Individualized visualization of energy transition measures with AI technologies

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***Abstract* — To transition the energy supply in Germany into a sustainable system, the interaction between energy demand, supply of specific sources of energy and social processes must be explored extensively, as it has been studied seldom so far. The discrepancy between environmental awareness and environmental action of citizens is of special interest in this regard and especially in combination with social and technical innovations derived from the energy transition.**

The EnerVi project aims to strengthen citizens' involvement in the energy transition process by developing a web application that visualizes environmental consequences caused by climate change and potential energy transition practices and options for private households for two model regions in the city of Berlin and the local community of Neuerkirch/Külz in Rhineland-Palatine.

Keywords—climate change, energy transition, socio-technical energy transition, digital nudging, pro-environmental behaviour

I. Introduction

The current legislature in Germany has introduced a variety of laws and policies to transform and enable the economy and society to be more sustainable, sufficient, and resilient against challenges imposed by climate change. One of the latest introduced policies is the law for district heating planning and for the decarbonization of the heating network that aims to boost the so-called heat transition in Germany by using more renewable energy, reuse waste heat or a combination of both to make the overall heating supply more cost efficient and sustainable [1]. The goals of the law contain the reduction of terminal energy until 2030 by at least 26,5 % to 1.867 TWh in comparison to the base year 2008. A big part of the overall heating demand in Germany stems from private households. Around a third of the total terminal energy demand is consumed by this sector. Of the total 987 TWh in 2021 around 54,5 % is used for heating and warm water supply, 32,8 % for car fuel and 12,7 % for powering electrical devices [2]. Regarding CO_2-emissions and the sustainable transformation of the economy, it is crucial which energy resources are being used. In 2021, private households consumed 281 TWh of gas (primarily natural gas), 127 TWh electricity, 107 TWh renewable energies, 92 TWh mineral oil (mostly heating oil), 58 TWh district heating and lastly 4 TWh of coal for the last remaining ovens have been used. The total energy demand of private households in Germany fluctuates between in total 639 TWh and around 800 TWh since 1990 ending with approximately 678 TWh in 2022 [3].

Albeit not the biggest lever to enable the energy transition in Germany, private households and the consumption still have a massive influence on the type of energy source demanded (e.g. by choosing renewable energy suppliers) as well as how efficient this energy will be used. Recent surveys state that environmental protection is still important for most German citizens and this attitude was intensified in recent years due to local ecological disasters [4]. With this growing ecological awareness more and more households try to design their living spaces ecologically sustainable [5]. There are many approaches to increase sustainability in the household sector, the most prominent approaches address the energy consumption, namely buying climate-friendly energies and increasing the efficiency of the energy usage. Respectively, switching to renewable energies meets the growing demand of residents to become more ecologically friendly, but it also tackles the issue of currently increasing energy costs and the fear of being too depending on undesirable energy suppliers [6]. Secondly, lowering energy usage includes mindfully regulating heating and warm water usage in the individual living space, reducing energy in the individual mobility, decreasing the energy consumption concerning the procurement and operation of electronic devices and finally, generating your own heat and power supply if the necessary resources like technical equipment and financial means are realistically attainable.

Nevertheless, although the climate awareness and intentions to support the energy transition by adjusting one's behaviour are prevalent in private households, the translation into meaningful actions is insufficient and questionable [7]. This phenomenon is subject to current scientific research and is defined as the intention-behaviour-gap (sometimes also referred to as value-intention-action gap), here more fittingly described as intention-behaviour gap in private climate change adaptation. This means that claims by private households to become more sustainable do not translate into feasible actions or at least not to the degree that was claimed beforehand. Reasons for this 'self-blocking' are manyfold. Moreover, structural challenges such as the lack of financial capital to invest in renewable energy technologies such as heat pumps or photovoltaics, and tenants' dependence on their landlords to buy and install these technologies pose further challenges [8]. Additionally, the success of solutions tackling problems of climate change, limited resources and negative environmental effects of societal consumption depends more and more on whether private households can adapt their prior consumption behaviour to the new framework set by climate change. One way to approach this behavioural change in the private household sector include IT-enabled solutions. Recently, an interesting new strain of scientific research evolved from environmental sustainability research in information systems concerning changing individual behaviour by utilizing nudging with digital technologies, resulting in the discipline coined "digital nudging" [9]. This paper describes the current development of a digital tool that visualizes the effects of climate change as well as different technological means within the German energy transition for private households. The goal is that the tool will be able to morph individual pictures and predetermined points of interest (POI) on demand with help of artificial intelligence (AI) as well as show these described scenarios in model regions, that mirror the economic and societal structure of the general German population.

II. Methodology and Project Description

As underlined in the introduction, the research project involves an interdisciplinary approach with four main objectives:

- Establishing cross-sectoral development scenarios for energy generation and supply and their immediate effect on the local environment,
- Participatory research to gain insights from energy transition stakeholders in the model regions on existing challenges, future opportunities for action and best practice examples. Additionally, gathering input for the visualisation tool and its potential uses. Participative development and evaluation of a visualization application by utilizing AI technology,
- Diffusion analysis and creating a communications strategy for transferring the results and gained information.

The following sections are structured according to these objectives. Given the multidisciplinary nature of the project as well as the technological readiness of the innovation, a qualitative approach was deemed most suitable. For establishing the development scenarios for future energy supply in Germany and especially in the model regions of Berlin and Neuerkirch/Külz an extensive literature review has been conducted to accumulate the current status quo on how climate change will transform the energy framework and the overall German power supply [10]. This information will serve as groundwork for the content displayed within the digital visualization. During later stages of the project, we plan to receive relevant input from stakeholders on which approaches to use to showcase adequate best practices in increasing sustainable environmental behaviour for private households with different social conditions.

