching greenway. Within the greenway, Spinelli plays a crucial role as the 'Missing Link'. Guiding the open spaces toward the city and activating Spinelli are both major tasks in the development of open spaces. The park sequence creates a chain of open spaces with varying qualities, capabilities, and uses by utilizing existing potentials. Each park has unique suitability, symbolizes something special, and offers a pivotal contribution to the overall experience and diversity of the greenway. Furthermore, each park has an ecological aspect as it serves as a habitat and a connecting function. In the long term, a sequence of diverse, high-quality open spaces will be established between Luisenpark and Spinelli under the guiding principle of "Modern Park." Modern parks offer extensive public access and are designed to accommodate multiple interests and functions, creating a multi-functional, multi-dimensional space. Ultimately, modern parks serve as a platform for addressing forward-looking topics in urban development.

Figure 58: Luisenpark-Spinelli Park sequence development plan to activate the northeast green corridor.



Source: Sinai. (2013). MachbarkeitsstudieGrünzug Rhein-Neckar, p.9

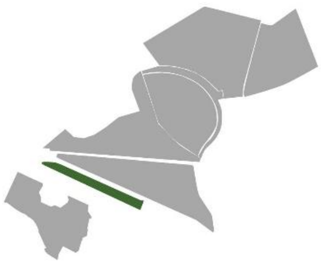
Characteristics of the Luisenpark-Spinelli Park sequence

Luisenpark
"Represent, Diversity, Commonality"

Characteristics:
Located south of the Neckar River and easily accessible from the city center, Luisenpark is the most popular and well-known park in Mannheim. Created for the 1975 Buga event, this classical, compact park offers a wide range of activities, from gondola rides to strolling, sports and play, to relaxation and recreation.
The representative green space has a strong impact on the entire city and the Rhine-Neckar metropolitan region and attracted approximately 1.2 million visitors in 2012.

Measures and Goals:
To activate Luisenpark as part of the green belt, the development of connections with the larger green belt and the crossing of the Neckar River are crucial.
A solution needs to be developed to access the Neckar riverbank, the Neckar cycle path, and further down the river to the lock system from Luisenpark.
Moreover, the park should be carefully adapted to changing demands for open spaces over time. (Sinai, 2013)

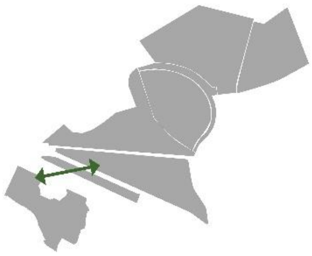
Inselpark
"Neckar bank, nature, protection"

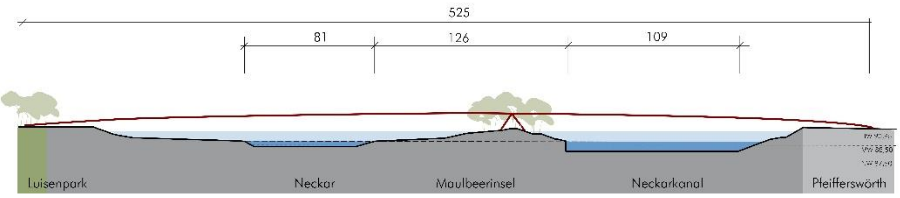


Characteristics:
Mulberry Island, which was formed in 1930, lies between the Neckar and Neckar Canal. It is considered a historic landmark of the town, boasting the remnants of a former mulberry plantation. The island is a part of the "Lower Neckar" nature and landscape conservation area.
Located in the heart of the city, visitors have the chance to witness nature and enjoy the Neckar river banks first-hand.

Measures and Goals:
As a nature reserve, the development of Mulberry Island must be done with caution and consideration. Protecting and preserving its current qualities should be the top priority. The addition of facilities for nature observation and experiences, such as hiking trails or birdwatching stations, can increase awareness of the island's uniqueness and the importance of nature conservation. (Sinai, 2013)

Leap over the Neckar



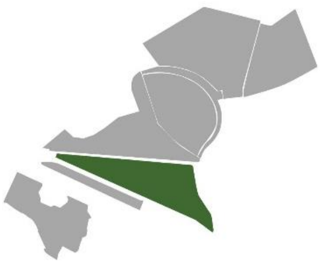


Source: Source: Sinai. (2012). MachbarkeitsstudieGrünzug Rhein-Neckar, p.31

Characteristics:
- Pedestrian and bicycle bridge over the Neckar and Neckar Canal
- Connection of the Luisenpark to the Au
- Inclusion of the mulberry island possible
- Connection of the green corridor

Measures and goals:
- Connecting the parent green corridor
- Setting a new character / brand in the shape of the city of Mannheim Connect.

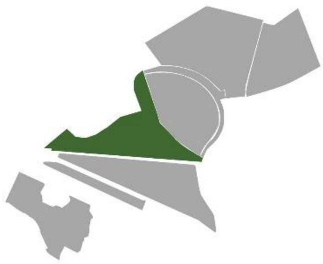
Sportpark
"Sport, exercise, energy"



Characteristics:
Across the Neckar Canal, in the areas of Pfeifferswörth and Neckarplatt, there is a space characterized by a mix of diverse uses. Large portions are dedicated to organized sports and are heavily utilized. The area is very purpose-driven and has a single function. This is reflected in its spatial structure as well, as there are no public open spaces and crossing through it is challenging. Additionally, there are no links or connections to the surrounding urban areas, and the nearby Neckar Canal has yet to be fully explored.

Measures and Goals:
The long-term goal for Pfeifferswörth and Neckarplatt is to develop it into a "modern sports park". This involves not only the creation of new sports facilities and a modern mass sports offering, but also the opening up and integration with the green belt and a focus on the water through specific measures. These steps are crucial for the development of the area. (Sinai, 2013)

Gartenpark
“Gardening, encounters, Contemplation"



Characteristics:
Adjacent to the north of the sports park are several allotment gardens. These gardens, which are intensively used by members of the association, are not very welcoming to non-members.
The restricted usage can also be seen in the spatial design, with its difficult crossability, low public character, and lack of connections to the surrounding areas.

Measures and goals:
To attract a wider range of users, the proposal is to create a modern "garden park". To achieve this, the quality of the facilities should be improved by offering shared open spaces. Integrative gardening projects, such as urban gardening, multigenerational gardens, and intercultural gardens, will also enhance the range of uses.
Designing the garden park with attractive and spacious public paths and connecting it to the open space system is another effective measure to improve cross ability. (Sinai, 2013)

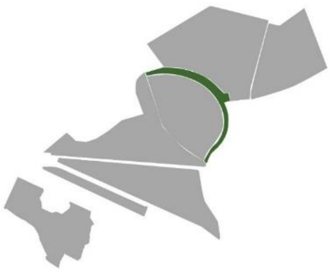
Feldpark
"Agriculture, Space, Water"

Characteristics:
Located in the heart of Mannheim, on the former floodplain of the Neckar River, is an agricultural area that is also a designated landscape protection area. The Hochgestade, the

former rampart of the Neckar, borders the expansive open space to the northeast. The soil in this low-lying area close to the groundwater remains particularly fertile today.
Having such wide open spaces in close proximity to a densely populated city center is a rare and special experience.

Measures and goals:
The long-term goal is to preserve the expanse and large-scale structures of the Feldpark. Reorienting agricultural use and/or intensifying it is a possibility for the Feldpark.
Additionally, it is proposed to create a semi-natural watercourse in the location of the former Neckar loop to take advantage of the floodplain's water potential. The diverse and valuable water and water edge biotopes created in this way would enhance the biotope function of the floodplain.
The improvement of the paths and their connection to the higher-level development system will also continue. (Sinai, 2013)

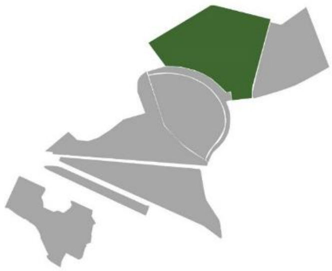
Panoramapark
"Outlook, expanse, topography"



Characteristics:
The high shore was created by the meandering Neckar River and used to be the bank of the Neckar loop. Currently, it serves as a connecting link between Spinelli and Au and is bisected by the street called "Am Aubuckel". The high shore is considered an important part of the green corridor in Mannheim, but its potential as a viewing platform to view the city center and the Palatinate Forest has not been utilized.

Measures and goals:
The goal is to develop a panoramic park that takes advantage of the unique height difference and the stunning view. To achieve this, selective measures should be taken while preserving the high shore as much as possible. These measures may include building viewing points or utilizing the relief energy in a playful way. Additionally, the street "Am Aubuckel" will have to be relocated as it cuts through the high-quality park landscape in its current location. (Sinai, 2013)

Spinelli-Park
"Liberty, public appropriation, urban landscape”



Characteristics:
The Spinelli Barracks conversion site extends north of the Au on a high plateau. With the release of the 80.9-hectare area in 2015, a huge development and experimental space is being created in the immediate vicinity of the city centre, which will play a key role in the overall green corridor.

Measures and goals:
The conversion of the site into an extensive landscape park with intensive borders, known as the park shell, will provide an attractive and diverse park strip that will offer space for forward-looking urban development. The central open area will provide an extensive landscape park characterized by sand dunes and dry grassland with shrubs setting accents in certain areas. The vastness of the area will be maintained through extensive pastoralism, including urban agriculture as a cost-effective operating and marketing tool. The park shell will serve as a usage filter for new living and will offer a variety of sports and play areas.
In addition, the fringes of the site are carefully planned for the further development of the city, with the western edge being compact and clear and the eastern edge being a permeable filter in front of the existing buildings. The process of Freiland Mannheim, through which citizens can temporarily activate the site, is subject to constant change and requires external control.
Overall, the conversion of the Spinelli Barracks site is an opportunity to create a large green area in the city centre and improve the urban climate by opening a generous corridor of fresh air into the city. The development of new path connections and networking with surrounding districts and the green belt is a key goal, and the site has the potential to become a flagship project for the city of Mannheim and the region. (Sinai, 2013)

Bürgerpark
"Together For Each Other"

Characteristics:
The Bürgerpark in Feudenheim was created recently as a result of the commitment of its citizens. It is a tree-lined landscape park that blends seamlessly into the neighboring agricultural areas. The park offers not only play and sports areas such as a skate track and a BMX course, but also space for recreation close to the surrounding neighborhoods.

Measures and goals:
The goal is to activate the art and work courtyards on Spinelli in a spatial-thematic connection with the Bürgerpark. Furthermore, measures to enhance connectivity with the surrounding open spaces are a priority. (Sinai, 2013)

Why is Spinelli's development so important for the overall green corridor?

Spinelli is important for the overall green corridor because it serves as a missing link in the green area and in the fresh air aisle, offering a scope for urban development and a proximity to the city center, making it a significant inner-city open space with enormous potential for development. Being located in the vicinity of relatively densely built-up residential areas, the conversion of Spinelli into an extensive landscape park can provide much needed access to green spaces for residents and improve the urban climate of the city. The creation of a park shell with tree-lined intensive landscape and extensive open spaces with urban agriculture offers opportunities for forward-looking urban development and recreational activities. The potential inclusion of the mulberry island and connection of the green corridor will further enhance the value of the park and its contribution to the overall green corridor.

