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PAPER

District Heating System: Interactive Website Project for Weilheim, Germany

Anita Feigl(✉),
Matthias Utesch

Technical University of Munich
TUM, Munich, Germany

anita.feigl@tum.de

ABSTRACT

District heating systems play a crucial role in the European Union for sustainable energy practices by contributing to reducing carbon emissions and thus counteracting climate change. In most European countries, the energy consumption for heating is a topic that needs to be considered. Germany has recognized the need for more awareness among its citizens about district heating systems. Therefore, an interactive website was developed in close cooperation with the city of Weilheim in Bavaria, Germany. The goal is to inform citizens about the district heating system under construction. The website aims to improve user engagement through interactive features, including a quiz, an interactive calculator, and various animations and images. The application focuses on the primary energy sources biomethane, solar energy, wood chips, and the use of environmental heat through heat pumps. The website was evaluated at a local secondary school, which yielded positive feedback.

KEYWORDS

district heating system, renewable energy, website, interactive

1 INTRODUCTION

In order to meet the European Union's (EU) emission objectives, renewable energy sources (RES) should replace fossil fuels [1]. Thereby, district heating systems play an important role. It is assumed that they contribute to the reduction of carbon emissions, thus preventing climate change.

Within this context, where does Germany stand compared to the EU? Currently, the share of renewable energies in Germany is 14 percent. The target value for 2030 is 27 percent. In order to reach this target, the government's main focus seems to be phasing out coal by 2038 [2] and promoting district heating. According to 2018 data, studies [3] show that Denmark is the largest market for district heating systems regarding trench length in the EU, followed by Germany.

The district of Weilheim is one of the pioneers of building a district heating network based on RES in Bavaria, Germany. With an area of 55.5 square kilometers

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and 24,033 inhabitants, the city has an energy consumption of 269,600 MWh of final heat, which must be provided for heat supply [4], [5].

So far, Weilheim still uses up to 90 percent fossil-based heating systems. One of the main challenges that *Stadtwerke Weilheim* (municipal utilities of Weilheim) faces is to generate the support of the citizens for the change towards a district heating system. The network will primarily utilize four renewable energy sources:

- Wood chips: Wood chips are small pieces of wood. It is most sustainable when residual materials such as wood waste are used. By the process of burning wood chips, energy for heat generation is produced [6].
- Solar: The renewable solar energy uses the sun to produce energy. Solar panels help to convert the sun's rays into usable energy [7].
- Biomethane: Biomethane is a renewable natural gas produced by the anaerobic digestion of biomass, such as wood pallets or agricultural waste. This gas can deliver a sustainable alternative to fossil gas [8].
- Waste heat from the water treatment facility: The heat from wastewater at the water treatment facility can be utilized for heating using heat exchangers. By employing heat pumps, the temperature can be adjusted to the desired heating temperature [9].

The main energy source shall be wood chips.

Currently, a majority of Weilheim's citizens are concerned that the use of wood chips would lead to cutting down the famous local forests. The most popular recreational forests among the residents of Weilheim are the *Weilheimer Au* and the *Unterhauser Forest,* as well as the *Gögerl*, the *Dietlhofer Forest,* and the *Hechenberg* as part of the city forest. Since 1996, forest biotope mapping has been developed for the city forest. In 2015, a nature conservation concept was adopted, and in 2017, a forest ecological account with conservation measures was created [10]. Another local forest is the *Paterzeller Eibenwald.* This forest, with its more than 2,000-year-old yews, has already been under nature protection since 1939. Therefore, this unique forest is one of the oldest nature reserves in Germany [11].

In addition, the project is also followed with suspicion regarding how the district heating network will be constructed.

Therefore, the first step is communication, to comprehensively inform the citizens about the design and function of the planned district heating system.

Secondly, which method would be best suited for implementing this communication? To establish broadly accessible communication, it was decided to create a website. A website is easily accessible to a broad audience, namely anyone with internet access [12]. Furthermore, this information source is available at any time and from every location [13]. These features provide unique accessibility for the visitor.

In addition, the website can be updated whenever new information or questions arise, and processes can be visualized for easier understanding [12].