A. *Digital Nudging to promote pro-environmental behaviour*

The German energy transition put the spotlight of the energy system towards private households. The broad and quick diffusion of technological innovations for fostering and accelerating the energy transition and environmental protection as well as increasing energy efficiency presume that individuals push this development with their own investment, buying and consumption habits [11]. The introduction gave a brief description of the underlying theory of utilizing an AI-supported web application to nudge individuals into a positive environmental-behaviour (PEB). This section goes more into detail on how the principle of digital nudging supports bridging the behaviour-intention-gap, which factors generally influence the proliferation of green or environmental innovations in the context of the German energy transition.
To evaluate whether the EnerVi visualization tool will be adopted by citizens with different social conditions, the project team will conduct a diffusion analysis to determine chances and barriers that lead to the positive or negative adoption of this innovation after the tool has been published. This section frankly outlines the concept of nudging and diffusion of innovations, that serve as the starting point for the future evaluation.

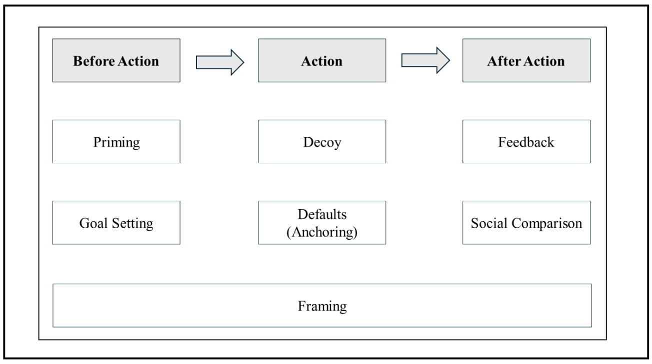
Nudging to promote PEB is based on behavioural economic principles [12] and in the EnerVi project referred to by the environmental economists[1]. Nudging uses modifications in the choice architecture to change the behaviour of individuals in a predictable way, either consciously or subconsciously. With the growth of e-commerce, more and more choices are made online through a screen by individuals. Subsequently, by changing choices architecture of a digital platform by e.g. setting a default in such a way, that promotes a behaviour that is expected or even advantageous for the designer of the choice architecture, the citizen will be nudged into a predetermined direction outlined by the designer. This is called digital nudging and includes all usage of user-interface design elements to guide people's behaviour in digital choice environments [14].

A literature review concluded that seven distinctively different classes of digital nudges exist within the space of triggering pro-environmental behaviour (PEB), namely priming, decoy, goal setting, defaults, feedback, social comparison, and framing [15]. These categories can occur before an action takes place - in this case choosing one of different offered options – during the action taking place or after this action has been done as depicted in the figure 1. For our research, only the classes priming and framing are of importance, due to the characteristics of the visualization tool, applicants are informed about consequences of climate change as well as about potential opportunities for action, especially for those groups who have less opportunities for actions, such as tenants. For example, by showing which actions could be taken in their immediate surroundings that

[1] The sociological perspective is more focused on social practices and less on behavior change. Referring to Shove and Walker (2014) "[…] social dimensions of energy transitions' […] only have meaning through and as part of the reproduction of specific social practices" [13]

are technically feasible, such as installing solar panels on the rooftop of the building of their rental apartments. The underlying message therefore stresses potential environmental impacts that could occur if climate change continues to worsen by heating the surface temperature further. Therefore, this visualization tool can be categorized as a combination of priming (providing information about consequences of specific behaviours before an action takes place, e.g. environmental catastrophes due to CO_2-intensive consumption habits [16]) and framing, since a physical reference point is used, to emotionalize climate change consequences for the individual user by altering the immediate surroundings visually and by morphing uploaded pictures with AI [15].

Figure 1: Digital nudging categories for PEB, own representation based on



[15]

The literature review currently states that priming to promote PEB by itself is not effective [17][18]. Rather that it should be combined with other categories to be more effective [19]. Which combination shows the most promising influences in the context of PEB must be further analysed and will be researched throughout the project by testing the prototypes with citizens [15].

B. *Diffusion of green innovations*

Sustainability or green innovation describes the development and implementation of novel technical, organizational, institutional, or social problem-solving solutions, that contribute to the conservation of critical natural goods and to transferable global and sustainable business and consumption [20]. To realise the full potential of disburdening the environment, green innovations must be accepted by the public; laws and politics must be introduced to ensure the broader diffusion. Diffusion in the innovation context describes the process of the application of an innovation by a growing number of adopters that encompasses the time after the first successful application or after successful market entry [20]. By a mass distribution the potential of an environmental innovation can become technologically ascertainable. There are certain factors that can influence the distribution and application of an innovation including product-related, adopter-related, supplier-related, industry-related, politics-related, and pathway-related factors [21]. For our research the focus lies on product- and adopter-related factors since the innovation will be developed for scientific purposes and the innovation focusses on changing the environmental behaviour of the applicants meaning that the factors concerned with framework-related influences are given and not immediately changeable. Product-related factors include

- relative advantage: involving optimal functionality, safety of the innovation and the price,
- perceptibility: meaning that applicants are aware of the innovation,
- compatibility: the connectivity to any cultural, technical, or economic soft conditions,
- complexity: describing how easy or difficult it is for users to gain access to the innovation and be able to use it intuitively,
- trialability: focusing on lowering the bar of acceptance.

