Integration of geothermal energy potentials into a sustainable land use plan as part of the heat transition at the northern campus of the University of Göttingen

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Abstract

The northern campus of the University of Göttingen comprises around 40 buildings with a heat demand of approximately 45 GWh per year integrated into a larger natural gas-based heat supply infrastructure. A decoupling from the central district heating system and a transformation to a low-temperature subnet is proposed to achieve a fossil-free heat transformation of the northern campus. This includes the utilisation of waste heat (e.g., from the computer centre) and the integration of a Geothermal Hub. The geothermal hub aims to supply heat by combining shallow and medium-deep geothermal energy, along with heat storage and cooling. Beyond evaluating and implementing new heating systems, the accompanying infrastructural changes present an opportunity to comprehensively develop a sustainable campus, including environmental and climate protection as well as social aspects. This work aims to gather and consolidate relevant infrastructure data and propose initial ideas for a holistic transition approach. Key data include buildings characteristics, traffic infrastructure, pipelines, water protection zones, as well as the reserves for the critically endangered European hamster. Open space maps have been created to identify potential areas for implementing various geothermal systems during the construction and operation phases. This initiative provides the opportunity to develop a sustainable land-use plan, which in this work has been based on the three ethical principles of permaculture design: “Earth Care”, “People Care”, and “Sharing of Surplus”. Coupled with a survey among students, this initiative results in recommendations for modifying traffic routes, designing a multi-functional parking layout, enhancing green area vegetation, and establishing more park-like spots students can use for recreational purposes. The proposed land-use plan incorporates the restricting factors for the installation of geothermal systems at the northern campus and turns them into beneficial aspects while simultaneously reducing the carbon emission of the campus.

1. Introduction

The German government has committed to achieving climate neutrality by 2045 (Bundesministerium für Wirtschaft und Klimaschutz, 2022). Within this context, the heating sector, comprising space heating, hot water, and process heat, accounts for over half of the nation’s energy consumption but relies on only about 19% of renewable sources (Umweltbundesamt, 2024). Biomass plays the most significant among these, contributing 83% of renewable heat. Despite a 7.8% increase in renewable heat sources since 2005, this sector remains responsible for 40% of Germany’s total carbon emissions Germany (BDEW - Bundesverband der Energie- und Wasserwirtschaft, 2021). Increasing the use of sustainable heat sources, such as heat pumps, district heating systems powered by renewables, and energy-focused building refurbishment, is central to the federal strategy. Göttingen has established guidelines to reduce carbon emissions and increase reliance on renewable energy sources. Highlighting the district heating system's optimization and expansion using renewable heat serves as a focal point. The University of Göttingen, including its medical centre, currently operates a high-temperature district heating system powered by natural gas. This system's carbon footprint constitutes a significant portion of the city's total emissions. To address this, a general concept of a “Geothermal Energy Hub” (Romanov and Leiss, 2022) and based on this, a specific project known as *CampusGeoHub* (Holler et al., 2024) has been proposed to model and implement an integrated neighbourhood energy solution. This thesis demonstrates the possibility of embedding the necessary changes for a carbon neutral heat supply in an integrated visionary plan, that results in mutual benefits for all participants.

1.1 Geological Overview of Göttingen and the Northern Campus area

Göttingen is located in the Leinetal Graben structure in southern Lower Saxony, an area defined by its relative complex geology. The region's stratigraphy includes Variscan bedrock, evaporitic Zechstein formations, and various Mesozoic layers (Leiss et al., 2011). These formations provide a natural framework for exploring geothermal energy targets, particularly in areas with quaternary rock, karstified Muschelkalk limestone, Bunter sandstone formations, dolomitic and rock salt Zechstein formations for shallow and medium deep geothermal systems as well as for heat storage systems. This lithology is overprinted by the eastern main thrust fault of the Leinetal Graben and a cross-strike fault forming a relay ramp and resulting in an intensive structural block formation. This geological setting necessitates further subsurface investigations to optimize medium-depth geothermal energy utilization including heat storage. Conducting seismic surveys and determining suitable drilling locations are essential steps in this process. The northern Campus of the University of Göttingen and its surrounding institutions, including the *Hochschule für Angewandte Wissenschaft und Kunst* (HAWK), Max-Plank- and Leibnitz-Institutions and other research centres, define the study area (e.g. Fig. 1).