Figure 59: Spinelli connects 1. the overriding green corridor 2.the adjoining city quarters.

Source: Prepared by author (Base map: Google earth)

6.8. Spinelli Site

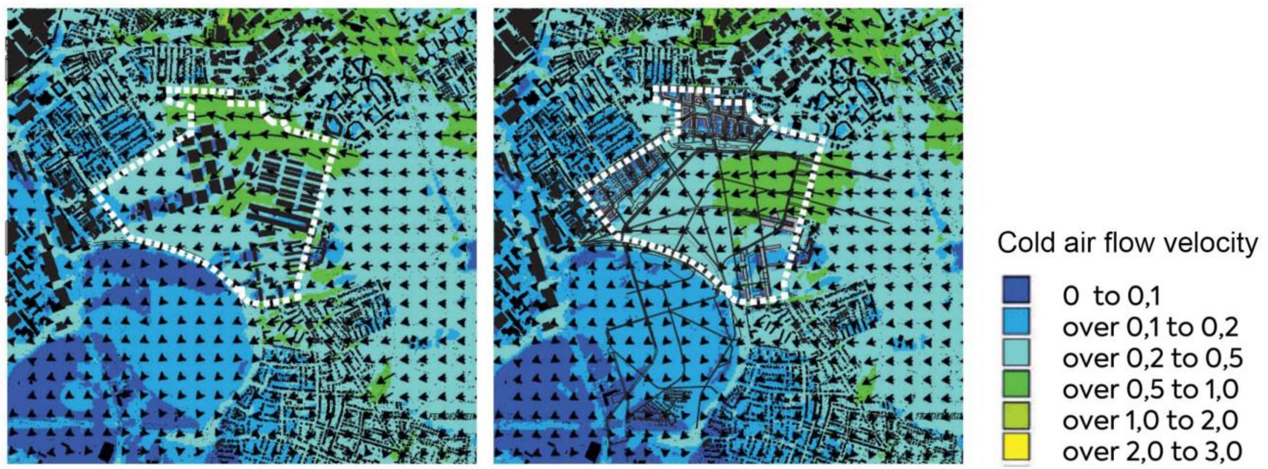
Barracks buildings demolition

The analysis conducted by Okopelana demonstrated that the removal of the barracks building in Spinelli Park had a positive impact on the local climate. This conclusion was reached through a comparison of the site before the demolition and the new master plan for urban development.The analysis showed that the demolition improved the connection of the Spinelli site with the green spaces and nature corridors in the surrounding area, leading to an overall improvement in the health and well-being of the local environment.

Figure 60: Before and after the dismantling of the Spinelli barracks building

Source: Kay Sommer_Luftbild Spinelli

Figure 61: Comparison of the Spinelli site before and after demolition



COMPARISON OF COLD AIR FLOW VELOCITY AND FLOW DIRECTION (LEFT -EXISTING, RIGHT -PROPOSED) (SOURCE: ÖKOPLANA)

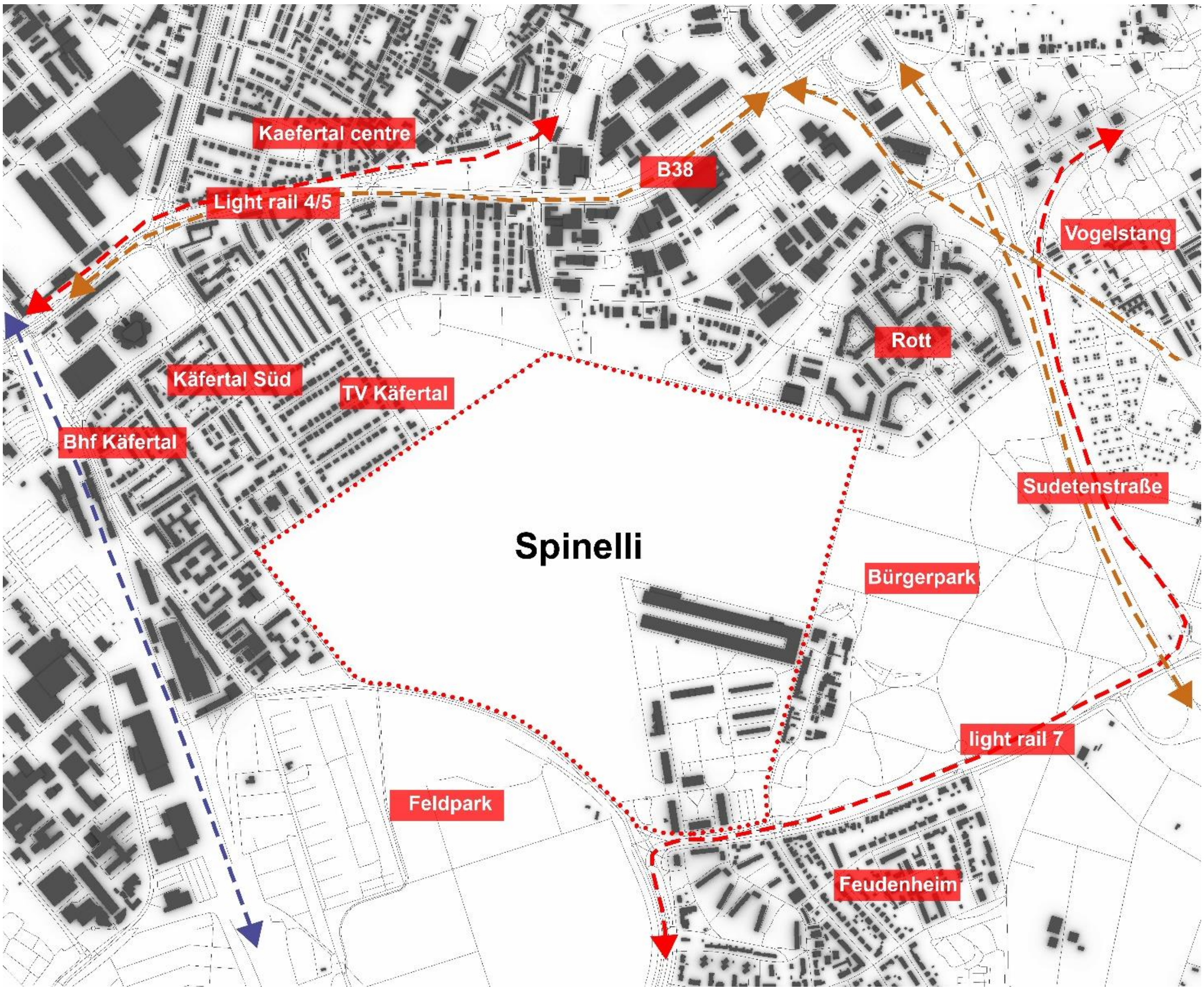
AIR TEMPERATURE DISTRIBUTION 2 M A.S.L. ON A WARM SUMMER NIGHT (10:00 P.M.) (L -EXISTING, R -PROPOSED) (SOURCE: ÖKOPLANA)

Neighborhoods and urban structures in the area

The neighborhood of Käfertal Süd/Im Rott is characterized by a diverse mix of building structures. The planned residential areas include a mix of detached single-family and semi-detached houses to the west of the sports field, terraced houses and smaller multi-family homes around Rüdesheimer Strasse, and small-scale commercial development in the south. The area west of Völklinger Strasse is made up of semi-detached homes and moderate apartment buildings, while there is a large commercial area east of B38. To the north, there are isolated allotments and single-family homes, and to the east is the residential area of Rott, shaped by urban apartment construction.

The residential development in Käfertal Süd/Im Rott is a mixture of moderate and urban apartment buildings, as well as single-family homes of varying degrees of density. The development structures are accentuated by public functions. There are larger contiguous commercial areas in the southwest and northeast that act as breaks in the urban fabric. Käfertal Süd/Im Rott is connected to the north, east, and west by higher-level traffic routes, separated from the surrounding environment. The Spinelli area to the south offers the potential to connect the fragmented neighborhoods into a coherent district with its own unique quality, shaped by a strong urban form and a spacious park. (Rahmenplan Spinelli, 2018).

Figure 62: Neighborhoods and urban structures in the area



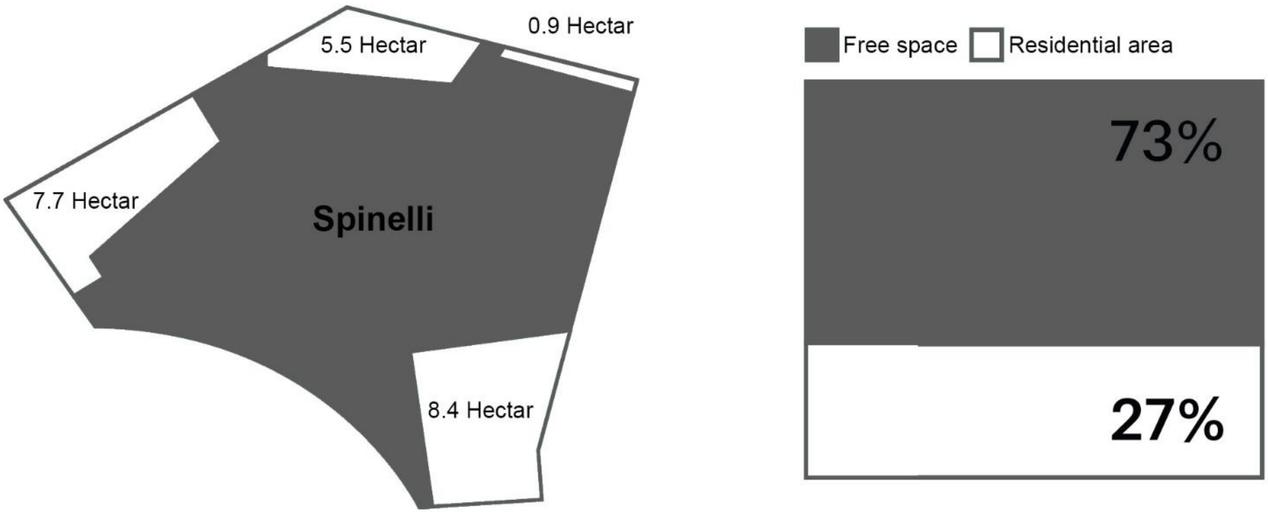
Source: Prepared by author

Existing development plan for Spinelli Park

The Spinelli conversion region is the second largest residential expansion area in Mannheim, covering approximately 80 hectares, which is half the size of Franklin's Käfertal region. Both areas will be responsible for a significant portion of the 10,000 additional housing units required in Mannheim by 2025. (Rahmenplan Spinelli, 2018)

In addition to housing development, which is crucial for urban growth, the emphasis of the planned transformation is on open spaces. The conversion of urban areas presents a unique opportunity to create green corridors and fresh air pathways within the city. With changing weather patterns, Mannheim has a critical opportunity to address the necessary adaptation of the city to climate and ecology. As a result, the future open space in the area will account for more than 70% of the area. The neighboring districts of Käfertal and Feudenheim in the north and south will be completed, while the central area will remain a green area. (Rahmenplan Spinelli, 2018)