Furthermore, on the adopter-side influences can stem from

- existence of usage innovators: a group of highly compassionate lead users and stakeholders that get involved in the production process early on,
- requirement for behavioural change, describing the need for consumers to change or adopt new consumption routines,
- uncertainties in functionality and product quality,
- prices, costs, and economic efficiency [22].

Nevertheless, the degree to which these factors influence the innovation depends on the attributes of the very same. For further research, we are going to use these factors as basis for the development of the tool – its status being outlined in the results section- input gained through different participatory events throughout the project as well as the diffusion analysis after the tool has been made available to the public.

C. *Stakeholderworkshops for early-stage risk and potential assessment*

One of the main goals of the research project is the involvement of stakeholders to collect a broad insight about opportunities and challenges of private households facing climate change and the energy transition. Key stakeholders including local energy suppliers, civil society organizations, sustainable companies and start-ups, municipal and city administration representatives and other relevant groups in the model regions were invited to participate. By considering different living conditions, the innovative potential lies in using a visualization tool to reach citizens who have been less active in the energy transition so far. Hence, we present the preliminary results of five workshops in the model regions of Berlin (three workshops) and Neuerkirch/Külz (two workshops). Through the stakeholder workshops we obtained multi-layered narratives and knowledge about challenges, future energy transition measures and existing best practice examples. The results will inform the development of the visualisation tool by providing courses for action to users, ideally considering different living conditions. The preliminary results are yet to be methodologically analysed and serve only as a first indication in this paper. Nevertheless, the final results will be used as base for the parameters utilized in the visualization tool.

III. Results

The following sections show preliminary results from the literature research for forecasted energy scenarios for Germany and which measures the city of Berlin and the congregation of Neuerkirch/Külz plan to introduce to transform according to the framework set by climate change. On this basis, potential approaches, and guidelines for citizens to change their environmental behaviour in line with the overall German energy transition will be displayed within the visualization tool. Some of these potential approaches have been published in our scenario review [10].

A. Climate change and energy scenarios

Global forecasts and estimates for region-specific impacts are uncertain. Nevertheless, to be able to state potential effects of climate change in the model regions of Berlin and Neuerkirch/Külz, town- and region development concepts as well as area specific outlooks have been identified to derive expected environmental issues.

The city-development climate concept 2.0 for Berlin [23] stresses that open space is becoming sparser, which already causes a bioclimatic burden for some districts. Further implications include a wide range from bioclimatic burdens to health issues due to heat waves during the day and growing tropical climates during the night, stronger droughts up to water scarcity for city trees, green fields and bodies of water that are unable to cool down the city any further, more local flooding and higher risk of damages by heavy rain. In its core, the concept assumes that the temperature in the city will increase, and the pattern of precipitation will change, resulting in more frequent periods of drought and heavy rain. The climate outlook Berlin goes more into detail [24]. It is based on the fifth IPCC [25] status report and its "Representative Concentration Pathways" (RCPs) demonstrate three scenarios that analyse prospective climate changes in Berlin: The scenario RCP8.5 assumes a continuous rise of GHG emissions that plateaus at a high level by the end of the century; the middle scenario RCP4.5 expects growing emissions until the middle of the 21. Century and with sinking rates afterwards and finally, the climate protection scenario; RCP2.6 involves very ambitious measures for the reduction of GHG emissions and by the end of the century even "negative emissions". Those three scenarios are depicted in figure 2 to see how the temperature changes according to the scenario and its deviation.

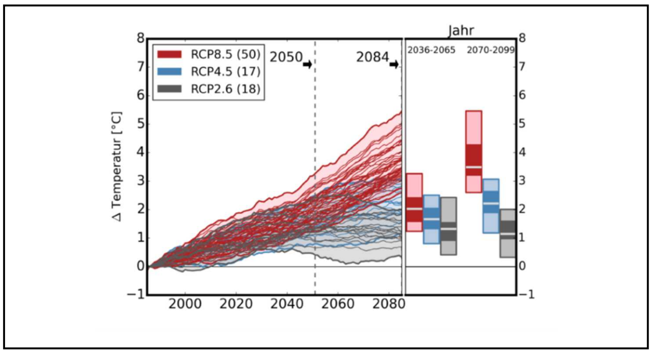


Figure 2: Bandwidth of annual average change in temperature in Berlin [24]

Another report, the environmental Atlas Berlin from 2013 [26] shows additional indicators for temperature considering the steady incline of summer days, heat days, tropical nights, and the maximum period of extreme heat. Those effects are stronger in RCP4.5 and RCP8.5 than in RCP2.6. Simultaneously, the number of freezing or icy days declines steadily. The number and intensity of heat waves will presumably continue rising. This can cause health issue risks, especially for elderly people and people with prior history of illness [25][27]. However, there is no clear indication, that any of these assumptions are undoubtedly expected, since the current reports also differ in the definition of the scenarios themselves.

The local congregation Neuerkirch/Külz in the federal state of Rhineland-Palatine counts 300 residents (and 480 respectively) and both places stand at 359 m above sea-level. The climate related scenarios for those congregations are also based on the fifth IPCC report. Figure 3 illustrates the aggregated timeline from 2000 and relates the scenarios to the real data up to 2022. We can see that even the pessimistic scenario of RCP8.5 is surpassed by the real development.

