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Towards Carbon Neutral Settlements. The Importance of Early-Stage Urban and Energetic Optimizations

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Abstract

The aim of the research was to verify the essence of interdisciplinary energy optimizations in early-stage urban design process. A further aim was to the find most optimal design variant and scenario in terms of urban energy efficiency for the future development in Nowy Port, located in Gdansk, Poland - a place requiring complex revitalization. The research combined qualitative and quantitative approaches; an urban design layer (architectural analysis of spatial systems and planning) and an energy layer (simulations). For energy and environmental simulations, the ELAS calculator was used in an innovative way, that enabled comparison of results of several projects in terms of energy demand, carbon dioxide lifecycle emissions and ecological footprint for different urban layouts. The innovative method including the application of ELAS tool in early-stage design phase proved to be relevant and allowed for an appropriate pre-assessment and comparison of urban energy efficiency parameters and life cycle analysis at an initial stage of the project. One of the key conclusions is that the design variant with the highest building density was not the most advantageous in terms of low environmental impact and energy demand. In addition, the research demonstrated that the individual behavior of residents, their mobility patterns and the energy systems are more important than the improvements focused only on building energy performance.

Keywords: Urban planning; energy; ELAS simulation; sustainable development

Citation

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Hacia asentamientos neutrales en carbono. La importancia de las optimizaciones urbanas y energéticas en etapas tempranas

Resumen

El objetivo de la investigación fue verificar la esencia de las optimizaciones energéticas interdisciplinarias en el proceso de diseño urbano en etapa inicial. Otro objetivo era encontrar la variante de diseño y el escenario más óptimos en términos de eficiencia energética urbana para el futuro desarrollo en Nowy Port, ubicado en Gdansk, Polonia, un lugar que requiere una revitalización compleja. La investigación combinó enfoques cualitativos y cuantitativos; una capa de diseño urbano (análisis arquitectónico de sistemas espaciales y planificación) y una capa de energía (simulaciones). Para las simulaciones energéticas y ambientales, se utilizó la calculadora ELAS de forma innovadora, que permitió comparar los resultados de varios proyectos en términos de demanda de energía, ciclo de vida de emisiones de dióxido de carbono y huella ecológica para diferentes diseños urbanos. El método innovador, que incluye la aplicación de la herramienta ELAS en la fase de diseño inicial, demostró ser relevante y permitió una evaluación previa adecuada y una comparación de los parámetros de eficiencia energética urbana y un análisis del ciclo de vida en una fase inicial del proyecto. Una de las conclusiones clave es que la variante de diseño con la densidad de construcción más alta no fue la más ventajosa en términos de bajo impacto ambiental y demanda de energía. Además, la investigación demostró que el comportamiento individual de los residentes, sus patrones de movilidad y los sistemas energéticos son más importantes que las mejoras centradas únicamente en el rendimiento energético del edificio.

Palabras clave: Planificación urbana; energía; simulaciones ELAS; desarrollo sostenible

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1. Introduction

In light of global urbanization, contemporary cities are exposed to numerous issues concerning sustainable development (Perez-Lombard *et al.,* 2008). One of them refers to the aspect of clean energy (Secretary-General UN, Council, 2019; Athanassiadisad *et al.*, 2017). The accessibility of clean energy and its application will probably become one of the greatest challenges in the coming years (Perez-Lombard *et al.*, 2008; United Nations Habitat, 2015; Nations, 2019; United Nations, 2015; Nations, 2017; Delia D'Agostino, 2015; Yong *et al.*, 2020). Numerous sustainable development factors can be identified that influence the sustainability of contemporary cities, not just environmental impacts, but also social and economic factors. Therefore, apart from the aforementioned issues, the energetic aspects will inevitably become a great challenge for planners in coming decades. However, the environmental impacts of different options in urban planning tend to be underestimated (Oke, Timothy, 2003; Carreón & Worrell, 2018a; Barrera *et al.*, 2018; Milner, Davies, & Wilkinson, 2012). Focusing on the effects of different design decisions could be a way forward.

Having considered the above facts, it is necessary to change the approach to design, particularly in the building, construction, and planning sectors (Perez-Lombard et al., 2008). Respecting not only the scale of a given object, but also its surroundings and the parameters that affect the characteristics of the entire building complex both at a regional and global scale will be fundamental (Carreón & Worrell, 2018a; Barrera *et al.*, 2018). The countries that signed the Paris Agreement 2015 (Paris Agreement, 2015) are preparing legal frameworks for rendering cities sustainable and severe measures should be taken to improve the energy performance of buildings, focusing on reducing material consumption in the construction sector as well as reducing pollutant emissions and implementing climate change adaptation and mitigation strategies . This is particularly important in the context of countries struggling with excessive environmental pollution(Bagheri *et al.*, 2021). For instance, the Polish cities whose economies strongly depend on non-renewable sources of energy belong to the cities with the worst air quality in Europe (Guerreiro *et al.*, 2018). Therefore, it is crucial to undertake collaborative actions in all sectors including planning and strive to achieve carbon neutrality. The paper addresses several research questions on the integration of spatial and energy dimensions in early-phase urban planning. The first question was, how we can design carbon neutral urban developments with low environmental impact. A further question was whether urban scale optimizations leading to energy efficiency can be achieved in early-stage design phases, and how far they influence the final energy consumption, CO2 lifecycle emissions and ecological footprint (SPI). As a result, the research question was to what extent early-stage design optimizations may influence the final energy demand and other environmental parameters.

In the new context of energy transition an urban planner's workshop and the approach to design needs to be changed. Urban design priorities are re-set and should rely on including energy planning already in the first design phase, as it was demonstrated in this article.

2. Method

2.1 Integrated spatial and energy planning – Developing districts' carbon neutrality

The interdisciplinary implementation of zero-carbon policy can be represented by the concept of integrated spatial and energy planning (Stoeglehner, Neugebauer, *et al.*, 2016) and was further developed in this paper. This concept tackles not only the issues concerned with sheer urban planning or energy, as it is also jointly tied with other sustainable development goals. In this way, it influences social factors

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as well, and if properly applied, it may increase the quality of lives and economic development. As previous analyses showed (Stoeglehner, Neugebauer, *et al.*, 2016), there are numerous considerable reasons for turning to sustainable integrated spatial and energy planning. It is important to consider them both in the context of global co-responsibility and at a smaller scale – allowing for the introduction of significant activities and strategies.

The main purpose of this study was to develop an understanding of integration energy efficiency and carbon neutral policies for urban planning. Hence, the major the goal of the investigation was to understand to what extent urban optimizations lead to energy efficiency, how necessary they are in the early stage design phase, and what advantages can be derived from their application.

It was also investigated if energetically balanced eco-settlements in the case study area reduce negative environmental impacts. Furthermore, it was researched if carbon neutrality could be enhanced in derelict areas by performing integrated spatial and energy planning. It was tested if such an approach may become a potential energy revitalization tool.

In the latter context, it was important to determine if energy-related optimizations in early-stage planning influence the final energy consumption, CO2 lifecycle emissions and ecological footprint of an urban district scheme (Sustainable Process Index) SPI (Stoeglehner *et al.*, 2016). To obtain quantitative measurement parameters, the cases were subject to a percentage comparison of the scenarios in regard to the most optimal design proposal in terms of energy consumption and CO2 emissions. Finally, the scenarios were assessed and compared in terms of economic impact (best and least beneficial scenarios).

2.2 Scope of work – environmental hazards in case study area

For the case study area, the Tricity metropolitan area located in northern Poland was chosen. The case study plot was Nowy Port district, located in the city of Gdańsk. Therefore, the findings and determinants to optimize building complexes refer to Polish conditions and the Polish climatic zone-temperate climate (Pratolongo *et al.*, 2019).

According to forecasts of Germanwatch (Eckstein *et al.*, 2018, Guerreiro *et al.*, 2018), Poland is not threatened to a large extent by remarkable climate changes in comparison to other countries most in threat such as Arctic, small islands and developing countries in Asia, Africa. However certain effects of extreme weather events can already be observed also in Poland, in the form of extreme precipitations, floods and extreme heat. Some researchers also forecast a potential increase in sea levels that may affect waterside areas. (Nyka, 2019; Styszyńska *et al.*, 2018; Matusik *et al.*, 2020).