A website offering a high level of interactivity for visitors by using multimedia elements such as texts, images, animations, and videos or audio for information dissemination serves as an excellent communication tool [14]. Deploying interactive elements as part of the user interface (UI) makes it more appealing for the citizens when they seek information. Furthermore, interactive elements deepen the learning process of the viewer by encouraging active engagement with the content [15].

These considerations lead to four research questions:

RQ-1: How to inform about the district heating system and its four main energy sources in order to raise the support of Weilheim's citizens?
RQ-2: What specific UI design elements and interactive information-sharing techniques can be implemented on the website to optimize user interaction and understanding?
RQ-3: How to model the complex process of district heating based on wood chips that is both scientifically accurate and easy to understand?
RQ-4: How can interaction with the website improve the target audience's knowledge of the district heating project in Weilheim?

Section two covers the state-of-the-art of district heating system implementations. In the third section, the implementation of the website is explained, focusing on the essential UI design elements. The fourth section presents the evaluation. Finally, the conclusion summarizes the key points and recommends future work.

2 CURRENT DISTRICT HEATING SYSTEM IMPLEMENTATIONS

The literature review closely follows the method described by [16].

The review scope according to (RQ-1) is: Which approaches already exist that inform about district heating systems and their four main energy sources in Weilheim? The conceptualization of this scope is: How can a website effectively and interactively inform Weilheim's citizens about the district heating system? The website should present the information as clearly as possible to engage the interest of the website's visitors while avoiding scaring the users off with the amount and complexity of information.

The literature search utilizes Google Scholar, selecting only articles that were not older than 2019, with the search strings: 'district heating OR district heating systems,' 'biomethane,' 'wood chips,' 'solar energy,' and 'heat pump.'

The synthesis of the findings is based on the concept matrix framework as presented by [17]. Concepts in our concept matrix for study about wood chips are 'costs,' 'CO_2 emissions,' 'base load capability of wood,' 'wood energy cycle,' and 'disposal.'

This paper focuses on an application of district heating. Hence the relevant results of the literature review are an integral part of sections 1, 2 and 3. A more comprehensive literature review would be the objective of future research, presented in an upcoming publication.

The development of district heating technologies can be divided into four generations [18]:

1. The first generation fell between 1880 and 1930, when heat production contained mainly steam boilers. The primary energy source was coal.
2. The second generation started after 1930 and continued until the late eighties. In addition to coal, oil came up as an energy source. Heat production was mainly based on heat-only boilers, with the first combined heat and power systems (CHP) emerging.
3. After the late 80s, there were significant changes regarding the energy source. Worldwide, biomass, waste, and fossil fuels came into use as the primary energy source. Heat production was shifted to large-scale CHP systems.
4. The most recent era of production and energy sources for district energy started after 2020 with the increasing awareness of the ecological problems, carbon footprint, and sustainability. It is forecasted that in 2050, renewable sources will take the stage while fossil fuels will be considered outdated. In addition, rather than producing additional heat energy, heat recycling will be preferred [18].

The dominant trends of these stages underline the significant role of renewable energy sources. For instance, studies on district heating systems in Järvenpää and Stockholm highlight integrating technologies such as solar collectors, heat pumps, and heat storage to create low-carbon systems [19]. This approach underlines the diverse technologies to ensure efficient, sustainable, and low-carbon district heating systems in the EU.

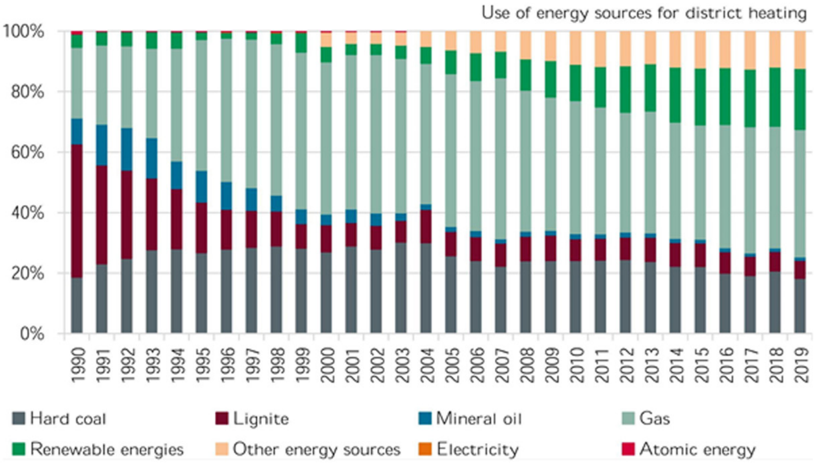

Fig. 1. Energy sources for district heating 1990–2019 in Germany [20]