1.2 Current Situation and CampusGeoHub Project

Heating on the North Campus predominately relies on fossil fuels, primarily natural gas to supply its high-temperature district heating system. The *CampusGeoHub* project (Holler et al. 2024), financed by the BMWK (Bundesministerium für Wirtschaft und Klimaschutz of Germany, 8. Energieforschungsprogramm) based on the Geothermal Energy Hub concept suggested byRomanov and Leiss 2022, involves a consortium of the HAWK and the University of Göttingen and focuses on developing a sustainable, multifunctional concept integrating renewable energy sources and heat storage options. This includes innovative approaches to utilizing shallow and medium-deep geothermal energy alongside solar and waste heat. The project aims to initiate an energy transition starting in 2025, providing a model for sustainable campus operations.

1.4 Constraining factors at the northern Campus

To determine the different potential of geothermal energy systems, the initial step is to define the available free space. Constraining factors can be environmental aspects, such as endangered species, structural or geological aspects and more. The following assessment focuses on the European hamster and the Weendespring water protection area, which limit the available area for geothermal systems at the northern campus.

1.4.1 European hamster *Cricetus cricetus L.*

The European hamster *Cricetus cricetus* developed around the Eem-interglacial and archaeological funds indicate its presence in most of Europe during that time (Weber and Endres, 1999). It can be found in meadows, (grain) cropland, and along field edges. Here, it uses deep and heavy soil to dig its broad burrows. In Western, Central and Eastern Europe, the population of the European hamster has dropped significantly since the 1960s’ with a current suspected reduction of 50% per year. This is mainly due to modern agricultural practices as well as the high rate of land sealing (Meinig et al., 2020). As a result, the hamster has a highly fragmented distribution within Europe and has continued to be listed as

“Critically Endangered” after the most recent assessment by the IUCN in 2019 (Banaszek et al., 2020). Consequently, Germany carries a high responsibility for the preservation of the animal (Rote Liste Zentrum, 2021).
With the establishment of the three-crops-rotation in the 14th century, with a focus on cultivating grain, the European hamster likely established itself in the study site (Weber and Endres, 1999). Up until the 19th century, staple crops for the hamsters’ diet made up 20% of the agricultural land in Weende. This changed in the 1960s’ with the expansion of the university and its establishment at the northern campus. In 1999 an agreement was made with the municipality Göttingen, defining two major protection zones of 7.2 ha acreage. Furthermore, a management and cultivation plan was developed, which requires the university to grow grain, seed mixtures and fallows in a small-scale rotation to cater to the needs of the animals (Biologische Schutzgemeinschaft Göttingen e.V., 2024). In 2001 a part of the hamster population at the northern campus had to be relocated into compensation areas due to the continuous development of the campus. The current protection zones make up 84,798 m², 3.26 % of the total survey area.

1.4.2 Water protection area Weendespring

In its Basic Law, the Federal Republic of Germany has appointed the protection of the natural basis of life as a constitutional objective (Bundesrepublik Deutschland, 2002). Part of this objective is the protection of all bodies of water, which is regulated through the Water Resources Act Wasserhaushaltsgesetz – WHG. To secure Germanys drinking water supply, water protection zones are established surrounding water sources, which are divided into three protective zones: Zone I is the well head protection zone and accommodates the water extraction plant. It has the highest restrictions to keep all pollution away. Zone II is the near protection zone and is established to keep pathogenic microorganisms at bay, which can impact drinking water extraction when there is a slow and/or short flow of the water body. Zone III is the additional protection zone, which preserves the site from negative impacts of difficult- and non-degradable chemical and radioactive contamination (Bundesumweltministerium, 2012). Within zones I and II of any water protection area, no drilling operation is allowed (Jensen et al., 2022). Within zone III, a permission from the water protection authorities of the municipality might be given, if all wells remain above the aquifers. This also applies for a buffer area of 1,000 m surrounding zone I.
Near the north-western border of the research site, the well *Weendespring* can be found (Bezirksregierung Braunschweig, 1994), which supplies a part of the drinking water for the city of Göttingen. The well head protection zone of the Weendespring is located outside of the north campus (Bezirksregierung Braunschweig, 1994). Protection zone II and the buffer area, however, overlap with the study side (e.g. Meischner 1980).