It is important to note that the whole Pomeranian Voivodeship is a region strongly dependent on external energy supplies (Zarząd Województwa Pomorskiego, 2018). Production in the region provides just over 40 percent of its consumption. There is a need to import over 50 percent of electricity from central and southern Poland through the National Power System. As a result, the regions of central and southern Poland are characterized by the poorest air quality in the whole country. Therefore, excessive dependence on non-renewable sources in Northern Poland may worsen the situation in the problematic southern areas. Therefore, in the investigation, it was important to indicate how to reduce excessive primary energy use and energy production from non-renewable resources.

Due to the problematic situation in the north of the country, a "waterfront test location" was sought for research. This location was to meet the following criteria: the availability of free land for new development and the possibility of revitalization and improvement of the existing situation in its neighborhood. Therefore, instead of suburban area, an inner-city location with promising development

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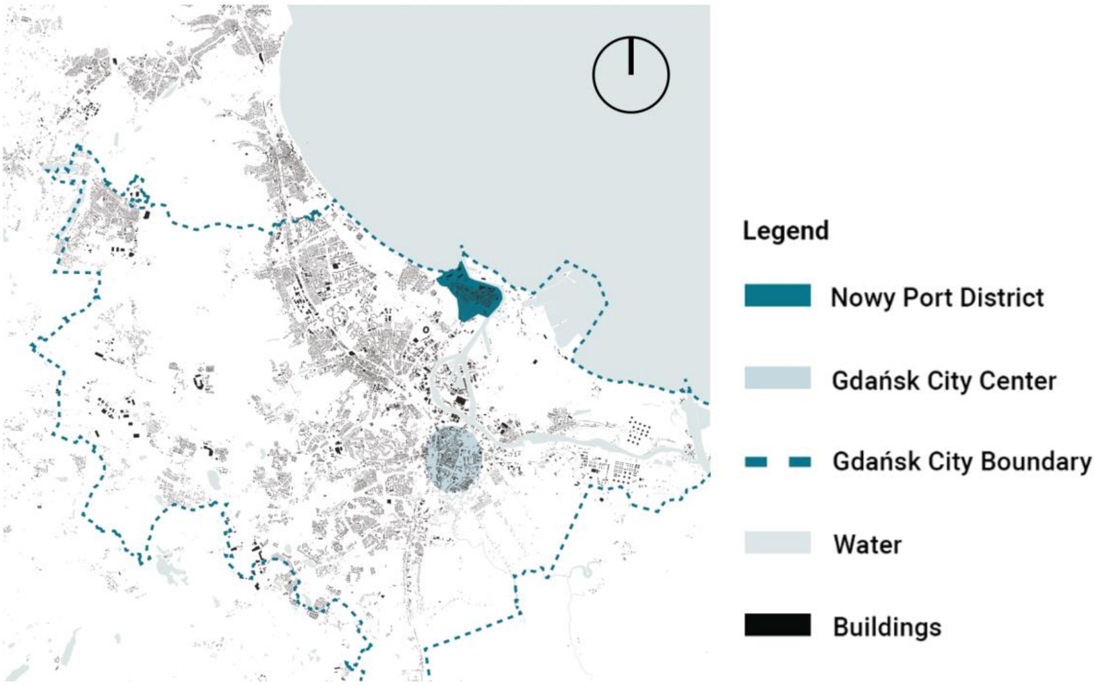
predispositions was chosen. It was also aimed to select an area that experiences environmental challenges to propose environmental measures and reduce pollution by introducing the changes. For the above reasons, a location in Gdańsk, in Nowy Port district was selected. Nowy Port is located in the coastal part of the biggest city of the Pomeranian voivodeship, Gdańsk. Due to its specific location, it has great development potential but is also exposed to numerous environmental threats. Especially air pollution in Nowy Port is problematic according to ARMAAG (Zgoda *et al.*, 2017) investigations. The region is also characterized by a high degree of flood risk in significant areas, not only Żuławy, but also Nadwiślańskie Lowlands (Figure 1.).

Figure 1. Nowy Port district in the city of Gdańsk as an important network point in Tricity Metropolis



Source: Koch, Rost 2018a.

In Nowy Port district the permissible dust concentration in the air of PM10 and PM2.5 as well as sulfur dioxide (Zgoda *et al.*, 2017) are regularly exceeded. Within this district dominates also low emission - individual heating systems in the form of fireplaces. Only a small number of buildings have a connection to the central heating system (Damszel–Turek *et al.*, 2017). Due to the above facts and further planned development, this district required a special interdisciplinary design approach with a special stress laid on environmental aspects (Figure 2).

In terms of energy efficiency, in the whole Pomeranian Voivodeship, there is a low energy efficiency in the built environment and inadequate support for high-efficiency energy systems. An opportunity for the development of the voivodeship's economy is the development of dispersed energy, including from prosumers, which will require significant investments in distribution networks.

At the same time, the Pomeranian region is characterized by exceptional natural value, resulting from significant diversity of the environment and landscape. This increases the comfort of living of the residents and at the same time requires the provision of infrastructure that limits anthropopressure and directs tourist traffic.

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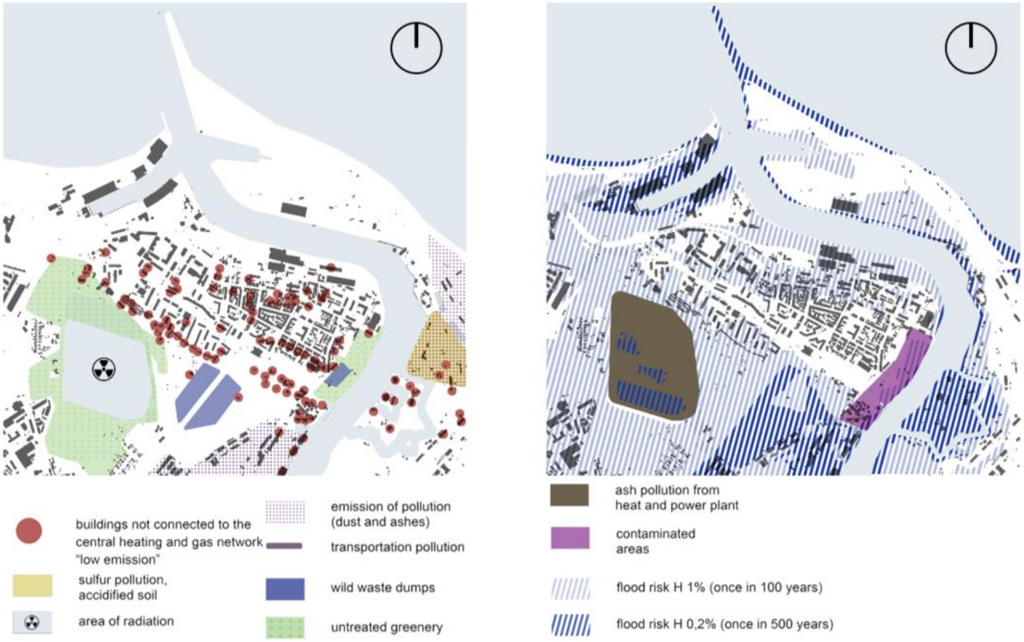
Figure 2. The main environmental Hazards in Nowy Port



Source: Authors' elaboration.

Therefore, in the investigation, it was important to indicate how to reduce excessive primary energy use and energy production from non-renewable resources. Such an attitude aimed at limiting natural resource shrinkage, as well as limiting poisoning of the district and the surrounding areas. An important role was also played by the circular economy and recycling regarding both the development and secondary use of energy as well as the raw materials used in the area. This should provide the residents with a healthier atmosphere, understood as fresh air with high oxygenation.