Regarding the comparison between Germany and the EU, it is worth looking at Germany's near future plans. By the year 2050, the energy transition plan specifies the reduction of CO_2 emissions by 40 percent in 2020, 55 percent in 2030, and at least 80 percent in the year 2050, in reference to the year 1990 [21]. Germany strives hard to replace coal with RES (see Figure 1). In 2019, RES constituted approximately 20 percent of all energy sources for district heating systems.

Moreover, it is essential to note that 56 percent of Germany's final energy consumption is dedicated to district and space heating, hot water, process heat, and cooling (see Figure 2). In 2014, renewable energies accounted for only 12.0 percent of this share, showing a marginal increase of 0.9 percent since 2010 [22]. This underlines the efforts in the heat market's development to achieve Germany's target of sourcing 14 percent of energy for heating and cooling from renewables by 2020 [22].

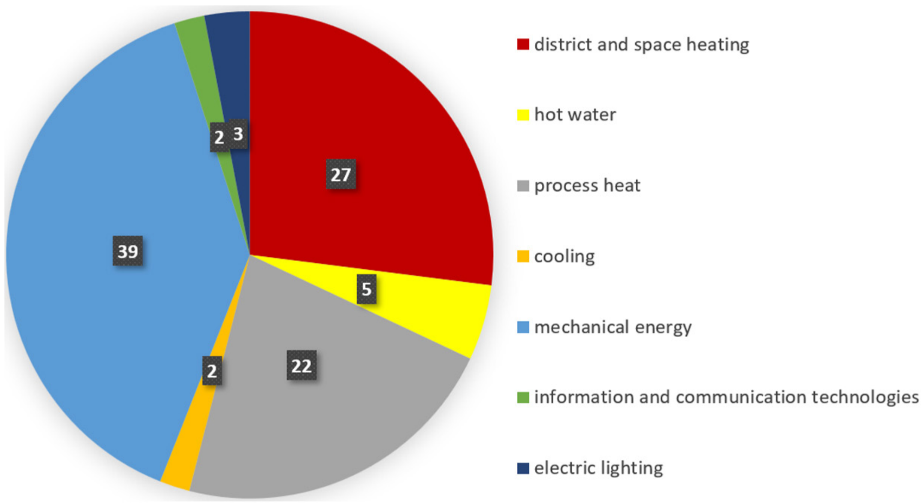

Fig. 2. Percent share of applications in the final energy consumption in Germany in 2014 [22]

Weilheim played an essential role in taking an initial step to integrate the "Enel Green Power project" into the German geothermal market. This indicates how Weilheim leads and gives recognizable importance to the heating industry [22].

3 IMPLEMENTATION OF THE WEBSITE

This section describes the specific UI design elements and interactive information-sharing techniques of the website that are essential to optimize user interaction and understanding (RQ-2).

According to *Stadtwerke Weilheim*, the main target demographic group are people who must independently manage their household heating supply. Due to the increasing number of single-person households and the rising ownership of homes, which are retained even in older age, and as household size usually decreases, the ratio of living space per inhabitant is steadily increasing. Consequently, the heating demand per resident in Weilheim is also rising. To meet this demand, 269,600 MWh of final energy is needed annually for heating supply, according to 2019 data [5]. For heat generation in private households, the fossil fuel heating oil is the most widely used energy source. Of Weilheim's total CO_2 emissions, 19 percent are produced by the electricity and heating requirements of private households [5]. To achieve the energy transition, the acceptance of these citizens towards the district heating network, which is to be operated with renewable energies, is essential [5].

As a consequence, due to its simple accessibility, a website implementation was preferred over an application that would require an installation [23]. To program the website, we used the *WebStorm integrated development environment* (IDE) by JetBrains [24] and initialized the project with the *hypertext markup language* (HTML) *5 Boilerplate* (H5BP) template [25]. The website consists of HTML [26] and *cascading style sheets* (CSS) for the front end, and *JavaScript* (JS) [27] for the back end. We utilized *GitHub* [28] to create a Git repository, enabling collaboration among multiple contributors.