1.5 Geothermal Energy

Evolving geothermal technologies offer potential heating and cooling solutions for the campus buildings. These range from shallow systems for residential applications to medium-depth geothermal doublets that can provide substantial energy yields. Specific technologies under consideration include borehole heat exchangers and ground heat collectors, as well as a medium deep geothermal doublet system. These each requiring careful planning to avoid disrupting existing ecological and geological systems.

1.6 Introduction to Permaculture Design

Permaculture as a design science was developed in 1974 by B. Mollison and D. Holmgren at the University of Tasmania in Australia (Mollison and Holmgren, 1980). It is a system of “[...] assembling conceptual, material, and strategic components in a pattern which functions to benefit life in all its forms” (Mollison, 1988). Any design is based on the three principles “care of the earth”, “care of people” and “sharing of surplus”. Although initially focused on agriculturally productive ecosystems, the guidelines and ethics can be applied to all areas of life. In this thesis, the proposed changes to the northern Campus, including new infrastructural elements like. car parks, mobility elements (e.g. bike lanes) and technological elements (e.g. the medium deep geothermal system), are placed according to permaculture design guidelines. The goal is to create mutual beneficial interactions between the users of the northern Campus and the static components on site.

2. Methodology

In this thesis three methodologies were applied to determine the potential of shallow and medium deep geothermal energy at the north campus and how it can be embedded into a sustainable land use plan. To establish the geothermal energy potential, several maps are combined and analysed in ArcGIS (ESRI, 2011). This process results in a map highlighting available sites for potential geothermal energy production. Additionally, a permaculture design approach is applied to create a sustainable land use plan for the northern campus. This plan embeds the potential geothermal sites into a land use plan that includes mutual beneficial changes which can be made as part of the transformation process to a renewable heating system. For a better understanding of the needs and wishes of the students using the campus, an online survey was conducted amongst the students. It included questions about mobility, general challenges while using the facilities on site, as well as ideas for a more sustainable layout of the grounds. It was distributed as a website link by the student body of the faculties of the University of Göttingen and partly the HAWK at the northern campus.

3. Results

3.1 Analysis of the Student Survey

The survey results reveal the students’ transportation habits, highlighting a reliance on environmentally friendly means such as biking and public transport, despite infrastructure challenges. Complementing these findings are suggestions to improve mobility, accessibility, and campus amenities, aligning with broader sustainability goals. One repeating suggestion from the survey is the increase in green outdoor areas, equipped with benches for the students to use.

3.2 Infrastructural and Environmental Aspects

Current infrastructure predominantly caters to automotive traffic, posing challenges for bicycles and pedestrians. Proposed changes emphasize reducing vehicular traffic, creating more green spaces, installing new pathways, and improving transit connections to support a sustainable campus development. By concentrating the parking lots in two multi-storey-parking lots in the east and west of the campus, space will be freed up for bike lanes and footpaths. To facilitate getting across campus, an additional shuttle service, run by the university, might be implemented, to benefit both pedestrians and motorists. The available space from previous car parking can be unsealed and used to implement geothermal systems and park-like structures for the students.