It is a common practice to assess energy efficiency and environmental impact in planning by measuring the energy and exergy performance of a particular building objects (Zhao & Magoulès, 2012; Schlueter & Thesseling, 2009; Reinhart & Davila, 2016). However, there are certain drawbacks associated with the use of this method (Carreón & Worrell, 2018a; Carreón & Worrell, 2018b; Milner, Davies, & Wilkinson, 2012) as it neglects the importance of the surrounding and environmental context. The influence from urban infrastructure, distance from services, and mobility issues are often underestimated in optimization processes (Barrera *et al.*, 2018; Carreón & Worrell, 2018b; Stoeglehner, Neugebauer, *et al.*, 2016; Milner *et al.*, 2012; Hay *et al.*, 2011; Gudipudi *et al.*, 2019). Therefore, in this study, it was decided to apply a research methodology based on the concept of integrated spatial and energy planning *(Stoeglehner et al.*, 2016). The aim was to measure spatial energy efficiency related not only to the buildings, but also to aspects of the surrounding environment, such as location, infrastructure, mobility and energy systems. As a result of this approach, the total energy demand as well as CO2 lifecycle emissions and ecological footprint of the entire urban district was researched. Because of the complexity of urban structures, there are no universal tools for the simultaneous measurement of all factors responsible for urban energy efficiency. Depending on the needs, various programs can be used for research focusing either on measuring the level of environmental impact of buildings or primary energy demand. In this study, it was decided to use the ELAS calculator – Energetic Long-Term Assessment for Settlements and Structures – developed by Stoeglehner (IRUB). This tool allowed not only the total demand and energy of the building complex to be obtained and compared, but also the ecological footprint and carbon emission impact to be calculated.

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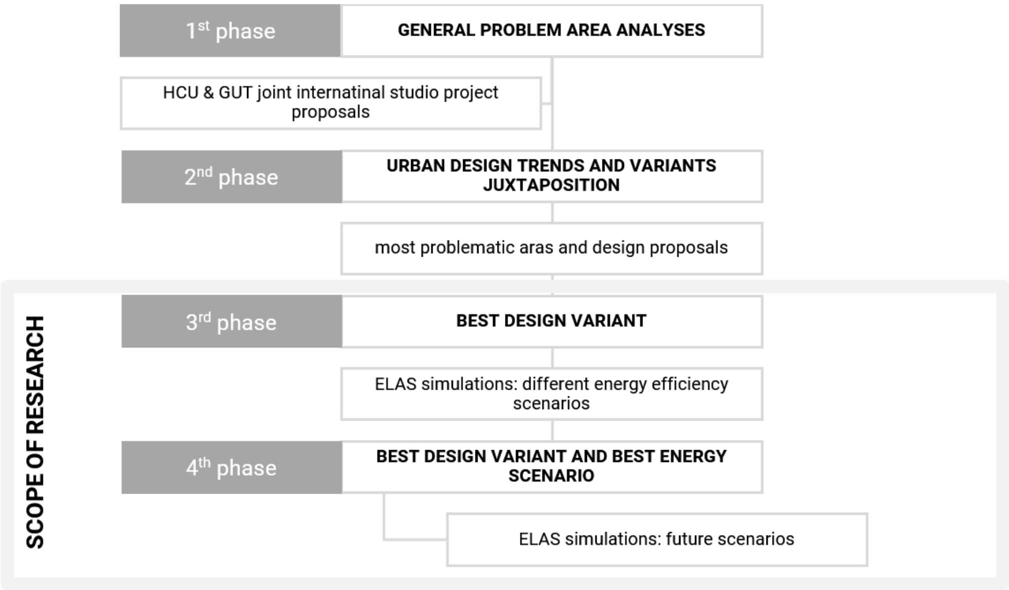
2.3 Design process of integrated spatial and energy planning

A graphical summary of respective research phases and brief methodologies undergone in the research is presented in Figure 3.

Figure 3. Authors' method applied in the research



Source: Authors' elaboration.
Note: Main focus of this paper encompasses 3rd and 4th phases. Diagram illustrating design process of integrated spatial and energy planning and usage of ELAS simulation tool.

- *First phase of the investigation*

In the first phase of the investigation, the scale of the problem was examined, and the most challenging areas were identified. As a result of this in-depth analyses, the decision was made to focus on the area of Nowy Port. An architectural analysis, performed jointly by (Koch & Rost, 2018a; Koch & Rost, 2018b) HafenCity University Hamburg and Gdansk University of Technology students, identified the basic traits of Nowy Port.

These numerous analyzes referred first of all to the aspects of Nowy Port and its surroundings, reconstruction, infrastructure, land uses, development land uses, public life, characteristic local elements and possible design areas. They were described in detail in Atlas 1 "Discovering of Nowy Port" (Koch & Rost, 2018a).

Based on the results from numerous analyses, the students of architecture and spatial planning from both universities created various urban design proposals as a part of international joint studio. These proposals were investigated and sorted by the major design trends – understood as prevailing planning solutions in the given area requiring special future project approach. The detailed procedure of categorizing and choosing design trends and identifying students' main design proposals was done by the authors and presented in the article (Martyniuk-Pęczek *et al.*, 2018). The most interdisciplinary spatial activities were proposed in the waterfront and port area. Therefore, this area became a focus of further research. Among the proposals of both HCU and GUT students in the waterfront and port areas dominated the housing function and broadly understood environmental activities. A lot of

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emphasis was also placed on services and public transport aspects. Based on these findings and criteria, four design proposals were selected for preliminary testing (Figure 8).

- *Second phase of the investigation*

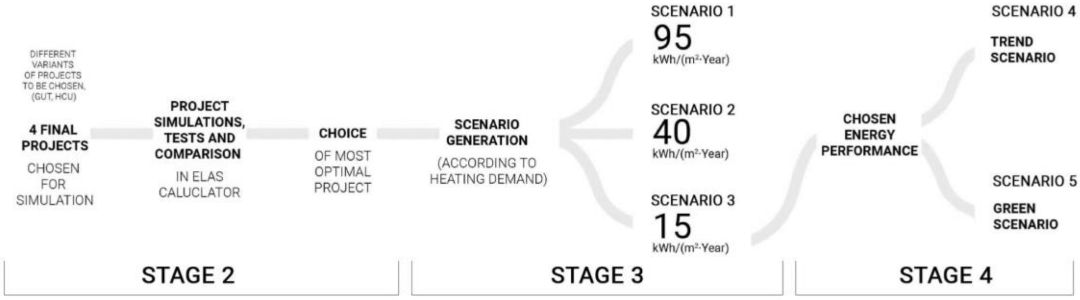
In the second stage, these proposals underwent preliminary calculations in the ELAS program. The goal of this stage was to select the most favorable design variant in terms of urban energy efficiency for further simulations. Therefore, it was decided to adopt a novel method of using the ELAS tool to compare several different design projects and compile their final results. For each design proposal, energy and environmental ELAS simulations were carried out. The preliminary comparative simulations for proposals were carried out assuming the passive building standard for all objects. They concerned total energy demand, carbon dioxide lifecycle emissions and ecological footprint. Then the most advantageous of the proposals in terms of planning and environmental aspects was selected for further simulation.

- *Third phase of the investigation*

In the third phase, the aim was to find the best design variant, understood as a balanced, energy-optimized dwelling and service development that is prepared for potential climate changes. For the most beneficial proposal chosen in second phase, it was decided to conduct scenarios and simulate the results depending on the energy performance standards of the simulated buildings based on standard energy requirements for buildings in the area. (Figure 4.)

It was decided to compare the results of these standard energy efficiency buildings with low energy and passive house standard variants. The passive house standard was chosen as probably most beneficial in terms of energy efficiency and LCA assessment (Kaklauskas *et al.*, 2012; *Energetic Long Term Analysis of Settlement Structures FACTSHEET 1. ELAS-Point of Departure*,). The aim of the simulations was to check how much the energy performance of the urban district is influenced by the energy performance of the buildings. This base on we were able to examine on whether this most likely scenario is also energy efficient.

Figure 4. Scheme of work with ELAS calculator. Stages 2, 3, and 4



Source: Authors' elaboration.

- *Fourth phase of the investigation*

In the fourth phase, two scenarios of future developments were simulated. Therefore, two scenarios for the next 30 years were created. The first one was based on the most beneficial variant from the previous design iteration, in a future scenario without sustainable development (trend scenario), and the second with a future scenario with realized sustainable development goals (green scenario).