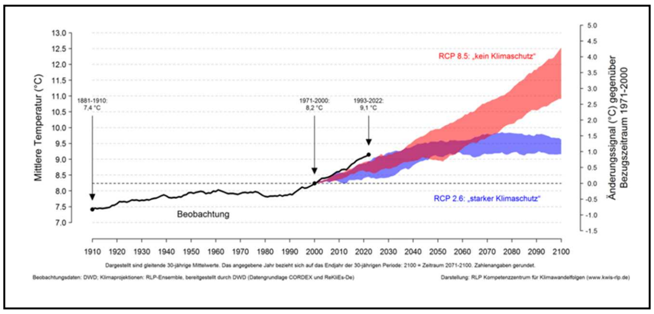


Figure 3: Projection of the development of the average annual temperature in Hunsrück [28]

The county of Hunsrück states already an increase of 1,7 °C in 2022 since 1910. Extrapolating this data to 2050 results in a further increase by 0,8-1,3 °C, thus leading to a total of 2,5-3 °C total temperature change in the county. The amount of summer days (over 25 °C) is growing since 1980 to almost double from 20 to 35 and the number of hot days also grows by the same rate and again, freezing, and icy days are decreasing in total.

The projections for precipitation follow a similar development as in Berlin. Down the line, the forecasts show a growing area of uncertainty. The real development accounts the same amount as the accumulated data, depicting a trend of diminishing precipitation in the last 15 years.

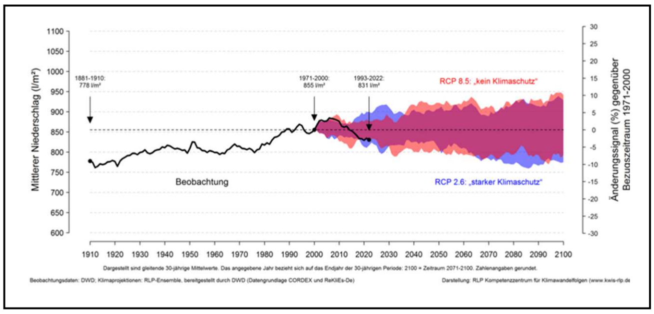


Figure 4: Projected development of annual average precipitation in the county of Hunsrück [28]

The introduction gave an overview about the current energy demand of private households in Germany. However, for the scenario visualisation the outlook for the projected energy supply in Germany and expected demand is required. The literature research concluded that most of the consumed energy in private households and industry stems from room heating and warm water usage. As previously mentioned, approximately 50 % natural gas and 25 % heating oil are currently utilized to meet this heating energy demand [29]. Figure 5 shows the development of natural gas up to 2045, based on five climate neutrality studies by the German think tank Agora Energiewende, the Federation of German Industries, the German energy agency dena, the Federal Ministry for economic affairs and climate action and the Kopernikus project Ariadne.

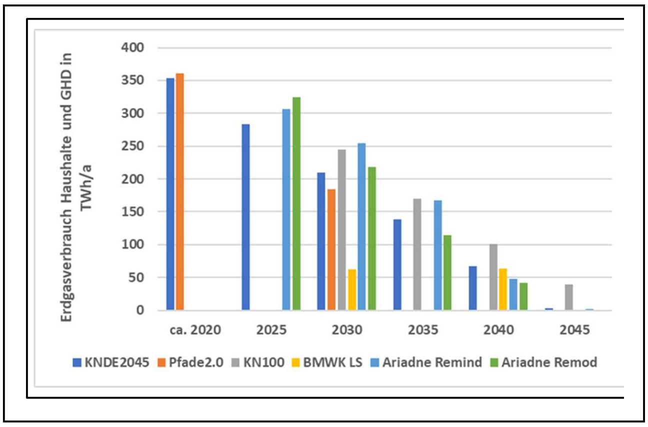


Figure 5: Development of natural gas consumption by private households, trade, and commerce in Germany until 2045 [30],[31],[32],[33]

While both scenarios of the Ariadne study prognosticate that the diminishing demand of heating oil and natural gas will be compensated by a noticeable increased consumption of electricity of 120-130 TWh/a, other scenarios see a stable electricity consumption in the upcoming years. Almost all studies forecast a strong increase of district heating from 60 TWh up to 100 TWh/a. Three studies also consider environmental heat as energy source, with an increase from 20 TWH/a in 2025 to 150 TWH/a in 2045 but these studies miss to consider the electricity that powers technologies such as heating pumps. Nevertheless, all studies agree that the following scenarios for private households, trade and commerce are the most realistic: the renovation rate and renovation success will gain considerably, initiating an overall energy demand decline by 2 % per year. The utilization of heating oil and natural gas will diminish in a linear fashion and end by 2045, the use of electricity however could increase but the use of district heating will increase. In addition, environmental heating will be used as well, but the use of biomass will decline slightly from an already low usage level, although some see a growing importance of hydrogen as energy source. Other studies suggest otherwise that the usage of hydrogen for warming will remain absent. To sum up, the studies state a clear picture of a heating transition in Germany with a decreasing amount of fossil fuels and (although ambitious) a reduction of terminal energy demand. Which combination of energy sources will finally be used to cover the total heating energy demand of around 600 TWh in 2045 in detail is still difficult to pinpoint, but all scenarios depict the amount of electricity usage will rise from 25 % to 50 % for buildings. Heating pumps and environmental heating will gain popularity and hold a share of 25 %, closing in on around 140 TWh/a but invertedly also increase the amount of electricity used. In addition, newly accessible heat sources that could be distributed by the existing heating network will become more important such as industrial exhaust, heat from sewage systems and rivers, heat from waste incineration and finally, geothermal energy and solar heat.