Figure 63: Area shares Spinelli



Source: Projektgruppe Konversion. (2018). Die Entwicklung eines Modell Quartiers Städtebaulicher Rahmenplan, p.15

Urban development characteristics

The 27% of urban development is already under construction, The future will offer a wide range of housing options for residents, both in multi-family and single-family houses, promoting diversity and social mix. The availability of social amenities and local resources add to this. The flexible planning allows for adjustments and the possibility of densification. Most areas are designated as general residential areas while the central district square is designated as a mixed-use area, providing the foundation for dense urban development. The district centre, including local businesses and a garage, will be designated as a special area. The various housing options, including multi-family houses, single-family homes, and terraced homes, will ensure efficient use of land and offer space for around 1,800 new residential units. Approximately 30% of the land will be used for single-family homes and 70% for apartment buildings, with 30% of these apartments designated as affordable housing. It's estimated that around 4,500 new residents will be accommodated, with an average of 2.3 residents per apartment unit and 3.5 residents per single-family unit. (Rahmenplan Spinelli, 2018)

Figure 64: Urban development concept visualisation

Residential area with single-family house typologies

Residential courtyard with apartment buildings

City edge with park promenade

Source: Projektgruppe Konversion. (2018). Die Entwicklung eines Modell Quartiers Städtebaulicher Rahmenplan. P.75, 76, 77

Figure 65: Urban development characteristics

				
Urban apartment building	Apartment building compacted	single-family house typology	Conventional terraced/semi-detached houses	single-family houses
Commercial building courtyard house, landmarks park	townhouse, park villa	duplex	Townhouse	Chain house, detached

Source: Projektgruppe Konversion. (2018). Die Entwicklung eines Modell Quartiers Städtebaulicher Rahmenplan.
Redrawn by author.

Mobility

Mobility greatly affects quality of life. At the same time, it is essential for everyday activities but also brings negative impacts such as noise, pollutant emissions, and traffic congestion. The mobility options available in the living environment significantly influence residents' transportation choices, as 80% of all trips start or end at home. People's modes of transportation are also greatly influenced by habits. In a new neighbourhood, the future residents are in a state of transition, and many are open to new ideas. This presents an opportunity to promote sustainable mobility that meets the needs of the new residents. (Rahmenplan Spinelli, 2018)

The residents of Käfertal Süd/Im Rott will have the ability to travel in an environmentally friendly and secure manner. The living environment will be improved to prioritize mobility, with the following objectives being monitored:

-Offering more appealing and easily accessible alternatives to personal vehicles, allowing residents to choose their preferred mode of transport according to their needs.
-Providing a diverse range of paths that can be selected, combined, and varied based on purpose.

-Decreasing noise and air pollution

-Ensuring mobility for seniors, families, and disadvantaged groups

-Lowering the amount of car parking spots in public spaces and reducing parking space demands by creating a mostly accessible living space with a pathway and transportation system that prioritizes eco-friendly modes of transportation. (Rahmenplan Spinelli, 2018)

Pedestrian and Bicycle Paths/Walkability

The goal is to design public spaces in a way that makes non-motorized forms of transportation, such as walking and cycling, particularly attractive, safe, and accessible. This will foster harmonious coexistence and low-car living. Short distances within the neighbourhood will encourage walking and cycling, as will a pleasant public space and easily recognizable landmarks. To promote cycling, residents should have easy access to safe parking options near their homes, an attractive cycling infrastructure with cycle paths and parking facilities, and convenient connections with local public transportation. The stops should be within walking distance and accessible by bicycle. To make it more attractive, improvements such as better crossing options, for example, across the railway line in the west and the B38 in the north of the neighbourhood, will be made. Safe and covered bicycle parking facilities should also be installed. In the future, a cycle expressway will run along the edge of the green corridor, allowing residents to quickly and directly reach the centre of Mannheim and providing a clear alternative to driving a personal vehicle. Other bike connections will be maintained or linked to the new network. (Rahmenplan Spinelli, 2018)

Public Transportation

In the Spinelli district, it will be possible to live without relying on a personal car. Therefore, efficient and attractive local public transportation is crucial, meeting the needs of residents and offering high frequency, even during non-peak hours.

Figure 66: Local public transport

Source: Prepared by author

BUGA23 Mannheim connects framework concept

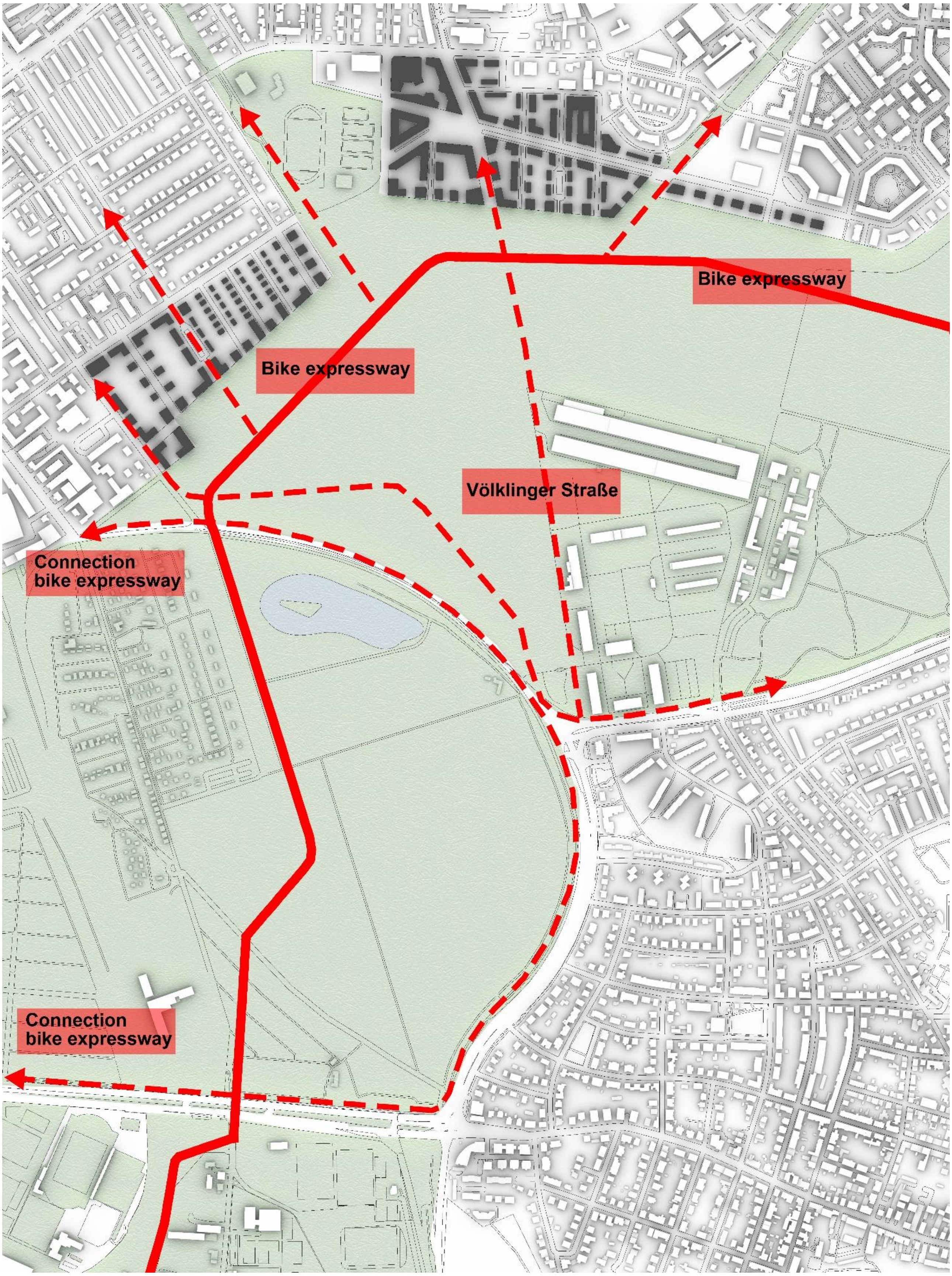
According to existing Spinelli Masterplan the goal is to minimize the amount of land that is covered and to create more open space. The site will be converted into a 23-hectare parking area for sports and leisure activities and a 45-hectare landscape park with a large-scale terrain design. In addition, a 4-kilometer cycle expressway will be built, connecting the districts of Käfertal and Feudenheim to the city center. A 1.5-hectare natural water system will improve the ecological health of the Feudenheimer Au landscape protection area. To ensure the development of the green corridor, three structures will be built and 3.9 hectares of high-speed cycle paths and footpaths will be constructed. These paths will ensure the seamless continuity of the landscape and reduce the volume of motor vehicle traffic. (Rahmenplan Spinelli, 2018)

The green corridor is surrounded by wide bike lanes and pedestrian walkways. The newly built barrier-free connections allow the flow of traffic from adjacent areas to converge and head towards Vogelstangseen or the city center. This provides fast and uninterrupted travel and links the area to the neighboring districts of Vogelstang, Käfertal, and Feudenheim. Riding along the bike path allows one to experience the various landscapes of the green belt. By reducing the use of private cars, peaceful areas are established. (Rahmenplan Spinelli, 2018)

The revival of the historic path connection along the Völklinger Straße reconnects the districts of Käfertal Süd and Feudenheim, which had been inaccessible for many years. The old Kastanienallee is extended into the quarter.