The percentage comparison of scenarios conducted afterwards, enabled the most optimal design proposal to be found. All the results from ELAS were provided as an annual per capita result and

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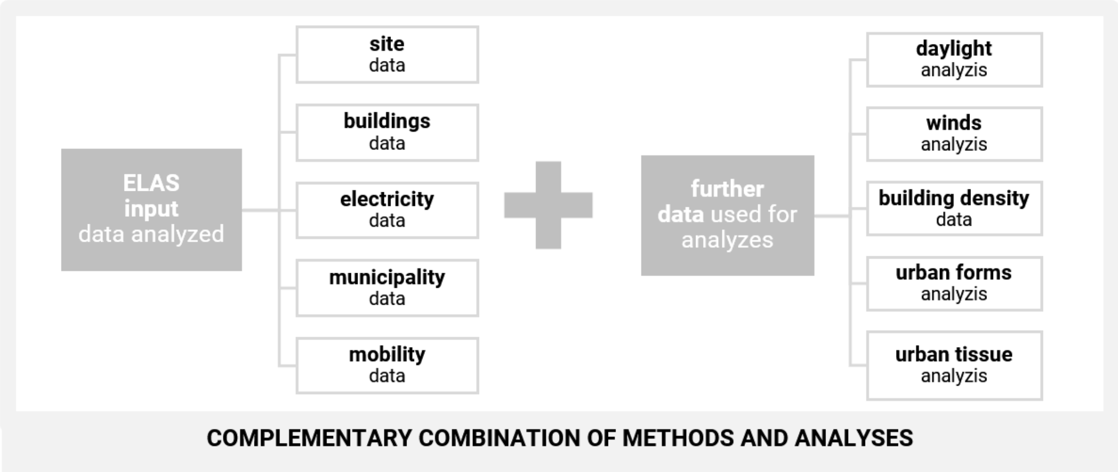
provided the possibility of comparison and taking up decisions concerning the most optimal solution. (Figure 5). Stages 3 and 4 by gathering research material with various projects, showed the most likely design scenario.

Figure 5. Scheme of work with ELAS calculator and additional analyses. Stages 2, 3, and 4. Data included in the fourth phase of the analysis in ELAS



Source: Authors' elaboration.

2.4 Data analyses – ELAS calculator: scheme of work and input data

GIS tools and tools based on empirical models can be used for energy simulations in an urban context. Due to the characteristics of this specific case-based study, the ELAS calculator had the best application. The ELAS calculator (Energetic Long-Term Analysis of Settlement Structures - ELAS-Calculator) (IRUB, n.d.) was chosen as the simulation tool for the second, third and fourth phase. The main reason for using this tool was the fact that it is most appropriate for such a type of project optimization – in terms of adjusting the density, and geometry of the buildings. They enable an objective assessment of energetic performance and environmental impact of a settlement complex in early-stage design. The ELAS calculator is a freely available tool used for calculations of housing structures regarding their energy situation and in particular their ecological performance. It can be used by both scientists and practitioners, as a tool for neighborhood-scale and district-scale energy and climate planning respecting settlements whole lifecycles. Its scientifically documented application for case studies was adopted among others in the European context. The ELAS calculator was used exemplarily in the context of the Austrian self-sufficient district Reininghaus District in Graz (Maier, 2016) and for smart energy communities in Norway (Walnum *et al.,* 2019).

The ELAS calculator measures urban energy efficiency for residential complexes expressed as total energy consumption, ecological footprint (Sustainable Process Index, SPI) and carbon dioxide emissions. In comparison with other techniques, this method had the advantage of respecting not only the parameters of the buildings themselves, but also their siting, infrastructure and mobility aspects along with other parameters of spatial energy efficiency.

This calculator includes interdisciplinary information about the entire building complex and its functioning in the city. The calculations in ELAS considered the overall parameters of the building complex resulting from its functioning in the urban complex. In ELAS calculator they are related to site specific data, buildings and household's data, electricity data, municipality data and mobility data.

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The variable used in calculations was the number of buildings and their cubic capacity as well as the number of inhabitants, their life model and the type of energy used. In order to objectively compare the total energy demand, ecological footprint and CO_2 lifecycle emissions results, the outcomes for the whole building complex were divided by the number of inhabitants. (figure 8) Calibration data was an extensive part of this work due to the multitude of parameters analyzed and the adopted scenario. The main parameters analyzed are contained in the appendix 1. The output data of ELAS calculator are total energy demand, ecological footprint and CO2 lifecycle emissions that are distinguished within detailed categories.

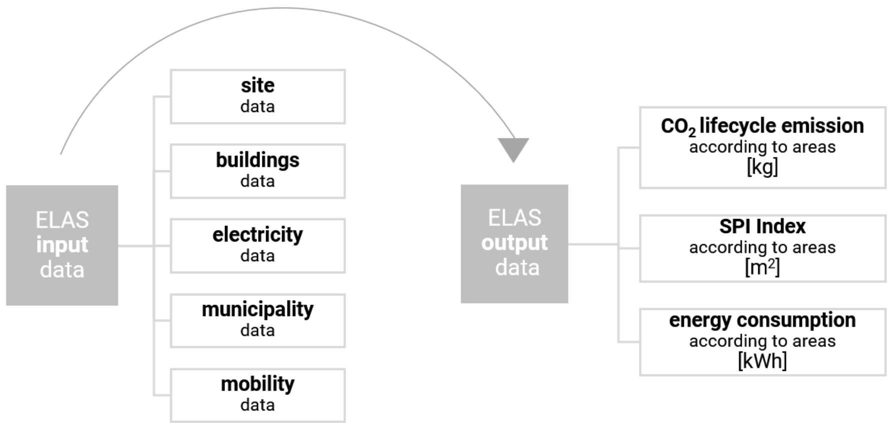
The energy consumption factor in the ELAS calculator was determined as follows. The entire energy consumption value referring to whole building complex and its surrounding was calculated. An input data was embodied energy, room temperature, hot-water, electricity, operation of municipal infrastructure and mobility data. Apart from this, the energy consumption for infrastructure construction was also included, that involved the embodied energy for the construction of the buildings, streets and sewers.

Another factor considered within the ELAS calculator constraints was the Ecological Footprint measured by the Sustainable Process Index, SPI®. In this method, all material and energy flows, which are necessary for a product or service, were converted into areas. Conventionally, this applies to both the production and the use of a product along with the involved emissions. The larger the ecological footprint is, the more harmful it is to the environment.

CO_2 emissions were calculated from the ecological footprint of the case study area. The consumption of fossil resources was taken into consideration for all goods and services and was based on the natural carbon cycle. It is important to note that for the authors of ELAS, the term “life cycle-emission” means that the emissions are not only local in the residential area, but they also affect the global scale. It also refers to the CO_2 emissions of the entire lifecycle of all products, i.e. petrol, insulating material, etc. The mentioned emissions can be specifically attributed to the residential areas.

The schematic way the ELAS calculator works is presented in the diagram below (Figure 6). The purpose of the simulation was to select the most optimal variant in terms of Energy Consumption in kWh, CO_2 Life Cycle Emissions [kg], and Ecological Footprint (SPI) [m^2] regarding the principles of sustainable development and spatial planning. In the case of this project, due to the lack of municipal data for the aim of designing new buildings, it was decided to use the tool in “private mode” instead of “municipal mode”.

Figure 6. Schematic work of ELAS calculator presenting general categories of input and output data



Source: Authors’ elaboration.

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For the simulations and project comparison, it was decided to choose the passive house standard as a possible lowest energy efficiency standard (Kaklauskas *et al.,* 2012; Sartori & Hestnes, 2007). As the numerical values are relative (due to the imperfection of the design tools) a percentage comparison of the results was made. To make the results comparable, in each project the resulting number was divided by the number of inhabitants so that the final outcomes are per capita results.