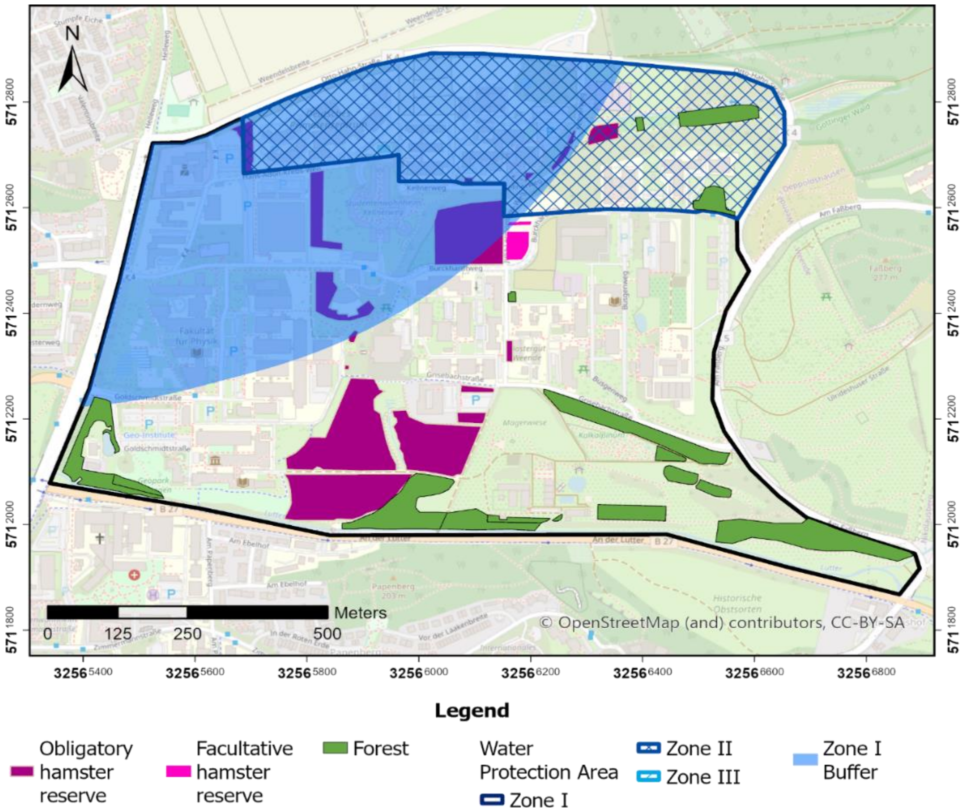

Figure 1: Exclusion zones for geothermal use due to ecological reasons.

The environmental exclusion zone in figure 1 is made of the protective areas of the European hamster, the water protection areas and forest areas across the Northern Campus. Additionally, the buffer zone around the *Weendespring* zone I is partly restricted and included in the map, as installing borehole heat exchanger and ground heat collector systems requires the approval of the water protection authorities of the municipality. Overall, 0.37 km² remain unaffected by these aspects.

3.3 Potential of Geothermal Systems

The exploration and implementation of geothermal systems on the Northern Campus provide a promising avenue for the transition to sustainable energy sources, addressing both the university's energy needs and its sustainability goals. The study identifies several promising areas for the deployment of different geothermal technologies, including borehole heat exchangers and medium-deep geothermal doublet systems.

3.3.1 Borehole Heat Exchanger Systems

Borehole heat exchangers are a viable option for the North Campus due to their relatively small surface footprint and feasibility for installation in confined spaces between existing buildings. Covering approximately 0.48 km² of potential installation area, this technology could provide significant contributions to the heating and cooling needs of campus facilities. These systems involve drilling vertical boreholes into the ground where a fluid can absorb heat from or dissipate heat into the surrounding earth. Their installation, however, requires careful planning to respect existing infrastructure, such as utility lines, and to mitigate any adverse impacts on the environment or geological stability. The modest space requirements make borehole heat exchangers particularly attractive for integration beneath parking lots and open spaces that may be freed up by proposed changes in the transportation and access systems of the campus. By converting these spaces into functional geothermal sites, the university can augment its renewable energy capacity without disrupting campus life or compromising on space use, providing environmentally friendly heating and cooling solutions.