Looking onto the future electricity production, forecasted generation of electricity will face three main challenges. Namely, the need to decarbonise half of the production that still depends on fossil fuels, (almost) doubling the amount produced and overcoming the fluctuating nature of renewable sources through load management and energy storages.

The climate neutrality studies differ in the projected electricity produced between 873 TWh/a and 1487 TWh/a by 2045 [29], [30], [31], [32], [33]. Figure 6 illustrates the future energy source for electricity generation based on the Ariadne Project [29].

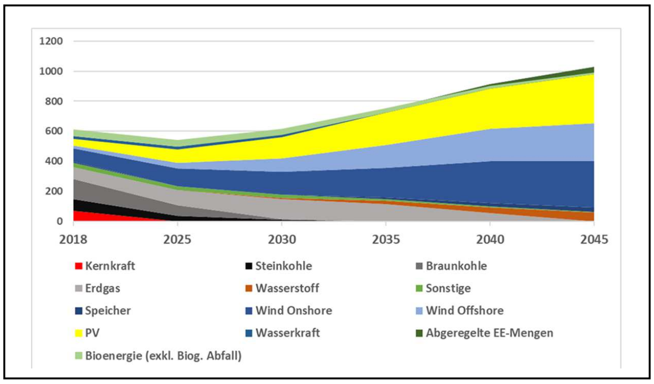


Figure 6: Energy sources of electricity generation in Germany by 2045 [29]

Consequently, the amount of energy sources that contribute to the electricity generation differs in these studies for onshore wind energy (303 to 582 TWh), offshore wind energy (114 to 360 TWh) and solar energy (151 to 473 TWh). But one conclusion can nevertheless be drawn: the required growth rate based on the concurrent share of renewable energies in the electricity mix is huge. Looking for example at the wind energy sector the growth rate to achieve the ambitious climate goals lies between 3 and 6 %. Another study calculates that the growing electricity demand from currently 560 TWh will already reach around 680 TWh to 750 TWh by 2030, assumes therefore a necessary growing rate of 120 to 150 % as depicted in figure 7 [34].

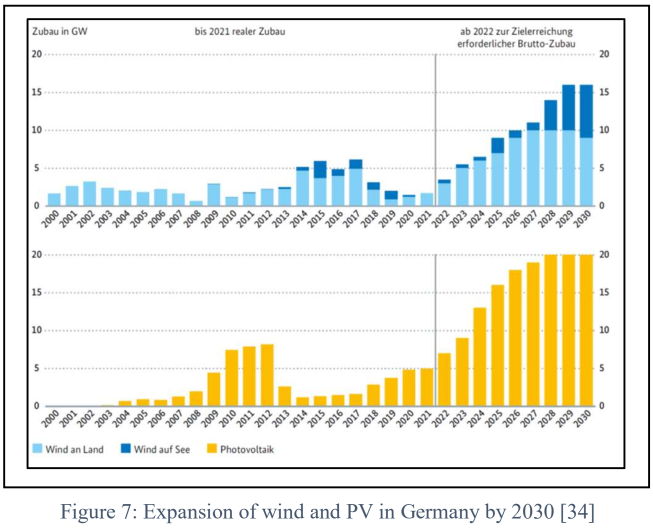


Figure 7: Expansion of wind and PV in Germany by 2030 [34]

At this point it is still being discussed, which information concerning scenarios, local specific impacts, and effects of climate change as well as potential individual measures to counteract these complications will be illustrated within the visualization tool and how it will be shown to the user by the interface.

B. AI-enabled visualization tool to showcase environmental impact in personal surroundings

This section presents how the web application will be structured, which technology is used to enable the text-to-image translation and which supporting systems are applied to inform the citizens about the consequences of negative environmental behaviour on the immediate surroundings and which measures to potentially take to stop or decrease the illustrated environmental impact.

1) Structure of the application

The web application will have two different features for visualizing climate change scenarios and local energy transition measures. The first depicts landmarks or rather POI in the respective model region such as e.g. Alexanderplatz in Berlin or the town hall square in Neuerkirch/Külz. These will be marked on a local map and after choosing one of these points, a publicly available picture of that landmark will be shown in combination with a drop-down menu, that list the different options the picture can be changed into:

a) Climate change scenarios

- drought/heat,
- flooding,
- additionally, utopian, and dystopian scenarios.

b) Energy transition measures

- Photovoltaics,
- wind generated power.

Figure 8 shows an example of a building in Neuerkirch, that showcases the scenarios heat, drought, PV and the original.

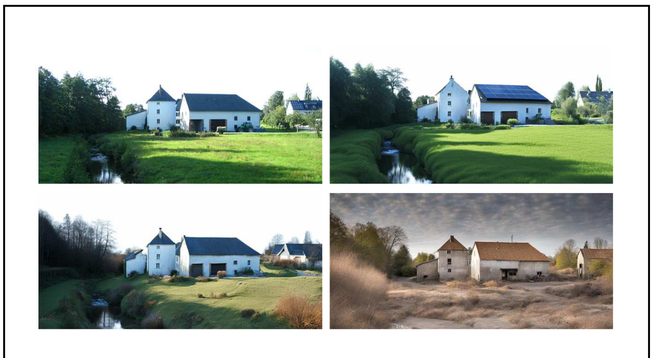


Figure 8: Example of scenarios depicted for selected POI [own creation based on Wikimedia]

After generating the scenarios, the user receives the opportunity to learn more about e.g. the energy supply in the region, local energy transition goals, how the local administration plans to achieve these and how the individual can support these goals with changing consumption habits and their energy demand.