Alongside Indicators from the building sector – such as space heating, electricity, and municipal services – transportation plays a significant role in urban scale energetic optimizations. Due to the complexity, a standard mode setting concerning transportation was chosen in the tool (In the ELAS calculator, the sustainable mobility mode was chosen based on default values, respecting the importance of walkability, connectivity and accessibility). All data for everyday mobility wass based on an ELAS survey, while data for leisure mobility comes from data provided by Statistik Austria, 2008. Due to the complexity of the study, it would be worth considering investigating transport-related factors in a separate study. In this investigation, the main stress is laid on the construction sector as most crucial in terms of awaiting legislation and climate changes. However, both transport and building performances are complementary and necessary to respect in the planning process. The main categories of input data in ELAS are presented in Table 1.

Table 1. **Main categories and subcategories of input data entered to ELAS tool**

Input data categories	Input data subcategories	Subcategories - further details
Site specific input data	nation	
	information about Inhabitants	-Number of municipality/city inhabitants -number of inhabitants of district
	degree of centrality*	Degree of centrality -distance from to the closest locality providing at least one of the following facilities: Degree 2- Grocery store, primary school; Degree 3- Branch bank, medical specialist, secondary school; Degree 4- specialised shops, high school or vocational school; Degree 5- theater, concert hall, university
Buildings and households input data	buildings structure	-building type and storeys -number of buildings -total living space, -building lot area, -number of households
	residents	-number of residents -residents age pattern -percentage distribution of residents
	energy, space heating, hot water supply	energy carrier for providing space heating and hot water supply: -solar thermal -heat pump, compact heating unit for passive houses -electric heating -district heating (biomass) -district heating (e.g. gas, waste incineration, fossil oil) -natural gas -heating oil
	Space heating (annual values)	-energy rating -total space heating demand -hot water supply -hot water demand per person -total water demand
Electricity	Electricity	-electricity demand of households: -of that, used for space heating and hot water generation: -number of kwh electricity provided from renewable resources
Municipal Services and infrastructure	Road Network – internal development	-municipal road -country road
	Road Services	-road cleaning -mowing and trimming -snow clearance -sanding

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		-snow pole setting
	Street lighting	-street lighting in the settlement -total electricity consumption: -number of lamps:
	Sewage Treatment	-total annual waste water -connection to sewer line -sewage treatment of the settlement is performed -technology is applied in the sewage treatment plant -the length in km of the sewer line between the settlement and the -sewage treatment plant -the energy consumption of the sewer pumps (if installed) for the -- -settlement per year
	Public solid Waste Collection	fractions of solid waste are collected by waste disposal companies or are collected at disposal points that may be reached by walking (residual waste, bio-waste, plastic, used-paper, tree clipping, lawn clipping, bulky waste) waste collection points - distance
Mobility	Everyday mobility	means of transport:
	Vacation mobility	pedestrian / moped / motor-cycle bicycle / car electric bike / hybrid car train / commuter train / electric vehicle tram / metro / e85 car bus / natural gas car bio-gas bus, trolley bus / bio-gas car,

Source: Authors' elaboration based on (IRUB).

3. Results

3.1 First phase investigation results

The detailed analyses conducted in first phase confirmed the location of Nowy Port as a crucial place for future redevelopment. The detailed information concerning initial design analyses can be found in Atlas 1 (Koch & Rost, 2018a) and Atlas 2 (Koch & Rost, 2018b), which are based on general analyses of Nowy Port by the collaborative project of HafenCity University Hamburg and Gdansk University of Technology.

Figure 7. The results from preliminary analysis and development directions of HCU and GUT students. Area of Władysław IV Basin

Source: Koch, Rost, 2018a.

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The figure 7 present respectively predominant functions in Nowy Port district along with new project suggestions indicating design development directions based on the collaborative workshops of HCU and GUT students.

Founded on a juxtaposition of design trends conducted in the second phase, it was concluded that waterfront areas were of particular interest. This was related to the potential of transformation of post-industrial areas and giving them a new meaning as well as fulfilling the possible function of spatial integration of these areas with the rest of the district. In addition, this area was characterized by the existence of very favorable factors in terms of location. Its assets included, among others, a unique entrance to the port and proximity to nature (Brzeźnieński Park, Gdańsk Bay) along with well-developed public transport and tourist attractions.

An area of interest from the point of view of potential future development was the Basin of Władysław IV. Considering the political and functional changes of this industrial area, it is probable that it will become vacant in the future. Furthermore, there is the possibility that the military base in the west of Nowy Port will no longer be used militarily if the political situation in Poland changes. Thus, the land would be ready for further development.

If the waterfront areas are going to be vacated by a possible relocation of the port industry, this shift will result in increased potential for land development. Accessibility to the water will play a central role here, which was previously limited by the industrial areas. The newly created waterfront locations will also offer new opportunities for uses that were previously unavailable in Nowy Port. It is also worth noting that these areas, especially the surroundings of the Władysław IV Basin, are characterized by above-average conditions as a green buildings' location. There is practically no shading there, and thanks to the prevailing west-east winds and the proximity of water reservoirs, there is the possibility of providing air circulation to the buildings. In addition, the proximity and accessibility of the infrastructure and the transport network that has broken down reduces the possible costs of reconstruction and creates the possibility of building a sustainable development complex.

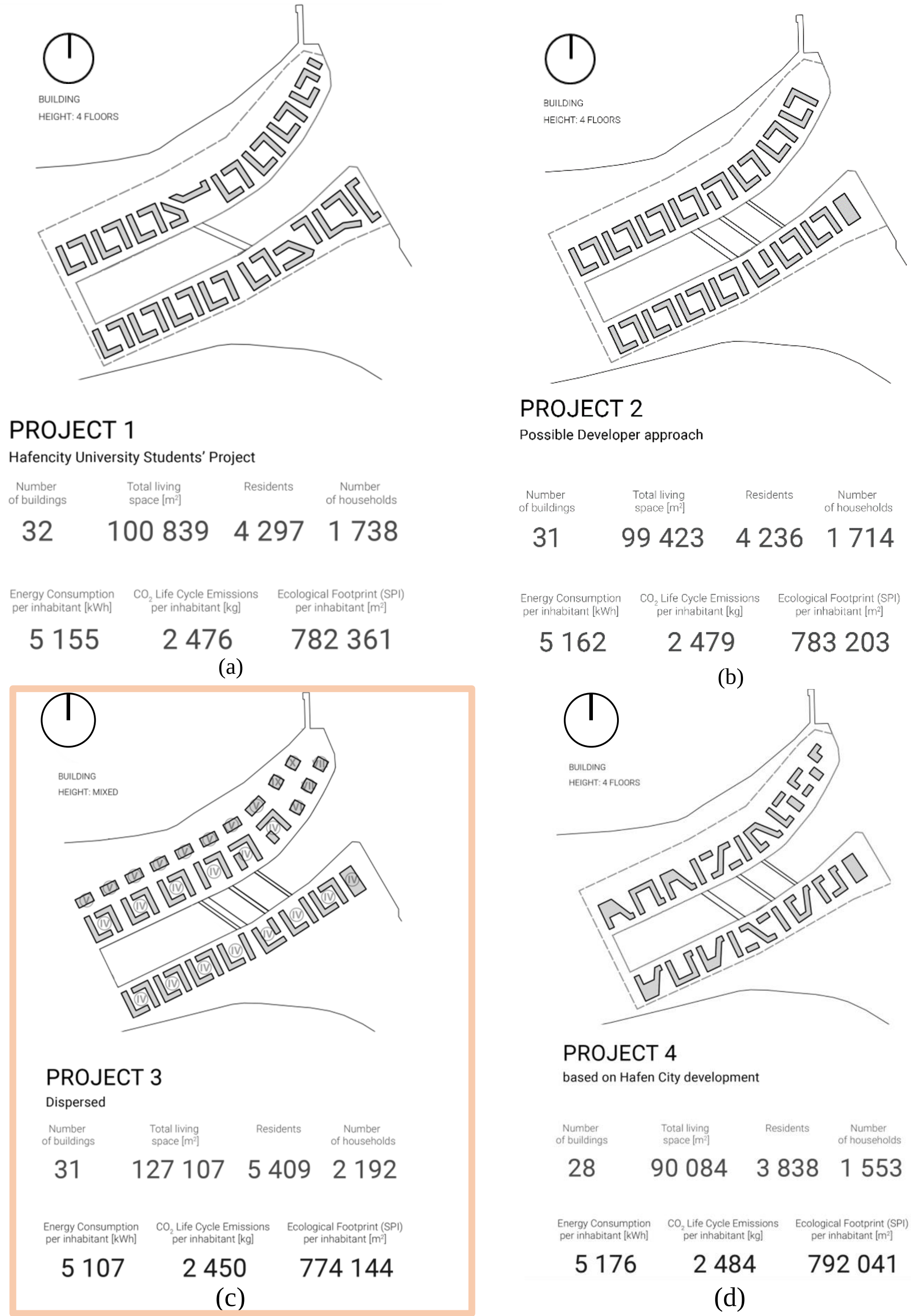
For these reasons, it was decided to focus on the Władysław IV basin as the most beneficial project for the test area. The further steps were based on activities related to optimizing the project proposed by the students in this area, as well as the development of several alternatives, and comparison of their characteristics by means of energy simulations.