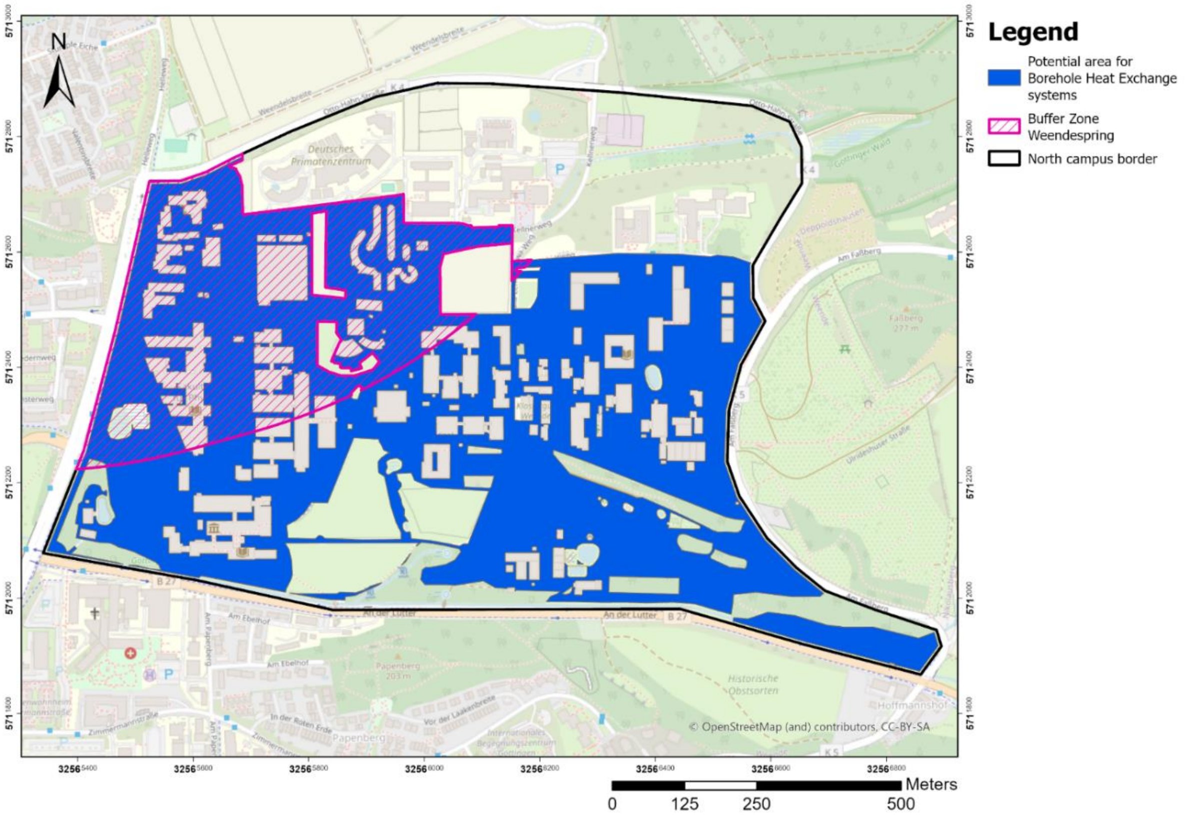

Figure 2: Potential area for borehole heat exchanger systems, including the restricted buffer zone around the water restriction are of the *Weendespring.*

3.3.2 Ground Heat Collector Systems

Ground heat collectors use horizontal piping systems buried at shallow depths to capture solar energy stored in the ground. These systems demand larger contiguous open spaces due to the horizontal layout of the pipes. The analysis identifies 0.27 km² of campus land suitable for these systems, offering a robust complement to vertical borehole systems with differing energy delivery profiles. Ground heat collector installations are most feasible in areas with minimal existing vegetation impact, allowing for an enhanced integration of geothermal energy solutions with the campus's landscape and ecological considerations. These systems could be integrated into new landscape designs as part of a broader campus greenification strategy, offering dual benefits: harnessing renewable energy while enhancing recreational space for students and faculty, which aligns with the permaculture principles of benefiting people and the environment simultaneously.