The Völklinger Straße creates a connection between the district square and the large park area. The pathway is lined with a variety of different spaces. The new district square marks the starting point and the park promenade serves as a transition between the urban areas and the open spaces of the green belt. Only limited sections of it are open to motorized traffic. The broad and continuous street design, with its shady rows of trees, offers ample space for walking. (Rahmenplan Spinelli, 2018)

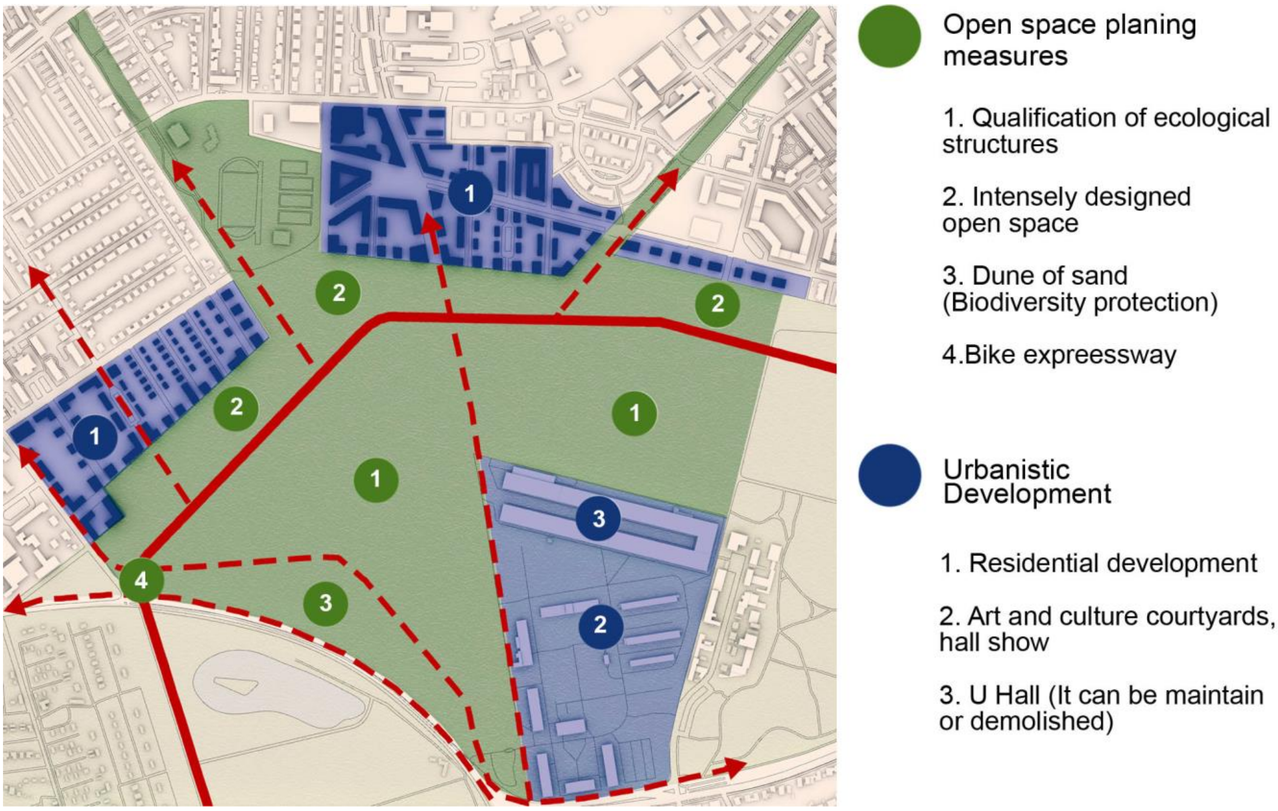
Figure 67: Cycle path connection in the north-east green corridor



Source: Prepared by author base on the information in the (Rahmenplan Spinelli, 2018)

The path connections outlined in the existing master plan provide a well-planned division for implementing a diverse range of open space qualities and incorporating environmental conservation elements.

Figure 68: Criteria for designing open space in Spinelli Park



Source: Prepared by author

Biodiversity

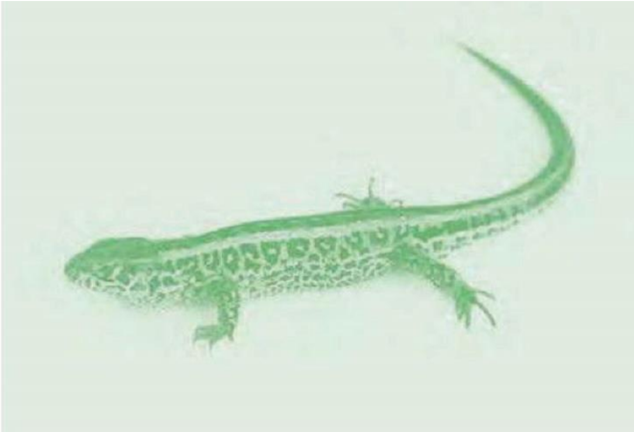
Urban areas that are well-vegetated already have a greater variety of species compared to open agricultural fields. Thus, the goal is to achieve a high level of biodiversity in Spinelli as well. Open and green spaces play a central role. The challenge is to develop an urban district that provides urban density, mobility, leisure, and relaxation options while also integrating flora and fauna.

Biodiversity should be promoted through suitable measures so that the quarter becomes a habitat for animals and a place of high biodiversity. Given its proximity to the north-east green corridor, there are close connections between the open spaces in the quarter and the green corridor. The green corridor is already a suitable habitat for many animals, including protected species such as the gray long-eared bat, crested lark, mason bee, and wall lizard. To ensure that these populations grow and persist, building sites will be designated with existing habitats in mind. Concentrating development on the edge of the green corridor will preserve and expand existing habitats for animals and plants. A comprehensive and long-term biodiversity strategy for buildings and their surrounding open spaces will be implemented to secure habitats for animals and plants. (Rahmenplan Spinelli, 2018)

The ecological quality of the district is primarily based on the concentration of buildings along the edge of the green corridor and the preservation of an open. This reflects the idea of sustainable and climate-friendly development and the importance of keeping large green areas intact, especially protected good soil and its associated climate-related aspects. Overall, the development of an ecological quarter that benefits not just residents but also animals and plants will provide a concrete benefit in the future, as the number of hot days, tropical nights, and weather events increases. (Rahmenplan Spinelli, 2018)

Figure 69: Examples of animal species worthy of protection in the north-east green corridor

Gray long-eared



Wall lizard

Crested lark

Mason bee

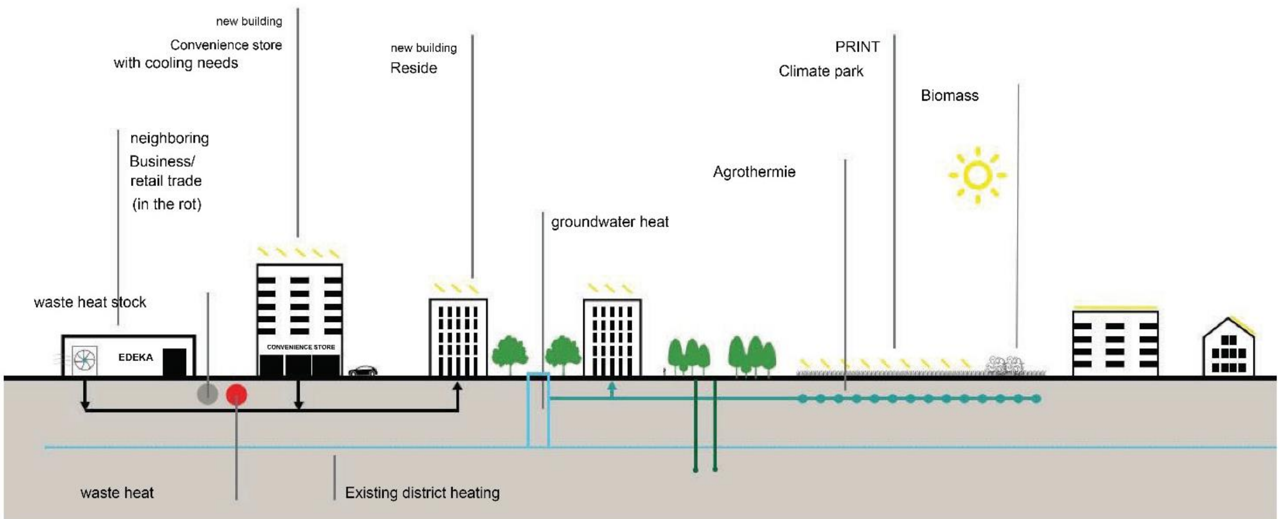
Source: Projektgruppe Konversion. (2018). Die Entwicklung eines Modell Quartiers Städtebaulicher Rahmenplan.

Innovations in the field of energy

Spinelli aims to protect the climate through energy-efficient buildings, utilizing renewable energy sources and advanced building technology. The Building Energy Act, which consolidates various energy laws, is currently being drafted. The city of Mannheim is committed to more climate protection through its "Mannheim on a climate course" initiative, which focuses on energy and climate policy measures. Several energy innovations have already been introduced in the Benjamin Franklin area, which will be further developed in Spinelli. The future tightening of energy standards is currently unclear. (Rahmenplan Spinelli, 2018)

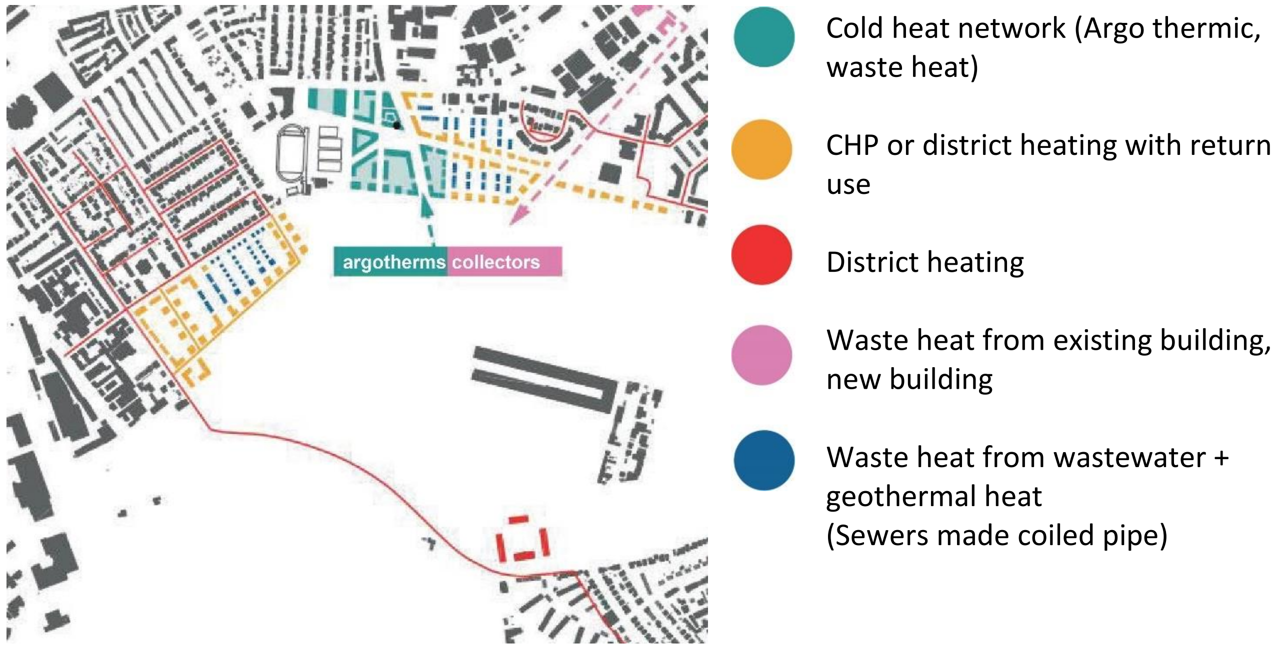
Spinelli intends to move away from the fossil-nuclear era and utilize intelligent energy sources. The goal is to provide the new buildings with a largely renewable and low-carbon energy supply for heat and electricity. As much thermal and electrical energy as possible will be generated locally within the district and its surroundings and used by the residents. The buildings in the Spinelli district will be incorporated into efficient heating networks, which have numerous advantages compared to individual solutions, such as a more straightforward conversion to new energy sources. Despite the current challenging circumstances, Spinelli can achieve an economical, affordable energy supply with a high level of innovation and self-sufficiency. (Rahmenplan Spinelli, 2018)

Figure 70: Energetic potentials in the Spinelli area.