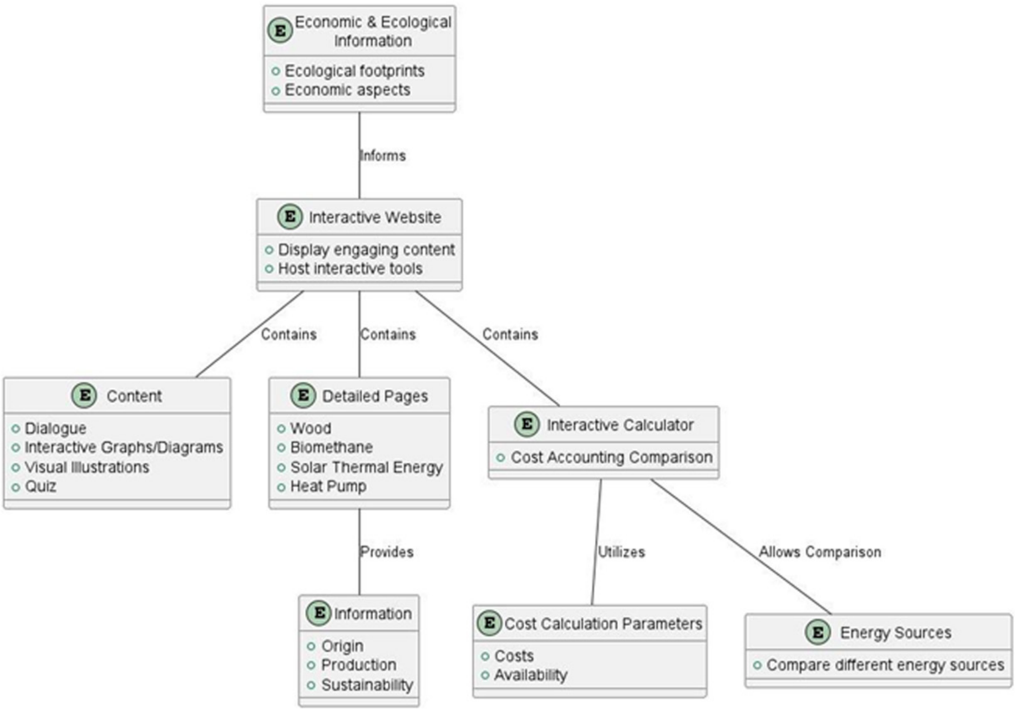

Fig. 3. UML diagram

Figure 3 shows the UML diagram of the website's elements. The top entity is the user. In general, the facade pattern [29] from software engineering practices was applied. This design hides the complexity of the website's subsystems, making it more user-friendly and interactive. The website is divided into four separate tabs that are navigable through a navigation bar located at the top of each page. These tabs in question are homepage, calculator, quiz, and feedback and imprint.

3.1 Homepage

The homepage should be eye-catching and attract users with varying knowledge levels. Hence, a short dialogue between two citizens introduces the topic of district heating.

The dialogue appears when first opening the website and only automatically reappears when a new instance is opened in a window. The dialogue is implemented as a container on the main website with the characters and dialogue bubbles within. After finishing the dialogue with only three user clicks, the whole container is hidden. To avoid having the dialogue reappear every time when the user returns to the homepage, local storage keeps track of whether the user has seen the dialogue already within that specific instance of the website.

In the bottom right corner of the slide section, there is a small version of Wilhelm, Weilheim's mascot (see Figure 4). The mascot can be reached from all sections of the homepage. Wilhelm is lowered so far that only the head is visible, prompting users to hover over it with their mouse.