The other feature involves morphing pictures of landscapes and buildings, uploaded individually by the citizens. Those changed pictures projecting potentially devastating environmental impacts of climate change are in line with digital nudging and trigger the users to question whether their own consumption habits and opportunities for action align to the necessity of climate change adaption and energy transition. To support the user in changing those habits, the application will include surveys, to evaluate the individual demand as well as further information via info boxes, best practices examples and helpful guidelines to increase environmental consciousness and awareness of the individual's ecological footprint and environmental impact.

2) Stable diffusion and other AI-automation for image-to-image translation

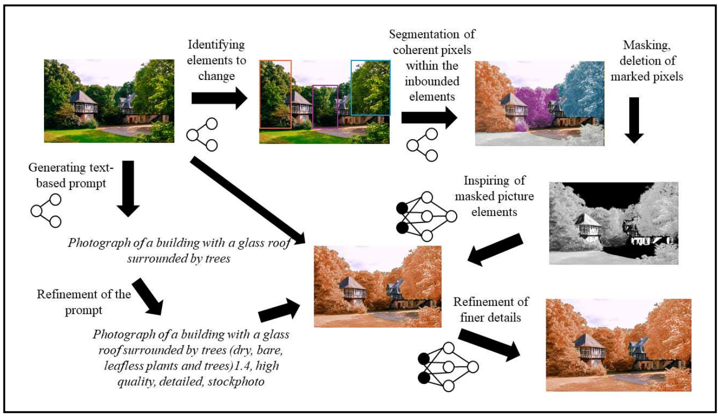


Figure 9: Schematic image-to-image translation process [own creation]

The web application is based on a summation of different AI-applications to automate smaller manual steps. Figure 9 shows the schematic process of how the uploaded pictures are changed.

Whether an uploaded picture is used, or the user chooses one of the provided illustrations of the POI, the initial process for changing specific elements within the picture is the same. This process is a combination of text-to-image translation and image inpainting.

The underlying AI model used to perform the inpainting is a latent diffusion model by the company stability AI. Diffusion models belong to the group of generative models that learn to generate images by learning the reverse process of removing noise in images [35]. The diffusion process nowadays involves encoders that are modeled in a UNet [36], enabling a bigger training set without losing quality by utilizing diffusion cycles in lower resolutions [37]. For a deeper understanding of latent diffusion models for image inpainting, please refer to the following literature which includes the paper that laid the groundwork for diffusion models [35][38][39][40].

For this paper it is relevant to know that the image generative AI is a trained and prompt-based open-source model that is based on 3,5 billion parameters. The usual approach for these models is to write a text that the AI then translates into an image. For our web application, this step must be automated since there are predetermined scenarios that the user can choose which in turn has to be transmitted into a code, that the AI is able to understand. Referring again to the figure 9,

we can see that the process deviates from the usual approach that involves using a text-prompt, that the pre-trained model can encode into readable data [37]. In our case we start off with an image, either by choosing one of the POI with prepared images of landmarks or the user uploads an appropriate (meaning an image of a landscape and buildings suitable for PV and wind energy plants) image. To enable the application to an image-to-image translation [41], two parallel processes are initiated; the first prepares and marks the elements in the picture that require modification or changing and the second tells the model with which information or data the changed elements should be replaced with. The first process follows the instructions given by the chosen scenario option to mark the areas within the image that must be modified. For the identification of the scenario-prompted elements in the picture another AI model is used that stems from meta called segment anything model (SAM) [42] which uses so called bounding boxes to mark all coherent pixels within these boxes (in this instance trees), effectively segmenting the image. The marked pixels are getting deleted resulting in a layer that outlined all elements of interest for further steps in the process that is known as image masking [42].
Meanwhile, the model requires information on what the diffusion model should generate to replace the now created free spaces which is more commonly known as image inpainting [40]. For this reason, the model requires a text prompt which must be derived from the uploaded or chosen initial medium. Again, an AI model has been used to create this text prompt [41] which must be refined into containing the appropriate vocabulary that triggers the generative model to develop the desired result. Finally, the text prompt tells the generative model what should be filled into the deleted spaces from the first process creating the final scenario chosen by the citizen.
This combination of different AI models and digital processes automates the typical approach of using generative models by automating the configuration and certain manual task to increase - in line with the innovation diffusion – the acceptability and usability.

C. Preliminary results of stakeholder participation

The preliminary results are yet to be methodologically analysed and serve only as a first indication in this paper. Nevertheless, the final results will be used as base for the parameters utilized in the visualization tool.

1) Berlin

The first workshop identified challenges and potential solutions for the local energy transition. The main drawbacks that have been identified involved especially legal and bureaucratic obstacles for individuals, initiatives, and organisations. Going more into detail, the challenges seen by the participants listed insufficient balancing of top-down and bottom-up processes, a difficult knowledge transfer due to plurality and lack of personal, gaps in non-bureaucratic support, the lack of an overall strategy considering the high demand for resources for decentralized actions and lastly, legal obstacles and time lags in cases of individual activities in the local energy transition e.g. investments in balcony power plants. Simultaneously, the stakeholders see risks to the transition in rising overall prices, especially for people in precarious living conditions, the medial reporting on energy transition measures and in transition delays due to short-term economic interests of the private real estate sector and renting companies. The second workshop focused mainly on the energy transition goals until 2050 in Berlin. The city plans to reduce GHG by 95% by 2045 in comparison to 1990. Therefore, the stakeholders were asked for their perspective on useful further energy transition measures, processes that should be reduced and fruitful cooperation between the cities of Berlin and the rural area. These results were plotted on a timeline which can be seen in Figure 10 and 11. Working with a socio-technical perspective, it becomes clear, that social and legal processes such as providing more information about energy transition, continuous incorporating education on sustainable development in the educational system, and strategically dealing with community concerns about rising energy and rental costs, are as important as the technical aspects. Also discussed were best practice examples such as a climate neutral borough which can be replicated, using exhausted emissions for heating purposes, decarbonizing district heating as well as using alternative local heating systems such as low-level local heating systems and geothermal sources.