Source: Projektgruppe Konversion. (2018). Die Entwicklung eines Modell Quartiers Städtebaulicher Rahmenplan. P.110 (Diagram by HFT Stuttgart)

Figure 71: Conceptual considerations for different supply systems



Source: Projektgruppe Konversion. (2018). Die Entwicklung eines Modell Quartiers Städtebaulicher Rahmenplan. P.112 (Diagram by HFT Stuttgart)

Investment Budget

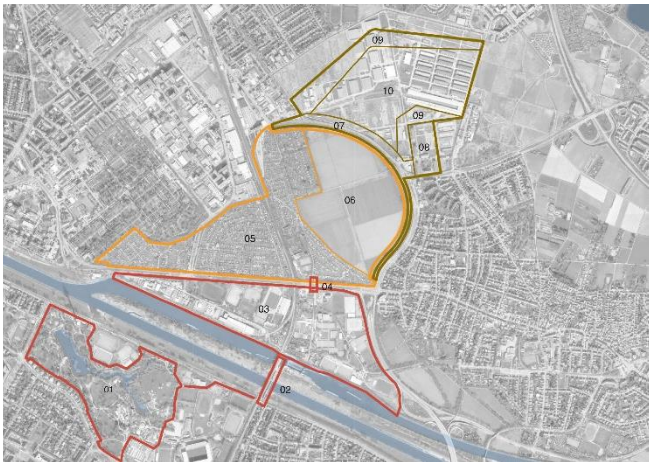
The investment budget for the upgrading and preparation of the green corridor in four sections for the Buga Mannheim 2023 has been determined. The costs include all the permanent structural improvements for the sub-areas that will become part of the overall green corridor after the event. This includes:

Measures to establish the basic structure such as paths, squares, plantings, and bodies of water.

Measures to create sports, play, and other recreational areas as well as the technical infrastructure for the green space.

The investment budget for the green corridor in the context of Buga Mannheim 2023 is 105 million euros. (Sinai, 2013)

Figure 72: investment budget area overview



The costs of the investment budget were determined using standard cost guide values for open spaces of different types.

Green corridor section 1 "From the city center to the Au"

1. Luisenpark and connection to the Neckar
2. Neckarbrücke staging
3. Sportpark Pfeifferswörth and Neckarplatt
4. Feudenheimer Straße crossing

13.5 million €

Green corridor section 2 "The floodplain with eye waters"

5. Gartenpark
6. Feldpark

21 million €

Green corridor section 3 “Panorama Park and Spinelli”

7. Panoramapark
8. Spinelli Park at the Art Courts
9. Spinelli Park parking shell
10. Spinelli Park Central OPEN AREA

48 million €

Green corridor section 4 "Superior infrastructure and Buga satellites" [not located]

11 traffic infrastructure measures, including the “Am Aubuckel” road 12 Buga satellites.

22.5 million €

Investment cost 105.5 million €

Source: Sinai. (October 2012). MachbarkeitsstudieGrünzug Rhein-Neckar, Buga 2023, Mannheim

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7

DESIGN PROPOSAL

Design ingredients based on research and analysis

A) Outdoor human space utilizing renewable energy technologies.

B) The use of renewable energy sources to generate electricity and heat provides communities with clean, carbon-free energy.

C) Keep power electronics and energy storage systems out of easy reach for people

D) Bringing a positive message about life in a post-carbon world and inspiring people with the beauty of renewable energy.

E) Advancing one or more Sustainable Development Goals

F) Showing beautiful energy generation capacity for both private gardens and civic park

G) Provide a variety of social benefits like urban farming (Agrovoltaic farming), recreation, gathering, and interactivity

H) Respectful of the history and surrounding context of the design site by considering the historical path that is passing through the site to connect two neighboring districts.

I) Supporting the objectives of the Green Corridor (Klimopass), a component of the Baden-Württemberg climate adaptation plan, The Green Corridor is intended to allow fresh air to flow unobstructed into the city.

J) Supporting the BUGA existing framework and masterplan

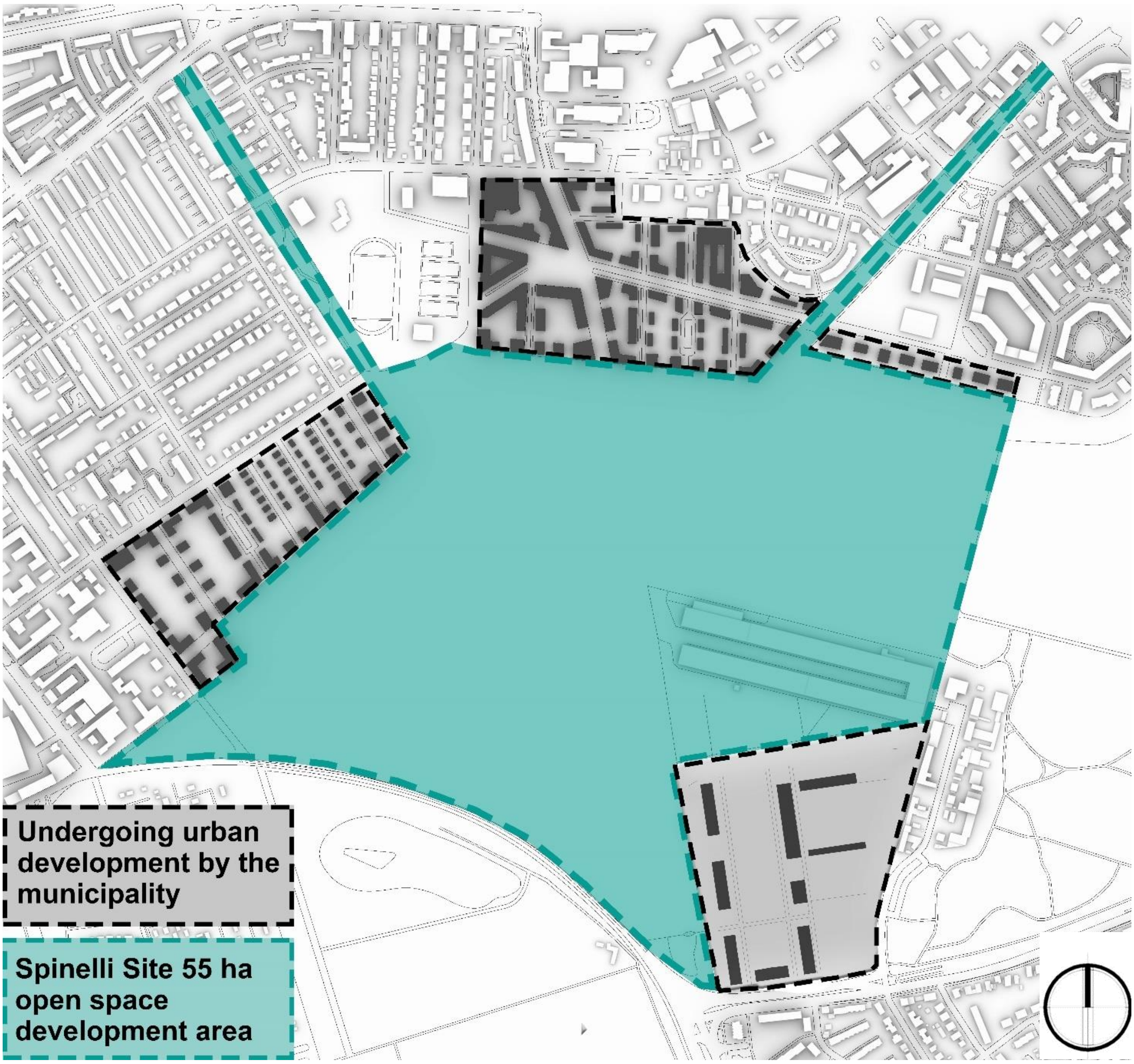
K) Preserving the existing Dune area to protect biodiversity

L) Providing the network of bike expressway throughout the Spinelli site

Design Process

Open space design project area

An area of 55 hectares has been designated for open space development in order to revitalize the northeast green corridor and offer high-quality outdoor space to the surrounding neighbourhoods.



Graphic by author

1st Design Step

The creation of a non-motorized Spinelli Park will provide a secure and inviting outdoor space for individuals to spend time in and experience the beauty of nature.

Width 10 m — **Bike expressway to connect the green corridor with a continius sustainable mobility**

Width 7 m — **Historical route revitalisation to connect 2 district**

Width 5 m — **Pedestrian routes are being considered to link neighboring districts and make the Spinelli site accessible and permeable**

A portion of U Hall will be demolished to create more space for the influx of fresh, cool air

Graphic by Author

The fulfilment of the research and analysis component within the first design step

1. The placement of the Bike Expressway is in line with the framework planning of the BUGA, aiming to establish a barrier between the low-density open spaces and the high-density green areas.

2. A historical path that was previously lost has been rejuvenated, serving as a means of giving the district a distinct identity.

3. The distribution of pedestrian paths has effectively connected all the neighbouring districts, fostering a sense of community and interconnectedness. These paths have also provided convenient and accessible routes for the local residents and visitors.

4. The demolition of a significant portion of U Hall is in accordance with the communal Climate Adaptation Act, with the goal of facilitating the flow of fresh, cool air and addressing the issue of nocturnal overheating, particularly in the city centre.

2nd Design Step

Upon initial inspection of the routes established, it becomes evident that three areas within the site have been given greater attention. The routes have strategically placed three crucial nodes in the centre of the site, in the most accessible locations. These nodes offer the potential for creating landmarks, as they are positioned in the heart of the site. These landmarks can serve as key features that make the site unique and easily recognizable. By doing so, the routes not only provide functional access, but also add a sense of identity and character to the site.

Graphic by author

The fulfilment of the research and analysis component within the second design step

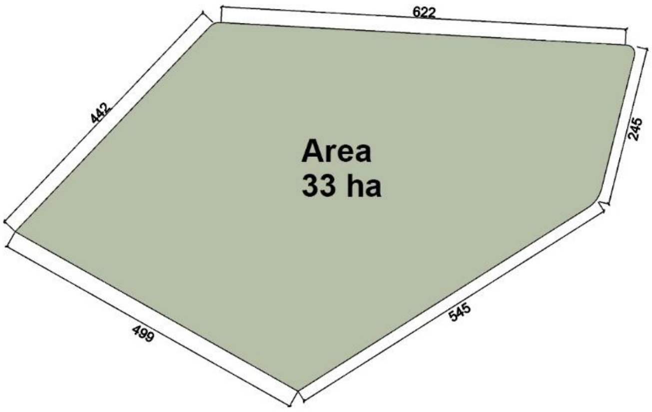
1. Dune of sand is preserved to protect the biodiversity in the district

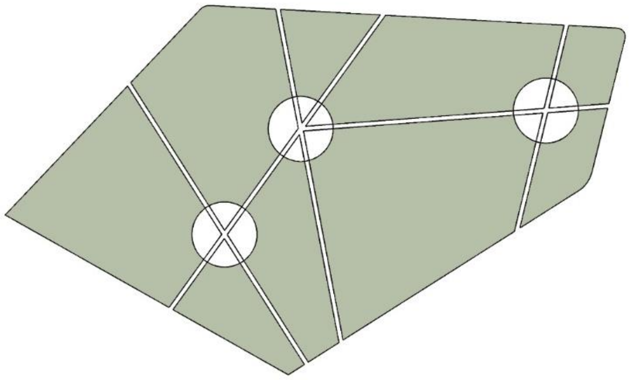
2. Three chosen locations that offer social benefits for the community are positioned in such a way as to provide equal access. They are strategically placed to ensure that all the districts can equally benefit.