3.2 Second phase investigation results

According to the initial assumptions, further steps of the research included the analysis of the urban structure proposed by the students of HCU and GUT. In this phase, the student design proposals were analyzed. On their basis, the authors prepared four different projects of a building complex for simulations in ELAS (Figure 8).

The tested building complex was located in Gdańsk, Nowy Port, the Basin of Władysław IV, in the first climate zone of Poland. Although the ELAS tool did not consider climate data, it was not needed for this type of study, because all of the building units were in the same location. Information about the climate zone was only useful for drawing up project concepts - at the planning first stage. In designs 1, 2 and 4, a fixed building height has been adopted - i.e., four floors, while in project 3 a different number of floors was adopted, the number of floors for each building was marked with Roman numerals in the Figure 8c.

Figure 8. Schematic view of most promising design proposals presenting different variants and their basic design parameters, and output from ELAS calculator: energy consumption, carbon dioxide lifecycle emissions and ecological footprint



Source: Authors' graphical elaboration of design variants and results.
Note: Presented variants: (a) HafenCity University Project version; (b) Possible Developer design approach; (c) Dispersed design; (d) Design approach inspired by HafenCity development.

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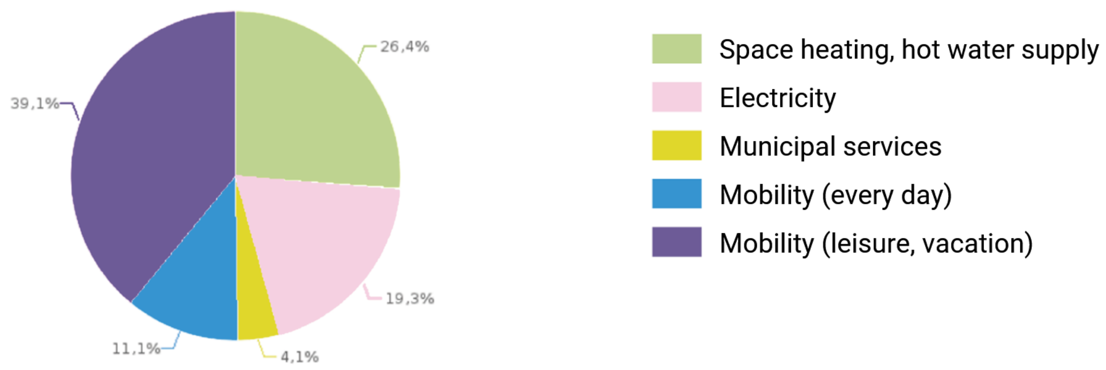
As it can be judged from the final values, most beneficial are projects number 1 and 3. Much worse parameters are present in project 2 whereas the weakest are in project number 4. As the difference between projects 1 and 3 is minor, but project 3 has in turn much more beneficial and interesting spatial values, it was decided to base further project work on this example.

Paradoxically, the variant with the highest building density did not have better energy parameters. The most advantageous variant in terms of energy and environmental aspect, contrary to initial expectations, was not the variant with the lowest building intensity and the smallest number of inhabitants, but the optimized and balanced one (Figure 8.).

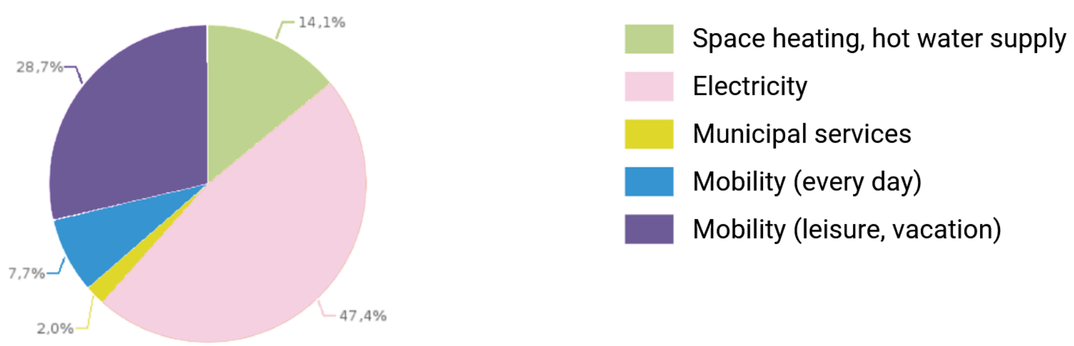
Interestingly, although the values of the results are different in these projects, each of them has an identical share of the percentages of Energy Consumption, CO2 Life Cycle Emissions and Ecological Footprint, as presented in the charts below (Figures 9, 10, & 11). This can be explained by the choice of identical building energy rating parameters (passive house standard with energy rating 15.00 [kWh / (m2 · Year)]), that affect the percentage share in all the categories. This could be also explained by the simplifications made by ELAS tool in setup preset concerning simulated same buildings values.

Figure 9. Energy consumption according to areas – identical for Projects 1, 2, 3 and 4. Percentage results were identical for all project variants 1, 2, 3 and 4



Source: Authors' elaboration.

Figure 10. Percentage chart for carbon dioxide lifecycle emissions – results according to areas. Percentage results were identical for all project variants 1, 2, 3 and 4



Source: Authors' graphical elaboration.

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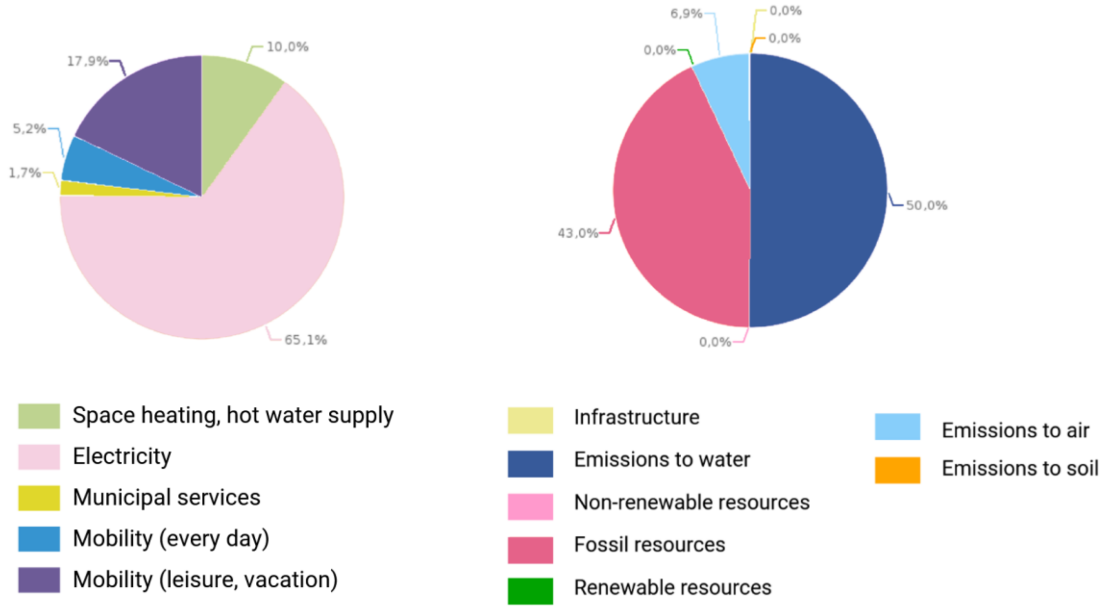
Figure 11. Percentage chart for ecological footprint – results according to areas. Percentage results were identical for all project variants 1, 2, 3 and 4



Source: Authors' graphical elaboration.