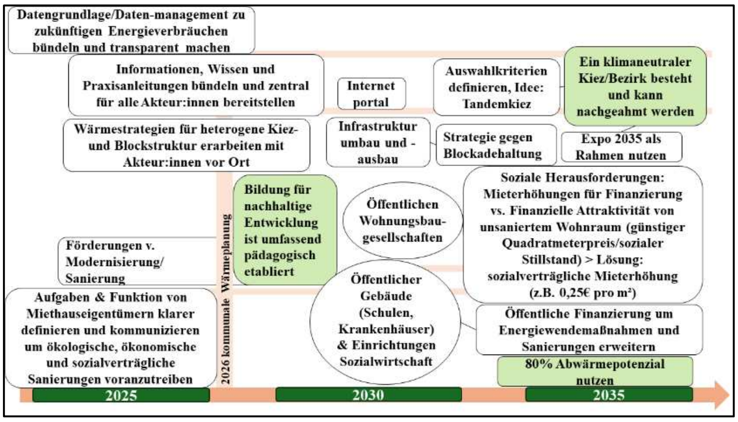


Figure 10: First half of the timeline of additional efforts for the local energy transition in Berlin [Schmitz/Ohde 2024]

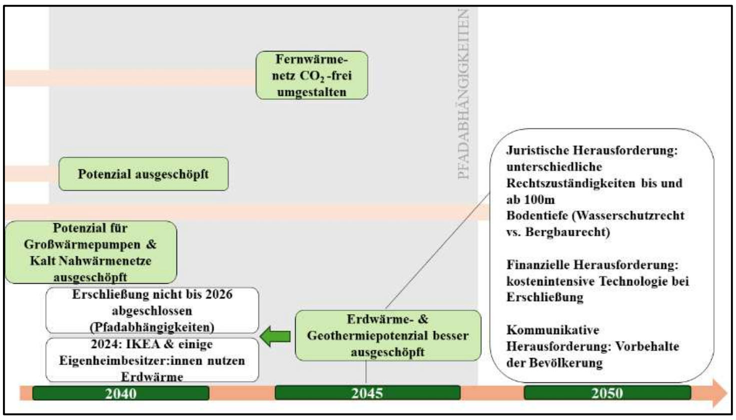


Figure 11: Second half of the timeline of additional efforts for the local energy transition in Berlin [Schmitz/Ohde 2024]

The final stakeholder workshop focussed on the participants input for the development of the visualization tool. The innovation was firstly introduced followed by illustrating the next steps in the development process. The given input from the participants is categorised in line with the introduced factors that influence innovation diffusion.

The first and biggest input is a mixture between product- and adopter-related factors, namely functionality and economic efficiency for the target audience. Generally, the idea of the visualization of environmental impacts on an individual level was received positively, but the participants noted that a more precise clarification regarding the usage group is needed, and which benefit citizens or stakeholders can draw from the innovation. Some ideas on which information should be provided on the website to reach a wider audience was to showcase and calculate economic advantages of measures for the energy transition for lower-income households especially how investments in increasing energy efficiency can benefit these households in the long run. This aspect was also mentioned in another point raised, concerning the features of the application. Those two points mentioned can be boiled down to the relative advantage of this innovation as well as perceptibility of the innovation. One participant asked whether the tool could draw a comparison between the status quo of e.g. his garden and an energetically modernized version of his property. Nevertheless, it was also pointed out that these morphed pictures should not be too futuristic in the sense of updating existing buildings with glass fronts, but rather show opportunities for using existing properties and how to energetically realign them. One critical point considered what dystopian version of images should evoke in the participants as this negative illustration could backfire and not support citizens in pro-environmental behaviour but rather pushing them into a counter position. Finally, it was mentioned that especially tenants and people without property do have fewer options for the installation of renewable energy technology due to legal obstacles. Another example are public buildings that are protected by preservation order, changing the structure of these types of buildings for the sake of increasing energy efficiency is more complex, raising the question of how this problem could be addressed within the application. Interestingly for the adopter-side factors, the participants mentioned a couple of possibilities on how to increase awareness of the application by using several multiplicators (or usage innovators) such as communities of tenants, seniors that have deep ties with their respective communities, housing associations to connect top down with bottom-up strategies within this conglomerate of different interests. In summation it became clear, that it will be necessary to clearly define a target audience, to amount other aspects, develop an appropriate communication strategy to enter the adequate user base especially socially and economically vulnerable households. Illustrating the benefit of using this innovation will also influence the diffusion and the stakeholders stressed that certain features could underline the relative advantage and compatibility of the application such as showing the temperature change in the different dystopian and utopian scenarios, using features to immerse the citizens deeper into the scenarios.

So far, green innovations such as IT-enabled tools that promote PEB specifically were not mentioned, but digitization does seem to play a crucial role in the eyes of the stakeholders from the very beginning in that transparent data base including information on local energy demand, potential local sources as well as measures for locally centralising the energy supply to increase the efficiency of local systems and simultaneously decarbonizing the system could be provided. It also became clear, that factors such as energy prices and affordable living space are the biggest obstacles for Berlin locals. Further factors include the fear of big individual investment costs to lower the personal CO_2-footprint as well as the bureaucratic burden that must be overcome.