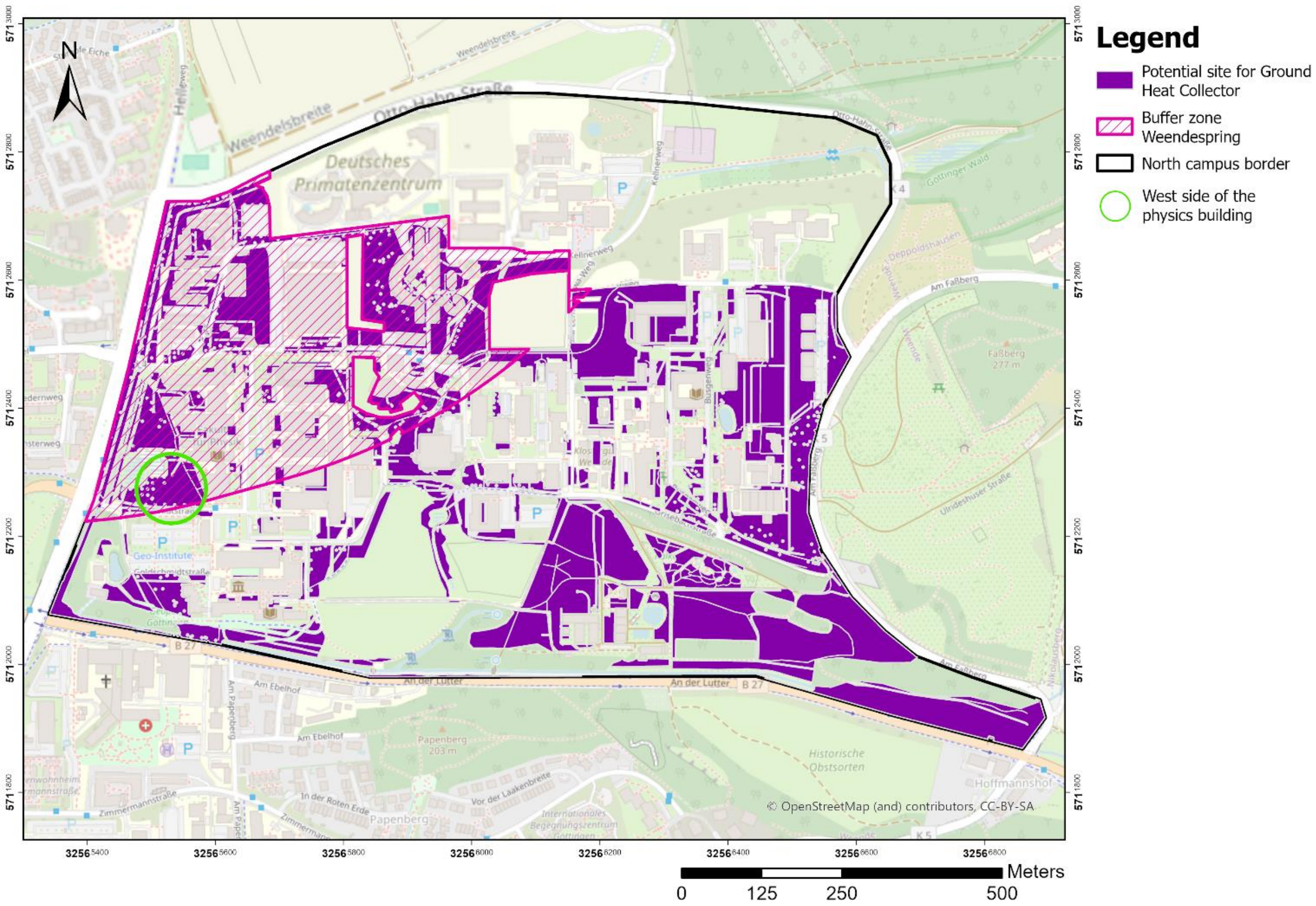

Figure 3: Potential surface area for ground heat collector systems with individual zones measuring above 100 m².

3.3.3 Medium Deep Geothermal Doublet Systems

Medium-deep geothermal doublet systems involve drilling pairs of wells to access geothermal reservoirs at depths up to 2,000 meters. These systems can provide a substantial and continuous supply of thermal energy, potentially making up a cornerstone of the campus's renewable energy strategy. The study identifies three main sites on the campus totalling around 0.37 km² as potential locations for these systems. These sites are strategically chosen to optimize the balance between technical feasibility, environmental safeguarding, and minimal disruption to existing campus activities. The implementation challenges include ensuring compliance with noise regulations during drilling operations and managing the technical and logistical complexities associated with deep well installations. With adequate noise control mechanisms and careful planning, these systems could provide substantial heating capacity that significantly reduces the campus's carbon footprint.