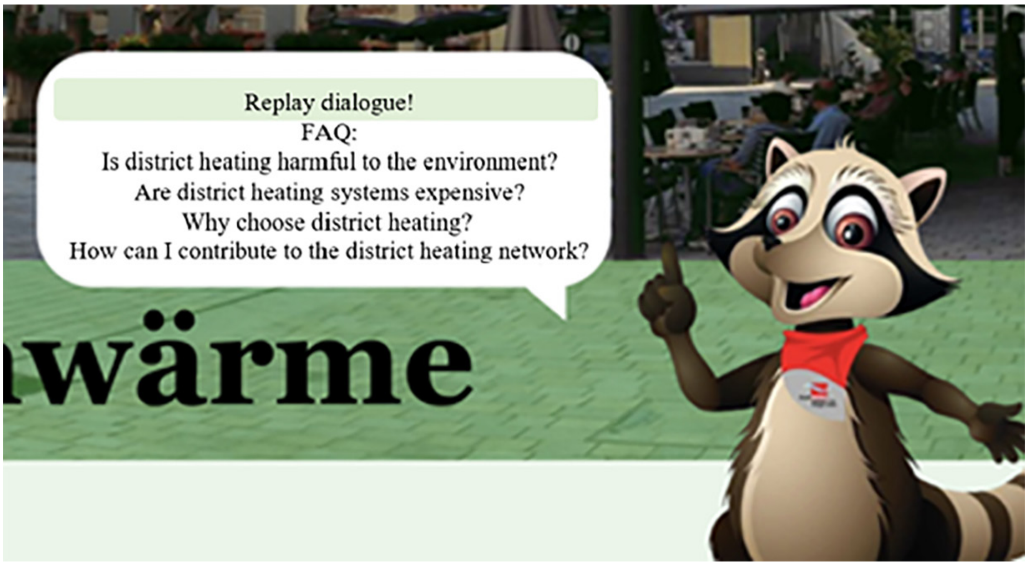

Fig. 4. Weilheim's mascot Wilhelm

The mascot will then be raised, and a speech bubble will appear containing a replay option for the dialogue and frequently asked questions (FAQ).

After the dialogue, an interactive slideshow starts presenting (1) a video and a picture with Weilheim's district heating plans and its four primary energy sources: (2) wood chips, (3) biomethane, (4) solar thermal energy, and (5) heating pumps.

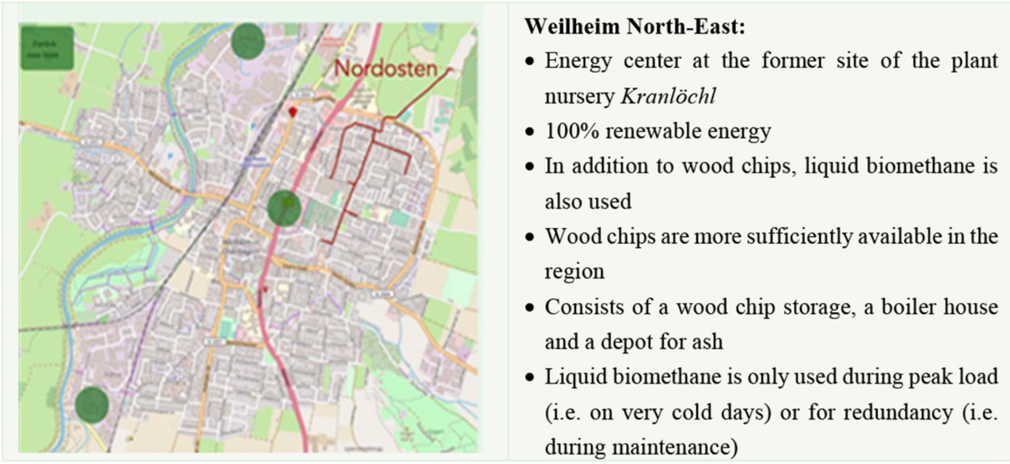

Fig. 5. Weilheim map

Each of these five parts changes the layout and presented elements when clicking from one to another by fading in and out different containers located underneath each respective part's picture. Each part has different interactive elements to make the learning experience as diverse, memorable, and engaging as possible. Users have the option to navigate either sequentially or to skip directly to any part by using the dots underneath the slideshow.

1. The first part is a video comprising a short interview with one of the project leaders of Weilheim's district heating and photos documenting the current state of the implementation. The pictures and sound recordings were edited with *Final Cut Pro* [30]. After the video, an interactive map of Weilheim (see Figure 5) shows the locations of the four planned district heating centers, implemented as buttons. Clicking on a button displays an animation that shows which center will provide heat for which specific part of the city. On the right side of the map, a container with text fades in and out, describing the primary energy sources that will be used at a specific heating center.
2. The second part of the slideshow informs about wood chips in Weilheim's heating project with the help of an interactive *scalable vector graphics* (SVG) diagram. Six pictograms (see Figure 6) show the process flow from the forest to the final disposal of ash. By clicking on a pictogram, more detailed information comprising pictures and text pops up.