3. As the southern border of the site is planned to connect with a bridge to the AU park, the placement of the community spots adds significance to the route that leads to the bridge

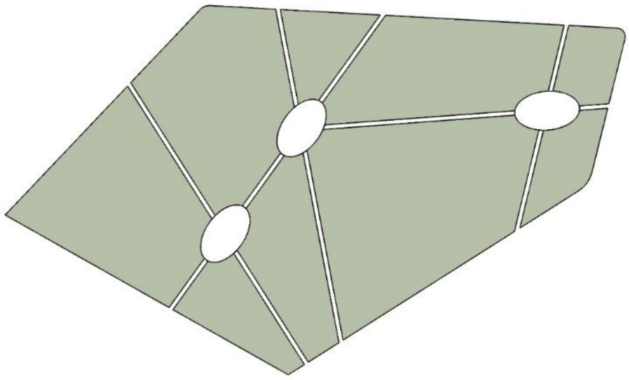
4. These three locations that offer social benefits for the neighbourhood are designed to generate energy using renewable technologies. The strategic placement of these locations offers easy access to the district's power grid, making it a convenient and efficient system for the community to benefit from.

3rd Design Step

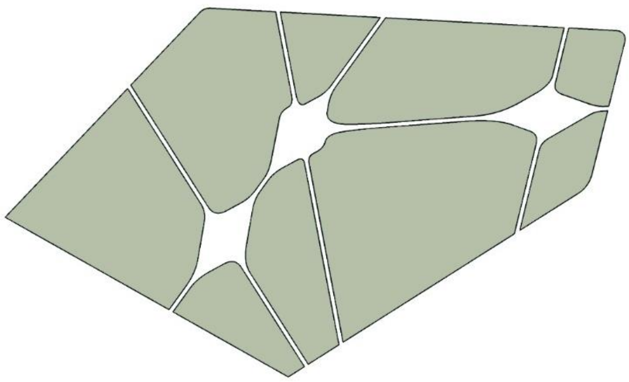




1. The allocation of public gathering spaces such as urban farming areas, recreational zones, areas for social interaction, and community gardens is planned within a 100-meter radius from pedestrian route intersections.



2. The social gathering area should be oriented in accordance with the site's pedestrian flow, while also ensuring a minimum exposure to the eastern adjacent land to facilitate the operation of the air fresh air.

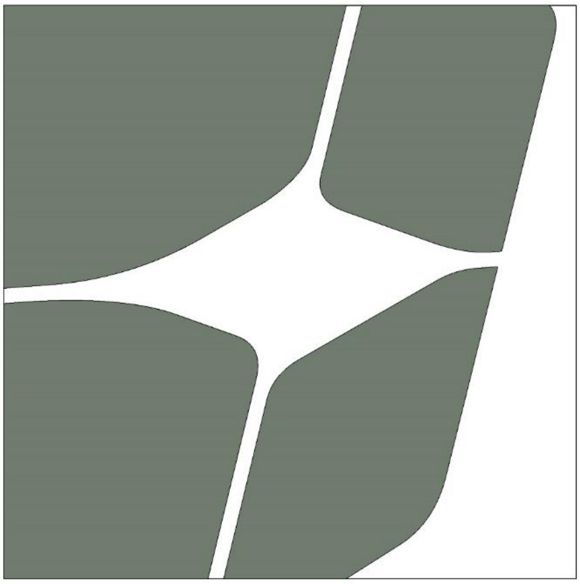


3. The integration of pedestrian pathways with the selected areas.

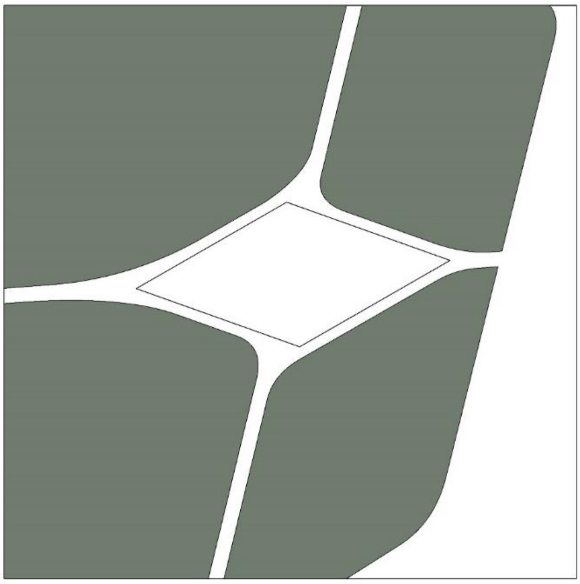
A 19,500 square meter area has been allocated for social collective activities.

Diagrams by author

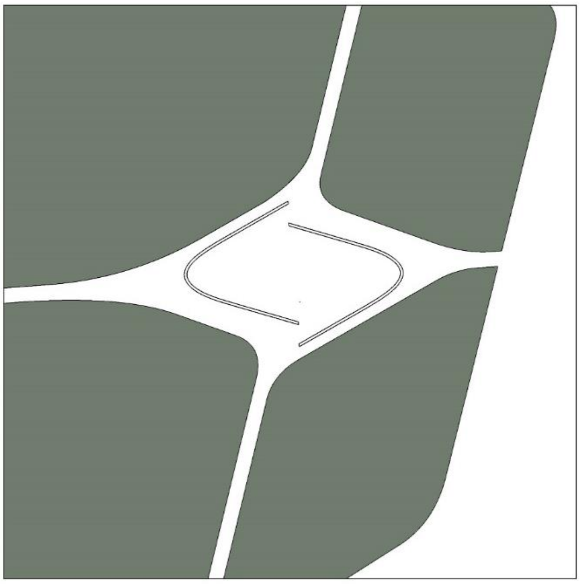
Productive Structure design process



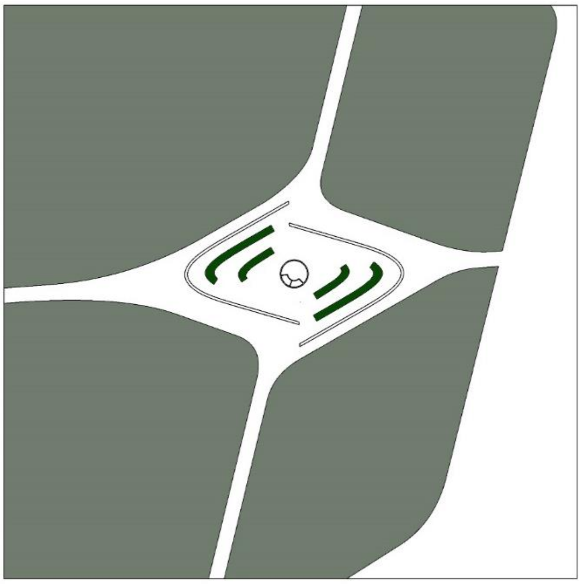
1. A public structure spot with an area of 6500 square feet



2. 5 meters of offset from the borders to create a circulation around the structure



3. Softening the edges of the structure and adding two entrances

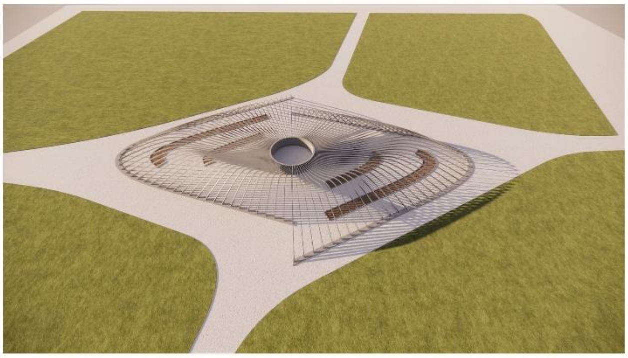


4. Allocating 190 square feet for urban farming and a community garden, along with space for hosting events and collective activities.