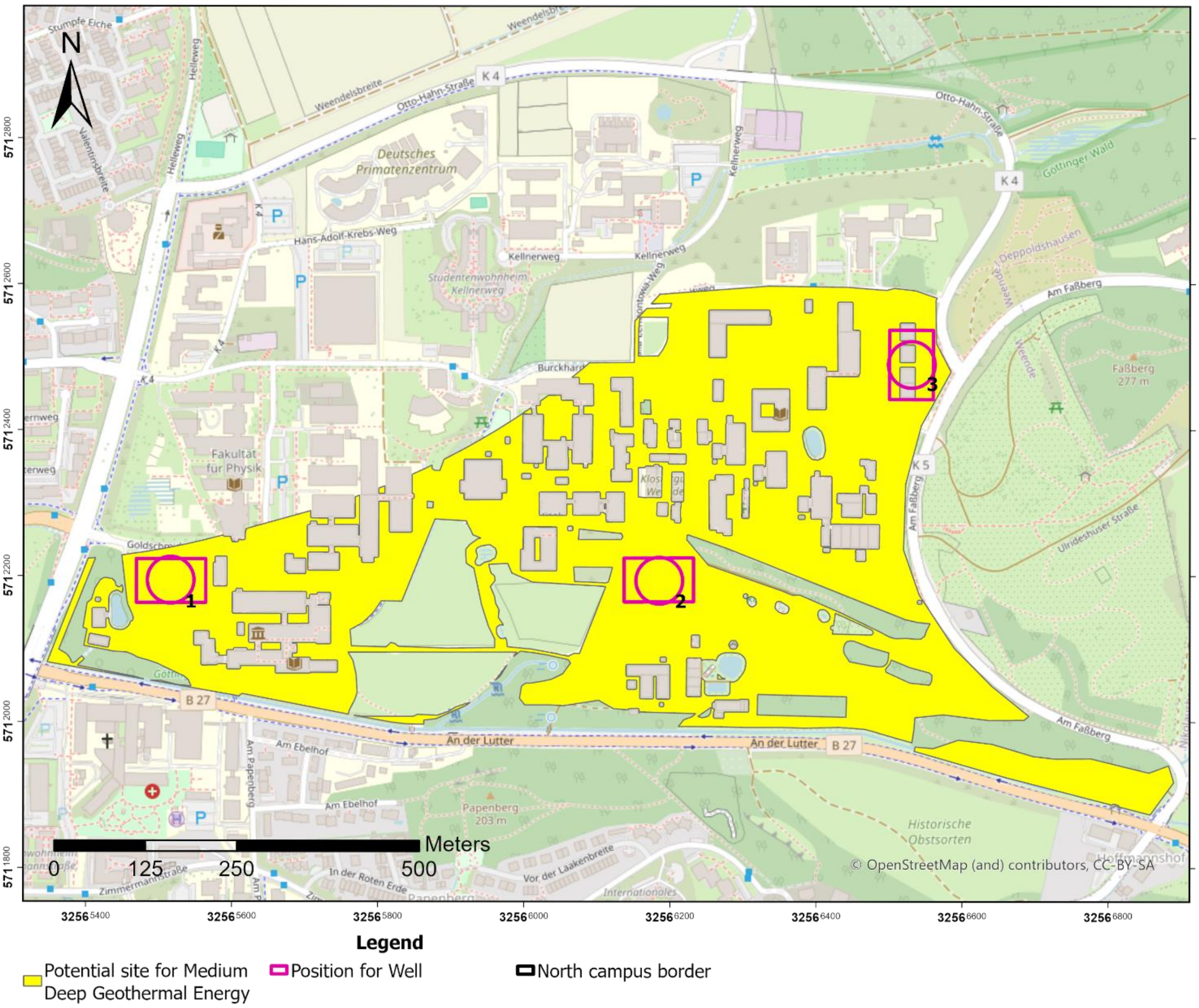

Figure 4: Potential area for medium deep geothermal doublet systems including specific sites that could accommodate the rig. They are located at the Goldschmidtstraße (1), within the Experimental Botanical Garden (2) and on the car park (3) between the forest faculty and the Otto-Hahn-Straße.

3.4. Discussion

The discussion focuses on implementing suggested changes and overcoming challenges. Recommendations include improving pedestrian and bicycle access, reducing the number of paved surfaces to increase green space, and implementing geothermal heating systems strategically. Enhancements to the parking system propose centralizing parking facilities, limiting vehicle access on campus, and transforming previous car parks into green spaces or geothermal sites. A complete map of the campus with the integrated proposed changes, including the positioning of a medium deep geothermal doublet system, can be found in the appendix.

Future research should address the technical, economic, and regulatory aspects of geothermal installations, including assessing groundwater depth, further site-specific geological analyses, and detailed noise management plans for medium-depth drilling locations. Additionally, integrating findings into a dynamic, long-term sustainable campus vision will require ongoing flexibility and stakeholder engagement.

Emphasizing geothermal energy as a critical component of the campus's sustainable future, the study outlines opportunities for reducing carbon emissions and enhancing campus life quality. Although significant challenges remain, especially in regulatory compliance and infrastructure adaptation, the proposed changes align with both ecological ethics and the university's emission reduction targets. The study suggests that adopting a permaculture framework in campus planning could offer a comprehensive path toward sustainability, fostering synergetic relationships among campus infrastructure, human activities, and environmental stewardship. By marrying technological advancements with ecological sensitivity, the campus can aspire to become a model of sustainable development in higher education.