2) Neuerkirch/Külz

In the municipalities of Neuerkirch and Külz in the county of Rhein-Hunsrück-Kreis the workshop was reduced to two events.[2] Subject matter of the first workshop was the further energy transition goals until 2050. The participants listed that among new measures the municipality should strengthen and foster social support measures, expand local energy circles, and increase efficiency in the usage of buildings regarding energy and social sustainability. Processes concerning recyclability of wind energy rotors, solar modules and batteries, energy storages and local energy generation with smart grids should be supported as well. Other activities such as solo efforts and monopolization in energy generation e.g. in ground mounted PV and land usage and gas emissions in building usage should be reduced or even changed to sustainable construction with increased recycling efforts and an overall more objective public discourse about the energy transition. The energy transition in Neuerkirch and Külz is linked to other transformations such as changes in housing forms or adaptation to climate change through nature-based solutions. For example, the idea of two small reservoirs that firstly can be used to produce energy in the future and secondly the evaporation water serves as a natural air condition.

Those results have been plotted as additional efforts to support the local energy transition on a timeline until 2050, illustrated in the figure 12 and 13.

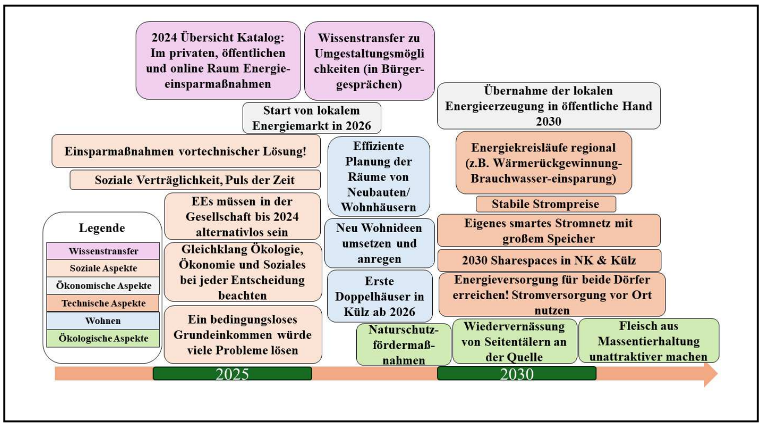


Figure 12: Firsts half of the timeline of additional efforts for the local energy transition Neuerkirch/Külz [Schmitz/Ohde 2024]

[2] The local stakeholders have already implemented many measures and are well networked, so an intensive exchange on current challenges in the energy transition was not necessary. Data on past challenges was collected through an online survey.

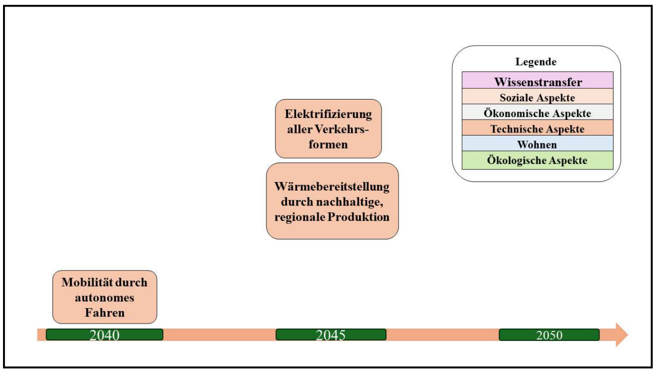


Figure 13: Second half of the timeline of additional efforts for the local energy transition Neuerkirch/Külz [Schmitz/Ohde 2024]

Although the transcript of the workshop focusing on the visualization tool itself is still being processed, preliminary results state that the congregation already conducted several means for the local energy transition, causing the participants to wonder if this tool will propose further activities to increase the local decarbonization of the energy supply and demand. To further illustrate, the citizens of Neuerkirch questioned how they can aggregate isolated single efforts and how these combined efforts and expertise could be used to increase energy transition activities even further. Therefore, the citizens require best practices that adequately meet a rather high starting point as for example other communities that start from a lower level of transformation. The local citizens see for example possibilities in combining transformational effort by using synergies with other sector transformations such as mobility and smart cities. Nevertheless, these efforts should specifically be focused on climate adaption, by changing living spaces such as promoting multigenerational housing instead of single living spaces.

A full-scale analysis with qualitative methods of these preliminary results is in process. These results should only give a brief overview about the feedback of local stakeholders in this paper. In total, the preliminary analysis shows that in both model regions, most barriers and risks are seen within social innovations in contrast to technical implementation, meaning that the technology and possibilities of instalment are available, but soft factors such as expertise and a promotional framework especially regarding bureaucratic and administrative barriers hinder citizens in PEB efforts.

IV. Discussion and Outlook

The project currently began with the development of the visualization tool. Nevertheless, the described involvement of stakeholders and citizens deemed to be very practical until this point. The visualization tool will be further developed and will include the feedback of ongoing exchanges via workshops and equivalent events. The first round with stakeholders has been conducted at the beginning of 2024 and the follow-up will include a citizen science-process to receive immediate input by the targeted citizens and private households from the model regions. First feedback has already shown that the target audience must be defined more clearly to display information in info boxes and further information within the web application that match the interest, requirements and need for support that in in turn increases the digital nudging effect that shall ultimately lead to PEB supporting the German energy transition. We expect to test the first prototype by the end of 2024 to learn more about potential barriers and ways to surpass these by providing economically adequate and required visualization.

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