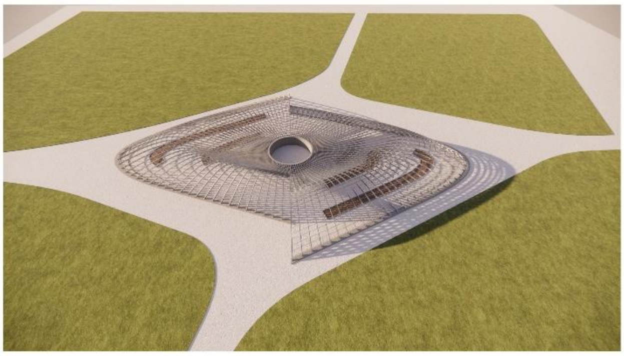
Diagrams by author

Structural component

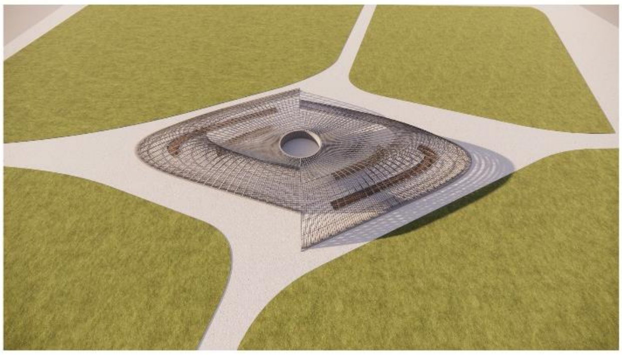
Base Structure



Vertical Stiffeners

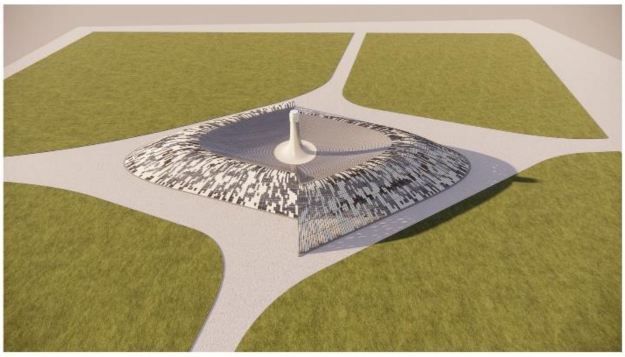


Horizontal stiffeners



Frame structure for photovoltaic system

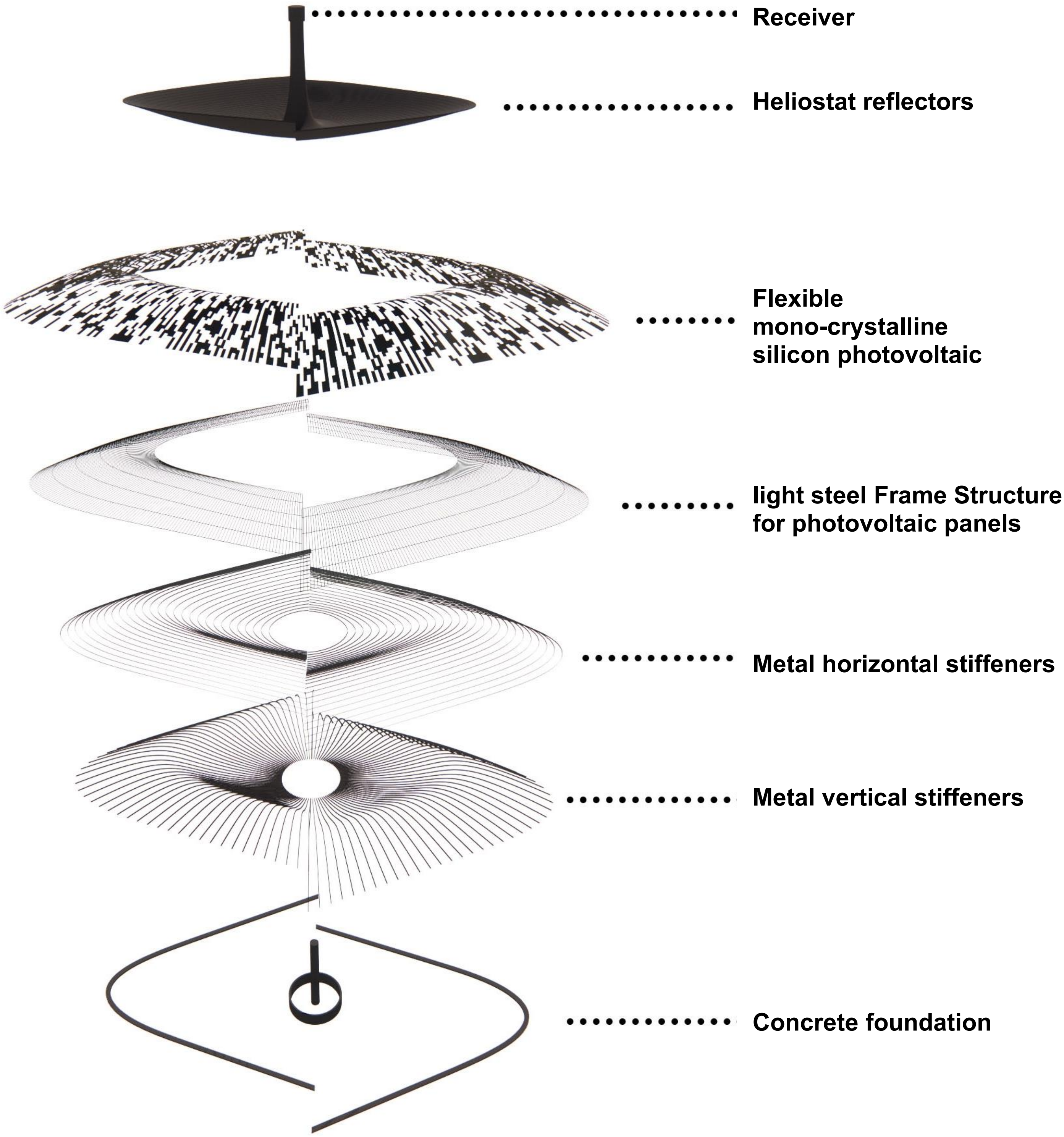
Flexible mono-crystalline silicon photovoltaic



Concentrated solar power (Receiver and heliostat reflectors)

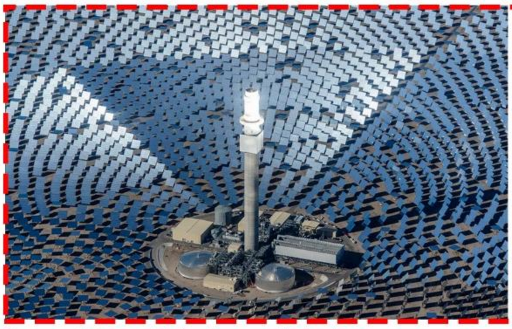
Diagrams by author

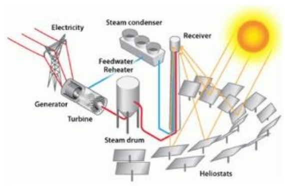
Structure explosion diagram



Diagrams by author

Technical details



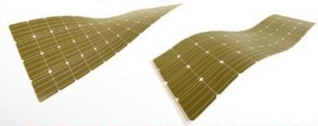


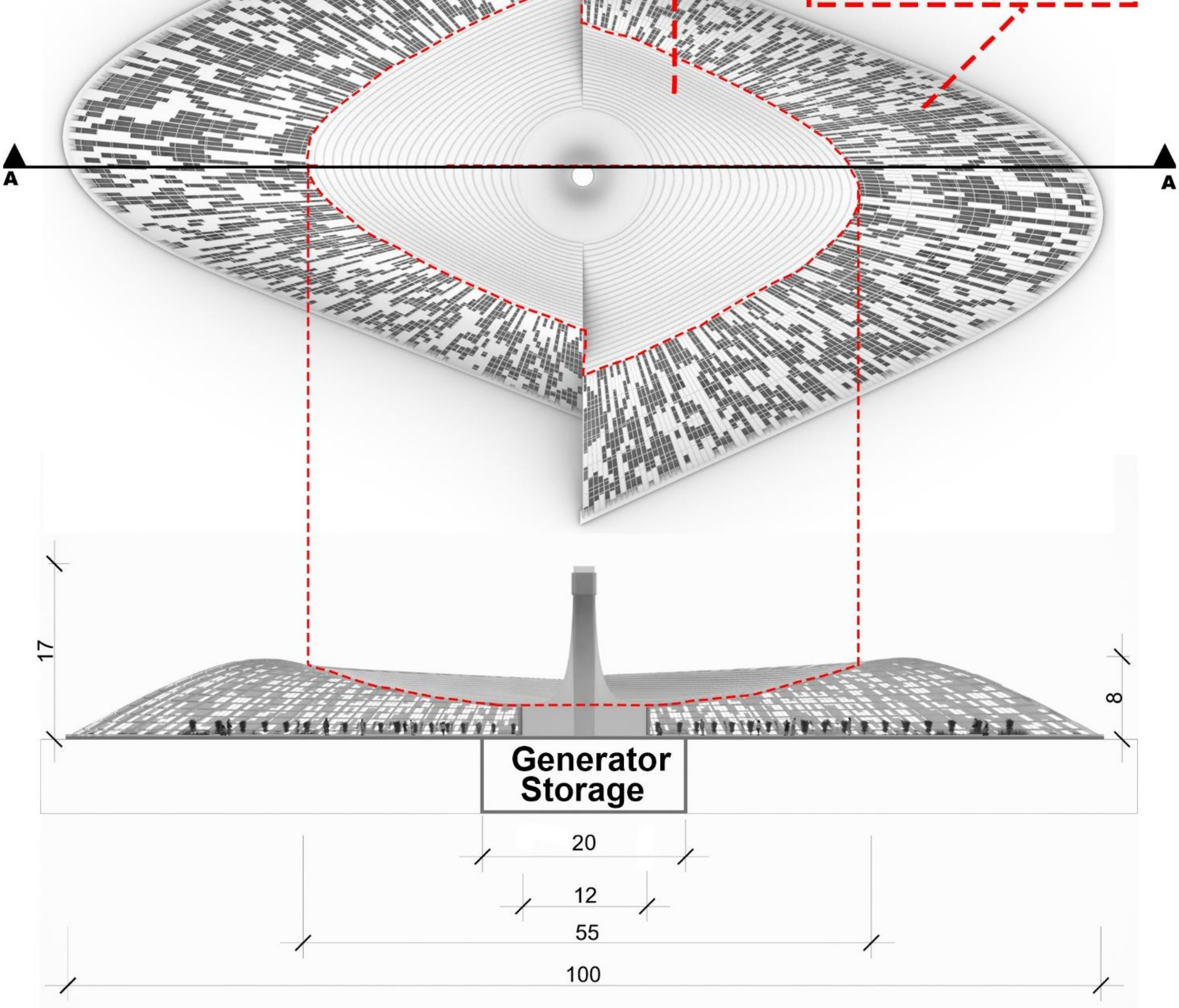
Source:
https://www.energy.gov/eere/solar/power-tower-syste-concentrating-solar-thermal-power-basics

Crescent Dunes Solar Energy Project
Source:
https://www.reviewjournal.com/opinion/editorials/editorial-failed-solar-project-offers-warning-209161

Lightweight Flexible mono-crystalline silicon photovoltaic

Although flexible solar panels are more expensive and less efficient than rigid ones, they can be a great option for people who need to install solar panels in non-standard shapes or require low-profile panels for mobility. Although they may need to be replaced more frequently, their flexibility





Prepared by Author

The fulfilment of the research and analysis component within the third design step

1. According to Germany's policy to transition to renewable energy, this project aligns with it and aims to showcase the beauty of renewables and their integration into our living spaces.

2. From a formal perspective, the project respects the communal plan for Spinelli Park, which focuses on climate protection and adaptation. The project's formal aspect does not hinder the area where decent wind generates because of its shape, which would not create turbulence in the flow of the wind.

3.The project produces energy for the district and encourages community involvement in collective activities. The productive structure can be a model to be adapted in private gardens, which is one of the important characteristics of outdoor activity in Germany.