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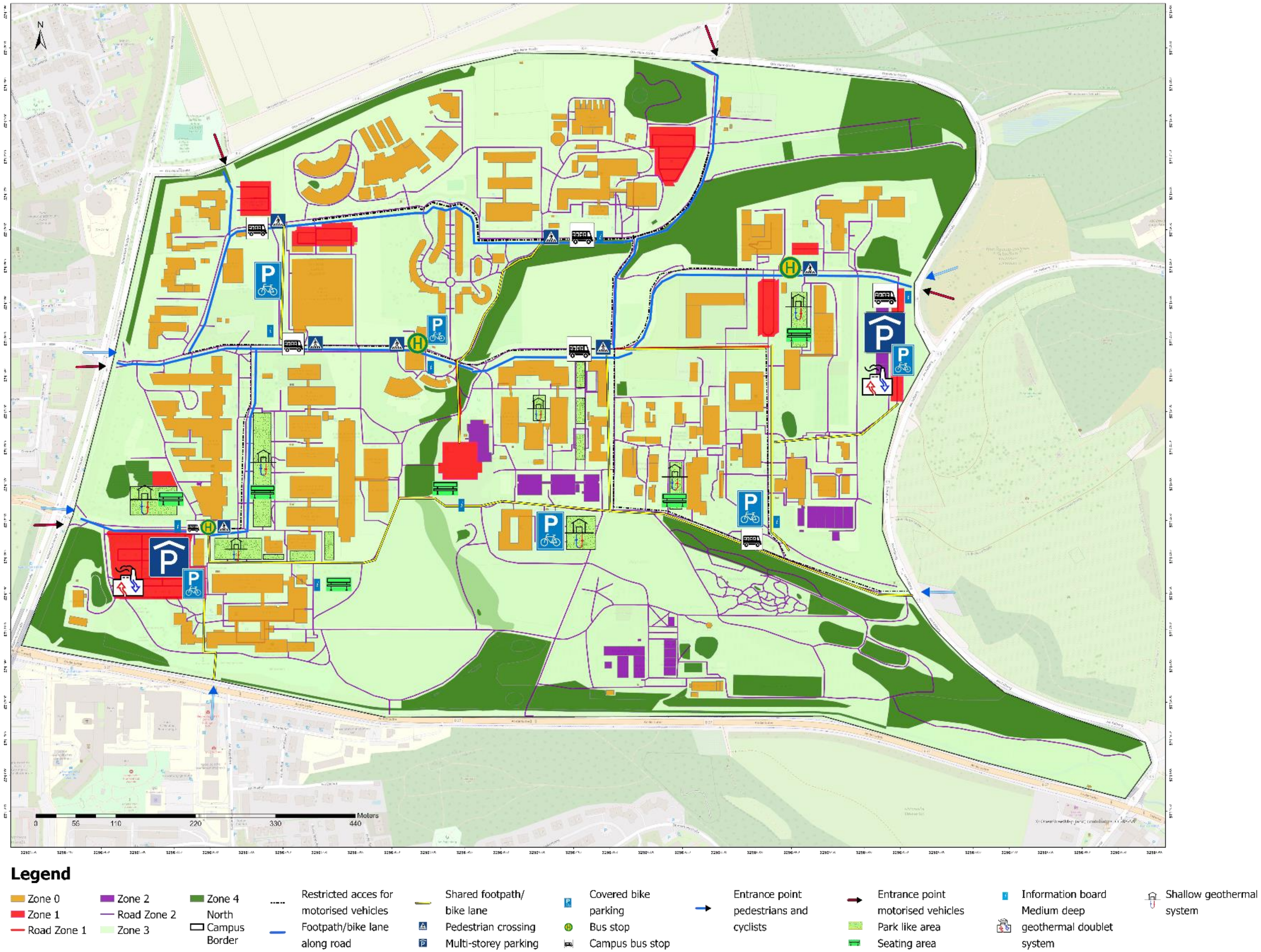

Figure 5: The above map is the final design, showcasing both potential geothermal areas and proposed changes to make the campus more sustainable.