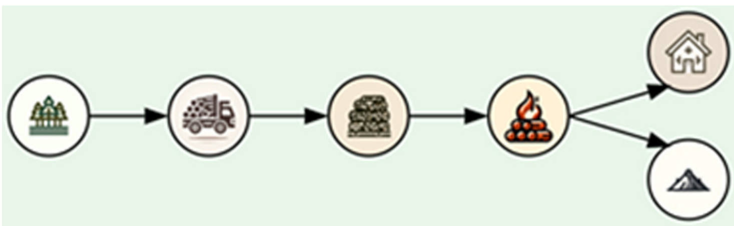

Fig. 6. Interactive circle graph

3. The biomethane part informs citizens about the production and transport of organic resources that can be converted into heating energy. A short introductory text explains a few basic concepts and prompts the most important questions. The next part is a visual interactive storyline adding playful elements. It consists of the Weilheim mascot and a short text in the style of the mascot, taking the readers

on an adventure where they answer questions to progress the story about biomethane. The slide offers two different answers, or approaches, respectively, to the mascot's information in the form of buttons below the story. The story progresses in multiple ways and informs about wrong answers or preconceptions.

4. For the solar energy part, an interactive image was created. Various representations of the sun, which are scattered over a solar thermal plant and can be hovered over, inform about the key aspects of solar heat generation. The information blocks offer insights into the effective location selection for solar plants, the reliability of this proven technology, and how solar collectors work with district heating networks. This was accomplished through the use of SVG. Most of the animations were created through CSS and its animation tag.
5. The heating pump part starts with a comprehensive overview of heat pumps, outlining their purpose and significance. The next section discusses the various types of heat pumps (air-water, air-air, water-water, and geothermal), their functionality, and the refrigerant cycle used in heat pumps to convert energy for heating and hot water purposes. It is paired with a video container that includes a video element, where the user is enlightened about the benefits of connecting a building to a district heating network versus investing in a private heat pump. An SVG of a heat pump diagram visualizes the function of the heat pumps and their components (see Figure 7). At the end, it is explained how heat pumps are implemented in Weilheim and what the reasons for integrating large heat pumps into the Weilheim district heating network are.

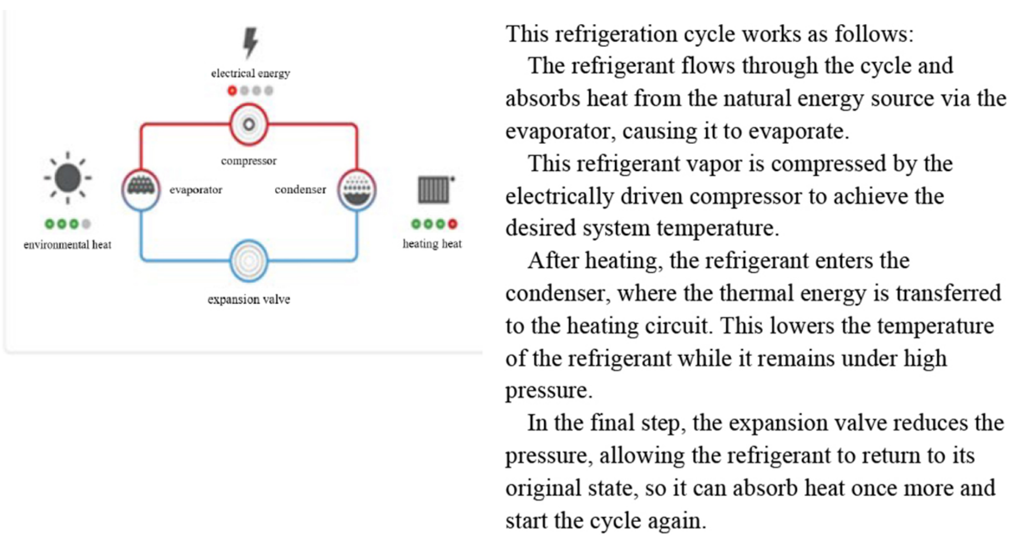

Fig. 7. Heat pump diagram

3.2 Quiz

Another aspect of the website is to test users' knowledge. For this, a quiz was implemented (see Figure 3). At its core, the quiz consists of a multiple-choice test with one question and a couple of multiple-choice buttons representing possible answers per page.