3.3 Third phase investigation results – analysis dependent on building energy rating

The final outcomes of the research include the results of scenario simulations for the best design solution. Numbers and percentages representing respective scenarios are shown in figures 9, 10, 11. Figures 12 and 13 present data of third and fourth research phase – ELAS simulation.

Figure 12. Simulation results and calibration data for final design proposal (Project 3). Stages 3 and 4. Authors' elaboration

3 RD STAGE RESULTS			4 TH STAGE RESULTS	
SCENARIO 1 standard energy efficiency* *Standard energy efficiency building model present in the district	**SCENARIO 2** low energy standard Building Standard: low energy	**SCENARIO 3** PH standard Building Standard: Passive House	**SCENARIO 4** trend scenario PH Trend scenario based on current estimates for the areas electricity provision and mobility	**SCENARIO 5** green scenario Green-Scenario (energy efficient) models - more conscious use of energy and resources
building heating demand: 95 kWh/(m²·Year)	40 kWh/(m²·Year)	15 kWh/(m²·Year)	15 kWh/(m²·Year)	15 kWh/(m²·Year)
Space Heating Energy rating 95 [kvWh/(m²·Year)] Total space heating demand: 12 075 165 [kWh/Year]	**Space Heating** Energy rating 40 [kWh/(m²·Year)] Total space heating demand: 5 084 280 [kWh/Year]	**Space Heating** Energy rating 15 [kWh/(m² · Year)] Total space heating demand: 1 906 605 [kWh/Year]	**Electricity:** 2,2 % increase per year Change of the electricity provision mix	**Electricity:** Decrease of total demand by 33 % 100% eco-electricity (from hydro power, biomass, wind)
Electricity demand of households: 5 308 632 [kWh/Year] of that, used for space heating and hot water generation 376 259 [kWh/Year]	**Electricity demand of households:** 5 308 632 [kWh/Year] of that, used for space heating and hot water generation 225 815 [kWh/Year]	**Electricity demand of households:** 5 308 632 [kWh / Year] of that, used for space heating and hot water generation 157 432 [kWh / Year]	**Mobility:** Increase of total milage of every day mobility by 25% Increase of bio-gas cars (to 10%) and electric vehicles (to ca. 15%)	**Mobility:** Increase of total milage like in Trend-scenario (25%) Bio-gas cars (70%) and electric vehicles (30%) provide individual mobility Buses run exclusively on bio-gas

Source: Authors' graphical elaboration.

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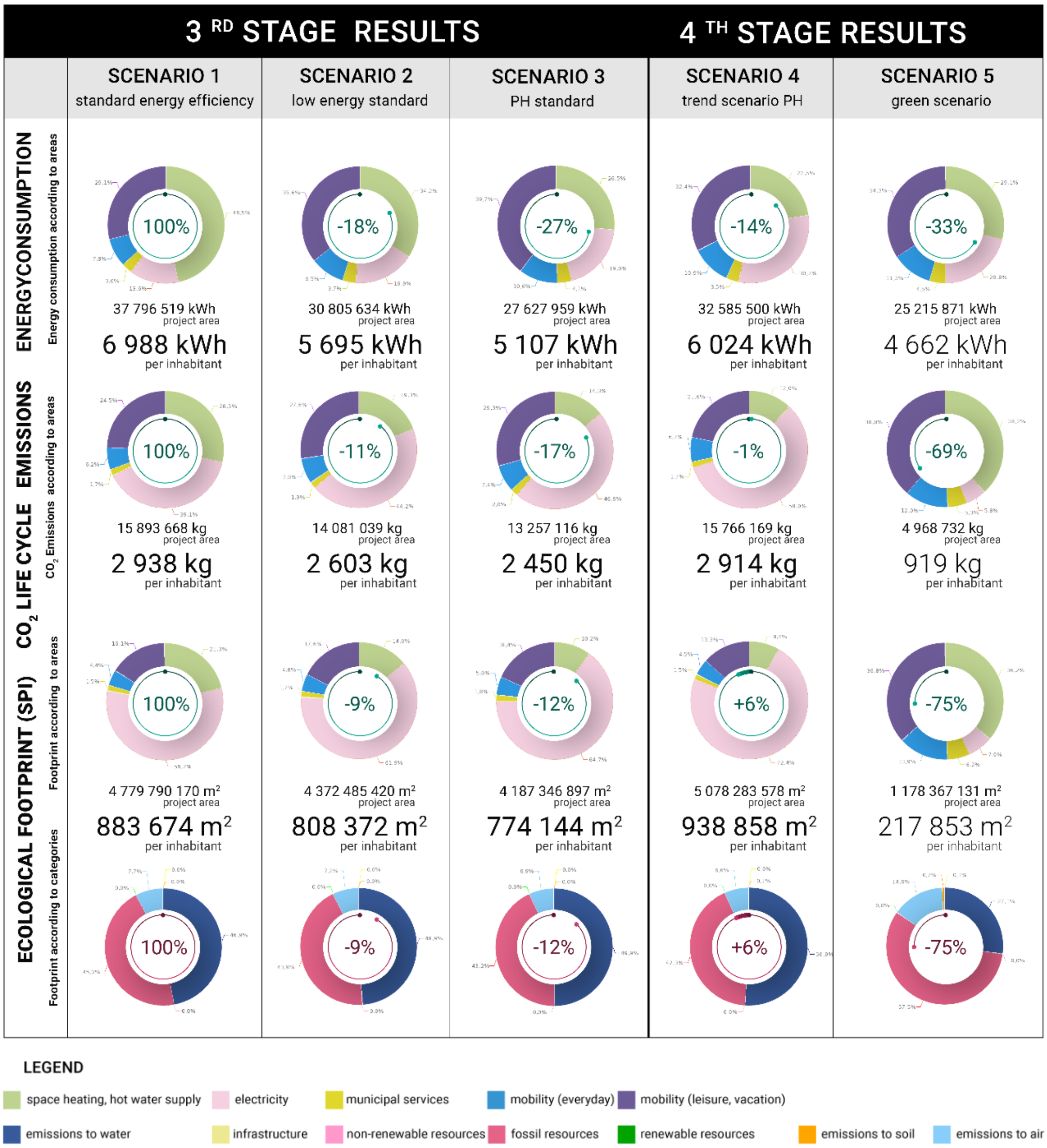
Figure 13. Results from 3rd and 4th stage of investigation for final design proposal (Project 3). Detailed data for each energetic scenario with results according to areas: energy consumption, carbon dioxide lifecycle emissions, ecological footprint



Source: Authors' elaboration.

- *Scenario 1 – Standard energy efficiency*

Scenario 1 presented the standard energy efficiency model already present in the district, that is, of an energy rating for space heating of 95 [kWh/(m2·Year)]. As the calculations for the district showed, total space heating demand was 14 217 984 [kWh/Year] and electricity demand of households: 5 231 673 [kWh/Year], of that 6 120 000 [kWh/Year] is used for space heating and hot water generation. This scenario is also characterized by the highest carbon dioxide lifecycle emissions and one of the highest ecological footprints. As it could be predicted, this is the least favorable scenario, but it reflects the

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current situation in the existing structures in Nowy Port. In order to compare the data, the value of the seemingly least ecological solution – scenario 1 was assumed as the basic one – 100 percent of the value.

- *Scenario 2 – low energy standard*

Scenario 2 presented the standard energy efficiency model which can be achieved in the district if low energy-construction is implemented, that is, an energy rating for space heating of 40 [kWh/(m2·Year)]. As the calculations showed, there is a decrease in total energy demand of 18 percent in comparison to the first scenario, despite decreasing heating demand by more than 50 percent. From the charts, it can be observed that despite the application of the recommended low energy standard, the reduction of energy consumption is not radical. Also, the reduction of carbon dioxide lifecycle emissions and ecological footprint is only slight. It is respectively 11 and 9 percent lower than in scenario 1.