Spinelli Masterplan

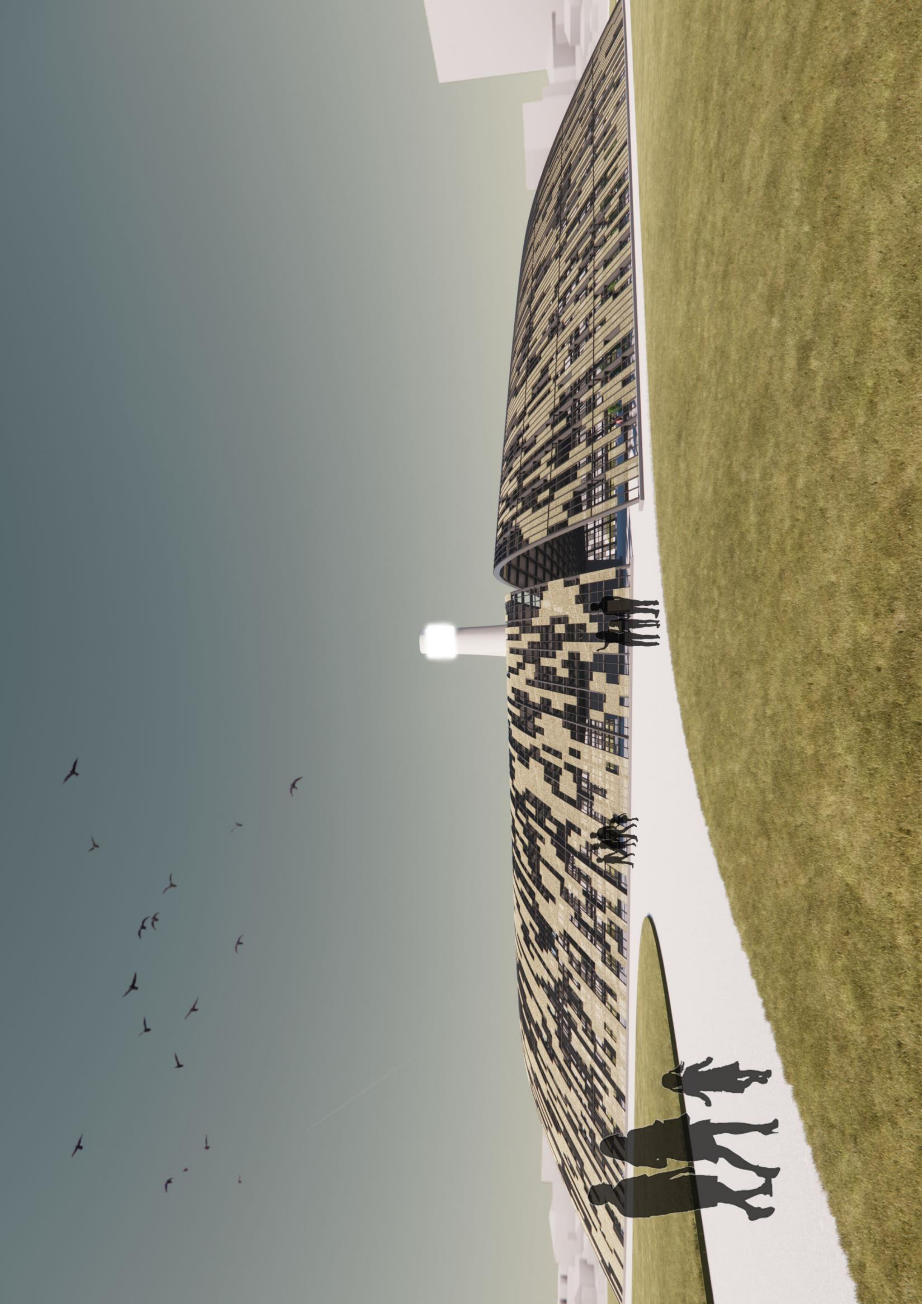
Prepared by Author

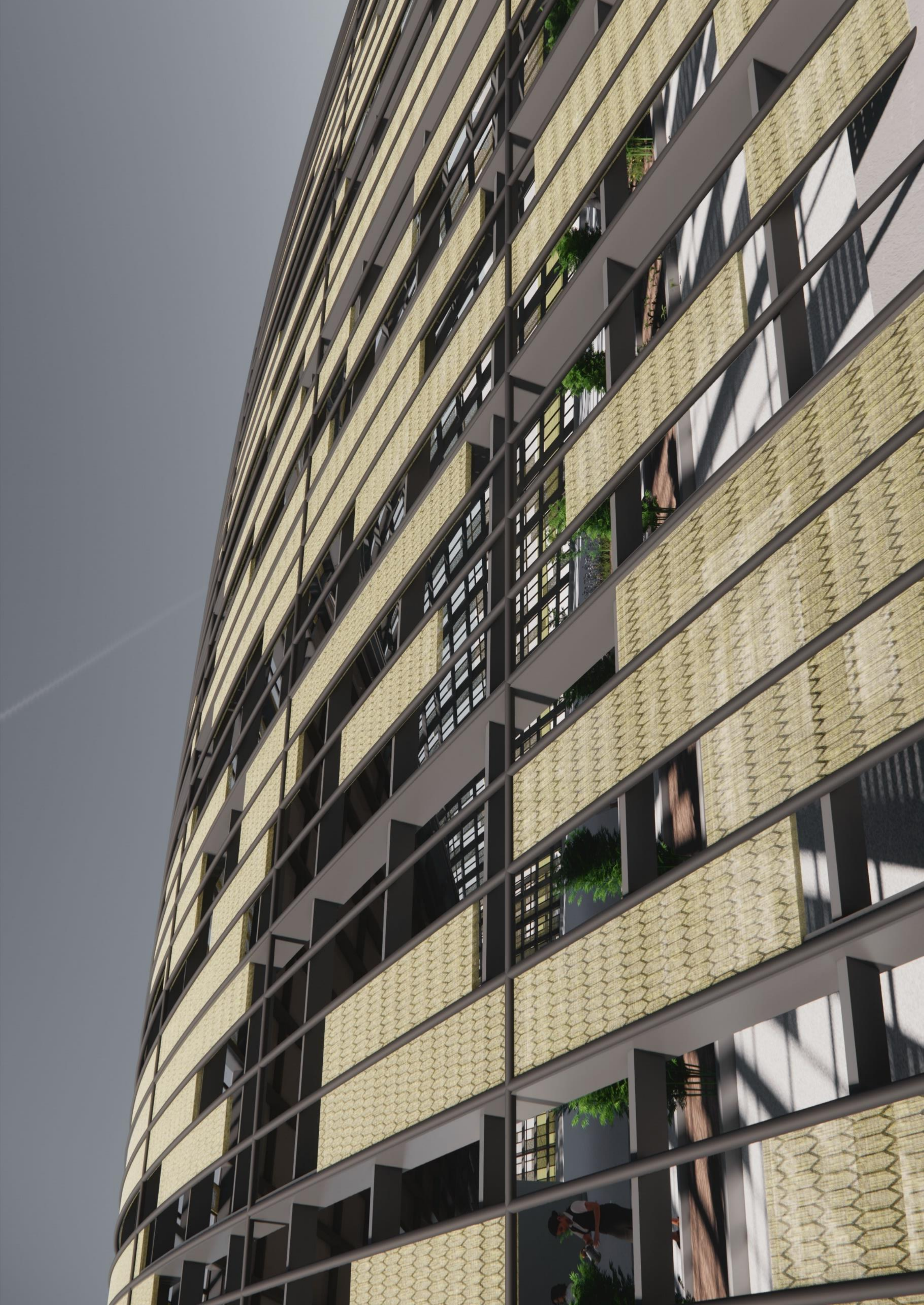
Legend

1. BICYCLE EXPRESSWAY
2. Historical path
3. Pedestrian path
4. Climate Park
5. Dune: The Dune of sand, Dry biotope
6. Play and activity park
7. Outdoor space, Agrovoltaic system
8. Cafe, Event spot
9. Parking area
10. CREATIVE WORKSHOPS
11. Feld Park
12. Burger Park
13. Panorama Park

Architectural visualization

All 3D visualizations were made by the author.





8

OUTCOMES AND RECOMMENDATIONS

At the conclusion of this research and design proposal, the following criteria are a series of potential actions that can be taken to utilize architecture as a significant advocate for climate adaptation and integration of urban inner-city areas with renewable technologies:

1- To effectively implement cutting-edge technologies, it is important to first understand the context in which they will be used. This includes assessing the infrastructure and relevant regulations that support the implementation of these technologies. One useful approach is to conduct an International Energy Agency (IEA) energy policy review for the countries where the project will take place. These reviews provide a comprehensive evaluation of member countries' energy policies and their progress towards achieving a carbon-free world.

2- Another important step is to analyse any municipal goals related to climate adaptation, which can provide a framework for defining microclimate adaptation strategies and the effectiveness of available technologies in an urban setting.

3- Finally, it is crucial to involve the community in the process by identifying their needs and expectations. This will help in selecting the best solution for integrating renewable technologies and ensure that the resulting urban spaces are both functional and aesthetically pleasing, representing the integration of science and technology in a safe urban environment.

Spinelli Park was designed with specific features in mind to meet the criteria outlined:

The park has implemented a comprehensive open space plan that is in line with the community's action plan for adapting to climate change. The park design allows for fresh and cool air to circulate from the green corridor into the residential and city centre areas, thereby reducing heat build-up and the urban heat island effect.

The park is part of Germany's efforts to tackle the impacts of climate change and lower carbon emissions through its energy transition strategy, with the aim of reaching these objectives by the years 2030 and 2050.

It offers various benefits to the community, such as urban farming, community gardens, and recreational facilities. The park features an Agrivoltaic system that utilizes two renewable energy sources - concentrated solar power and flexible monocrystalline silicon photovoltaics - to produce clean energy for the community.

The park places a high emphasis on safety, with all energy production and transformation components being situated underground and out of reach. It is self-sufficient, generating all the energy it needs while not contributing to the emission of greenhouse gases or other pollutants.

It serve not only as a source of clean energy but also as a visually appealing example of sustainable infrastructure seamlessly integrated into the urban landscape.

The development and design process of Spinelli Park serves as a blueprint for similar projects in other cities, showcasing how sustainable infrastructure can be seamlessly integrated into the urban environment. By using the Spinelli Park model, other cities can strive towards promoting sustainable development and reducing their carbon footprint.

Recommendation:

According to the findings of this thesis, it is suggested that cities and communities should embrace the integration of renewable energy technologies into their urban design, not just for the purpose of providing clean energy, but also to improve the aesthetic appeal and enhance the overall quality of life in the area. Policymakers are encouraged to prioritize the following aspects of sustainable infrastructure development:

Government Support: The government should provide financial incentives and regulations that support the integration of renewable energy technologies. This could include subsidies for the installation of renewable energy systems, tax breaks for businesses that adopt renewable energy, and regulations that require new buildings to incorporate renewable energy technologies.

Energy Efficiency: The implementation of energy-efficient technologies should be prioritized alongside the integration of renewable energy systems. This will help reduce energy consumption, which will help meet the energy transition targets of 2030 and 2050.

Public Awareness: There should be an increased focus on raising public awareness about the benefits of renewable energy and energy-efficient technologies. This can be done through education campaigns, workshops, and other public engagement initiatives.

Technological Advancements: Investment in research and development should be made to enhance the performance and efficiency of renewable energy technologies. This will help overcome some of the current limitations of these technologies and make them more accessible and economically viable.

Integration with the Grid: Renewable energy technologies should be integrated with the existing grid system to ensure stability and reliability. This could include the development of smart grid technologies that can automatically manage the flow of electricity from renewable energy sources.

Collaboration between Stakeholders: Collaboration between government, industry, and academia should be encouraged to promote the integration of renewable energy technologies and achieve the energy transition targets of 2030 and 2050.

Consideration of Environmental Impact: The environmental impact of renewable energy technologies should be carefully considered when implementing them. This may involve conducting environmental impact assessments to ensure that the integration of these technologies does not harm the environment or cause other adverse effects.

In conclusion, the integration of renewable energy technologies is crucial in achieving the energy transition targets of 2030 and 2050 and in creating a more climate-adaptive future. Further research be conducted on the integration of renewable energy technologies into urban landscapes, exploring new and innovative ways to integrate sustainable infrastructure into the cultural fabric of our cities.

In this thesis, an attempt was made to advance the following UN Sustainable Development Goals.

9

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