The back end keeps track of the score, using local storage and displaying the next questions after completing each one until the quiz is finished. The use of local storage has a drawback: The score cannot be kept between different instances of the web application. This approach strives to avoid cookies due to data protection. The quiz is also randomized so that users cannot just learn the location of the right answer. The random allocation of answers and questions is created with the help of a simple pseudorandom number generator that uses system time as a starting seed. After completing the quiz at a hundred percent, a golden trophy is presented as an achievement.

4 EVALUATION

Once the users of the website have successfully mastered the quiz, they will be invited to provide feedback. The objective is to evaluate, on the one hand, how well the website conveys the content about the district heating network and its energy sources (RQ-3). On the other hand, the website's design is evaluated (RQ-4).

The feedback form consists of two parts: Ten mandatory statements rated on a five-point Likert scale and an optional open text field. The feedback is always submitted anonymously. The ten statements correspond to specific components of the website, such as the dialogue upon opening the website, the slides covering topics such as wood chips, solar energy, biomethane, and heat pumps, as well as the calculator and the quiz.

Additionally, they address the overall design of the website, the integration of interactive elements, and the change of support in favor of district heating in Weilheim.

The feedback form is implemented as an array of objects, each containing a statement and its respective answers. After successful submission of the feedback form, a user is directed to a 'thank you' page. The website prevents users from submitting feedback multiple times in the same session.

The original main target demographic section of the website is adults. Additionally, inspired by [31], it was decided to present Weilheim's district heating approach to students of a local secondary school. The reason is that the curriculum of Bavaria's secondary schools from grade nine onwards covers energy technologies and their environmental impact [32]. This on-site presentation of the website made it possible to receive further valuable feedback for improving the website.

Table 1. Feedback results

No.	Statement	Average
Q-1	The dialog at the beginning prepared me well for the information to come, and I knew what topic was awaiting me on the website.	4.15
Q-2	The page on wood chips is informative, and I can cope well with the amount of information.	4.26
Q-3	Thanks to the intuitive structure of the solar energy site, I find my way around easily and have no difficulty in finding information.	4.18
Q-4	After the interactive explanation about biomethane, I am well-informed and have learned something new.	4.13
Q-5	The page on heat pumps is informative and clearly structured.	4.00
Q-6	The difficulty level of the quiz questions was appropriate. I was able to answer them well after browsing the website.	4.12
Q-7	The calculator for comparing energy sources is easy to understand.	3.64
Q-8	The general design of the website is appealing.	4.38
Q-9	The integration of interactive elements such as graphics or animations made it fun for me to visit the website.	4.41
Q-10	Overall, the website raised my support in favor of a district heating network in Weilheim.	3.92

The participants were students of four different classes (grades nine and ten). The students had no prior knowledge of the technology of district heating networks in general but knew that a district heating network is currently under construction in Weilheim. After a short introduction to Weilheim's district heating approach and the website, each class had 45 minutes to explore the website. At any time, the students had the opportunity to ask questions. Finally, the students had to take the quiz and submit the feedback on the website. Some students started by completing the quiz directly at the beginning and again after interacting with the website. These students recognized a higher quiz score after the website interaction compared to the initial quiz. This can serve as an indicator that the website has improved their knowledge about district heating. Furthermore, students compared their quiz results with each other and were eager to achieve the best possible outcomes. In total, sixty students submitted the feedback. Table 1 shows the ten statements and their related average feedback values. Each statement is assigned an identifier from Q-1 to Q-10.

The diagram in Figure 8 visualizes the average feedback values for each statement. The red line represents the average rating of all statements, which is 4.12. The highest feedback value for statement Q-9 indicates that the interactive elements were particularly well received. The low feedback in Q-7 can be explained by the fact that the data needed for the calculator is still under discussion, and therefore the calculator's usefulness was likely questioned.

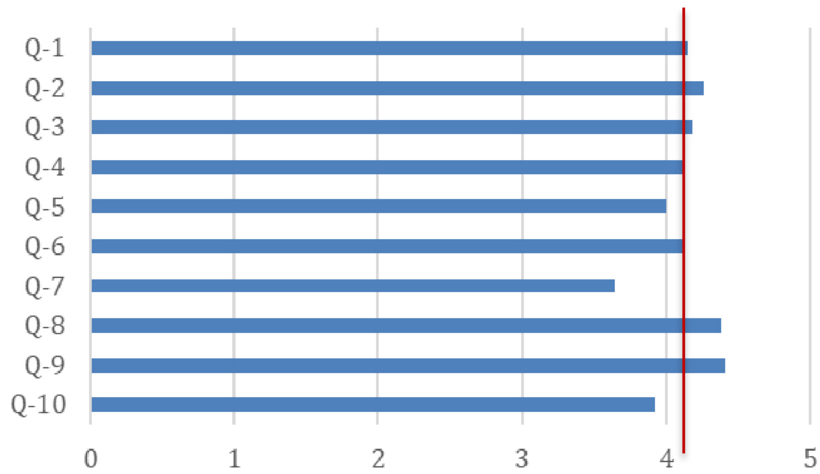

Fig. 8. Average rating values

Overall, the students particularly enjoyed the design of the website and the integration of interactive elements. One student wrote, '*The website is very nicely designed. The pictures and animations are easy to understand and very appealing.*' Another wrote, '*I think the website is very clearly designed and also varied thanks to the interactive content.*' There was also very good feedback on the dialogue when opening the website: '*I liked the dialogue at the beginning, and it makes it easier to understand the topic.*' A few students stated that they would like more general information about district heating networks: '*I wish you would have explained the basic principle of district heating in more detail.*' Overall, the points awarded by the students for the individual statements were in the upper range, and the feedback was positive.

5 CONCLUSION

According to RQ-1, a website should raise the support of Weilheim's citizens in favor of implementing a district heating system. This was achieved by welcoming users with a personalized dialogue, a visualization of the different project locations on an interactive map of Weilheim, and relying on the local mascot Wilhelm for the FAQ.

Regarding the RQ-2, the website consists of multiple interactive elements to engage users and offer them an outstanding experience. For every renewable energy source, a personalized design was implemented. For wood chips and heat pumps, a visualization of the complex material flow and its functionality by means of a graph made it easier for users to grasp the concept and its key technical subsystems. In the introductory text on solar thermals, users are directed to the respective YouTube video explaining Germany's climate protection plan.

The project showed that Weilheim's mindful choice of a district heating solution actively contributes to the sustainability goals of Germany and the EU. The design of the biomethane slide is similar to the idea behind the quiz with its 'visual interactive storyline' nature. Both the dynamic presentation and the testing of the information in a game/quiz format arouse one's natural curiosity. This makes the learning experience more memorable and entertaining.

Concerning RQ-3, it is confirmed that the interaction with the website improves the knowledge about the district heating project in Weilheim, comparing the evaluation results and observation of quiz results before and after visiting the website.

During the on-site evaluation at the secondary school, students from all four classes did the quiz before and after interacting with the website. They stated that they had higher scores afterward, which is an indicator that the interaction with the website enabled them to improve their knowledge on the topic. Further, the students compared their results after completing the quiz among each other's. This points out the social side of the interactive quiz.

Addressing RQ-4, a Petri-net-based simulation tool would be a nice feature to add in future versions of the website. Its interactive depiction of the complex district heating process could lead to a better understanding.

In total, an interactive website seems to be a suitable communication tool to promote district heating solutions.

6 ACKNOWLEDGMENT

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8 AUTHORS

Anita Feigl is a student in information systems at Technische Universität München (TUM) in Munich. Her main interests include process management and modeling, with a focus on domain-interdisciplinary tasks. She is particularly interested in areas such as Legal Tech and Business Informatics, exploring the integration of technology to enhance innovation and efficiency (E-mail: anita.feigl@tum.de).

Matthias Utesch teaches at the upper vocational school Staatliche Fachoberschule München-West and the Technische Universität München (TUM) in Munich. He is a member of the Executive Committee of IGIP. His main interests include IT-based learning, games engineering, and in particular the enhancement of study skills at the interface between school and university.