- *Scenario 3 – Passive House standard*

Scenario 3 presents the standard energy efficiency model which can be reached in the district if passive house construction is implemented, that is, an energy rating for space heating of 15 [kWh/(m2·Year)]. The almost 30-percent reduction in energy demand confirms the legitimacy of using the passive construction standard. The reduction of CO2 lifecycle emissions and ecological footprint is also visible by respectively 17 and 12 and percent.

3.4 Fourth phase investigation results -investigation of different scenarios dependent from chosen energy performance

- *Scenario 4 – Trend scenario Passive House*

The trend scenario was based on the ELAS authors' methodology. It estimated for the areas' electricity provision and mobility and most beneficial passive house standard construction. It assumed the same energy parameters as for passive construction – that is, 15 [kWh/(m2·Year)] and in terms of electricity consumption, a 2.2 percent increase per year along with a change of the electricity provision mix. In terms of mobility, an increase of total mileage of everyday mobility by 25 percent together with an increase of bio-gas cars (to 10 percent) and electric vehicles (to ca. 15 percent) was simulated. The unsettling part of this trend is the fact that the results are even worse than in scenario 3, that should be an early warning to alter attitudes and strategies referring future development.

- *Scenario 5 – Green Scenario (energy efficient) models – more conscious use of energy and resources*

The green scenario, also suggested by the ELAS authors, was the most balanced and ecological vision for future development. In terms of electricity consumption, it assumed a decrease of total demand by 33 percent together with 100 percent eco-electricity (from hydro power, biomass, wind). Regarding mobility, an increase of total mileage like in trend-scenario was simulated (by 25 percent). Moreover, bio-gas cars (70 percent) and electric vehicles (30 percent) were foreseen as providing individual mobility. Buses were simulated as running exclusively on bio-gas.

As expected, it proved to be the most beneficial scenario for Nowy Port district. Compared to the first scenario, it included 33 percent decrease of energy consumption, 69 percent decrease of carbon dioxide lifecycle emissions, and 75 percent decrease of ecological footprint. Thanks to the change in provision of energy, the total share of the particulars areas also changed. Unlike in the rest of the scenarios, most of the energy in the green scenarios was consumed by the mobility sector (leisure and vacation) – not by the electricity one. Although the share of fossil resources increased in percentage, if we multiply it into kilograms or squared meters it is still less than in the previous scenarios. Crucially, the share of the emissions to water is the smallest.

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Unsurprisingly, the most favorable future scenario for the district's development was a combination of the passive house standard with the application of renewable energy sources and more sustainable mobility of inhabitants. As it can be calculated, this approach can bring savings of over one million Euro annually. This information is particularly important due to subsidized housing and not affluent residents predominating in Nowy Port district (Damszel–Turek et al., 2017).

Significant 33 percent reduction in energy demand and a 69 percent reduction in CO2 lifecycle emissions, followed by a reduction in ecological footprint by 75 percent can be observed in scenario 5, compared to scenario 1. Regarding current electricity prices in Poland (for the May 2020) with 1kWh costing approximately 0.55 PLN (~ 0.13 Euro), the difference in energy consumption between the most favorable (scenario 3) and a less favorable scenario 1 is over 10 GWh per year. For the proposed district for 5409 inhabitants it translates into financial difference of 5.61 million PLN (~1.28 million Euro) per year

The scenarios (trend scenario and green scenario) showed that energy and environmental results improve when more stringent building energy performance standards are applied. However, the greatest impact on the final results proved to come from other urban factors related to the lifestyle of the residents – connected with mobility and energy generation method. This confirms the theses of other researchers(Hoes et al., 2009), (Young & Steemers, 2011) demonstrating the importance of user behavior in the assessment of building energy consumption. This research demonstrates that user behavior also plays key role not only in the assessment of total architectural energy consumption, but also urban energy consumption.

The most striking result to emerge from the scenarios were the results of the trend scenario (scenario 4). It showed the potential future functioning of the building complex in the perspective of 2050 with a non-ecological way of future development. This scenario demonstrated that despite the application of restrictive building energy standard and several urban scale optimizations, in a situation where the residents do not change their lifestyles, do not reduce the electricity demand and do not turn to renewable energy sources in all sectors, the results will be apparently worse even more than in any other unecological scenario. In trend scenario, the final ecological footprint results evicted to be visibly worse even if compared to those of ordinary energy-saving standards- like in scenario 1.

4. Discussion

4.1 Caution regarding interpretation of results

In the context of previously performed energy simulations, it is worth paying attention to imperfection of energy performance simulation tools in planning. The main difficulty with the simulation tools available is the lack of complexity – in the case of the ELAS calculator, it does not consider the building in terms of cardinal directions, solar irradiation and winds (which require very accurate and complicated calculations in the field of thermodynamics). Therefore, other parameters should also be analyzed and calculated separately. This will probably require an interdisciplinary collaboration of planners with other specialists to obtain possibly objective and precise results.

In addition, the inaccuracy of the result may also be affected by the lack of considering the height of individual buildings and the lack of the possibility to introduce a complex of buildings as mixed use – i.e. with services on the ground floors and dwelling on higher floors. Therefore, given the simulations for this investigation, the focus was laid primarily on comparing the proportions and percentage share

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of individual variants, more than on exact numerical values. It was sufficient to obtain preliminary information on the appropriateness of project decisions and to take preliminary, conceptual steps.

The ELAS calculator has no option of including in its calculations any elements of greenery and the authors focused only on other dependent variables indicated by ELAS tools (see fig. 6 and Table 1). The authors keep in mind that the application of greenery may change the final results and may have positive effect on energy performance of building complex having “natural isolation” function in cool temperatures and adiabatic cooling in hot weather.

4.2 Future development

As a result of the research, the urban design workshop was changed and now, when choosing the urban structure, the form and function analyzes for energy optimization should also be prepared first. The subject of integrating energetic aspects in urban planning definitely needs further studies and development, especially in the context of the creation of available simulation tools for architects and planners, education at all levels along with technological advancements. However, the proved importance of early-stage design optimizations should be the easiest way in achieving them. Therefore, the future interdisciplinary approach to planning from the very initial phase is inevitable.

Any other researcher or designer, after reading this article, may notice the usefulness of optimization tools and start using them at the first design stage. In the article it is not said that ELAS is the only advised tool so each designer can search for his own according to individual needs. It is important to start thinking about this problem and to test various scenarios already at the early design stage. It was demonstrated through the usage of urban design scenarios that energy optimization should be one of the first elements of design analysis and decisions.

In terms of urban development, it is also crucial to think ahead and respect the consequences of our current project decisions and lifestyles in future prospective changes. Therefore, cities worldwide should undergo severe measures aimed at implementing interdisciplinary programs concerning energy and climate action, both at architectural and urban scales. What is still strongly needed is raising social awareness and education to increase the consciousness of the problems we are facing now, and we are going to encounter in the future.

5. Conclusions

5.1 Significant results and conclusions

The results cast a new light on the importance of balanced ecological housing development and its maintenance in the future. Even with excellent energetical parameters at start, the end result parameters referring to whole urban complex can be worsened because of unecological way of development and behavior of inhabitants. These outcomes were proved in trend scenario. Trend scenario showed that despite using restrictive building energy standards such as passive-house standard and many other improvements, in a situation with no change in the lifestyles of residents and the use of non-renewable energy sources, the predicted results will significantly deteriorate. The results in trend scenario occurred to be less favorable even than in standard non-energy-saving design models.

It has been proved that urban design of carbon neutral settlements should not be intuitive when choosing urban tissue, as the energy-related aspects can significantly affect the choice of individual

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solutions. Therefore, solution scenarios were not only evaluated in terms of aesthetics and functionality, but also in an innovative way, assessing the sustainable energy aspects. When the most likely variant was selected in the second phase of this research, in the third phase it was shown that an urban energy optimization analysis is needed.

The research had an innovative approach in two aspects that show the planning process must change and be supplemented with energy optimization in the first phase of design decisions. These optimizations will inform not only about the location, but above all about the spatial connections that have a key impact on the creation of energy-efficient structures. Secondly, the optimization tool, in this case ELAS, was used to compare the results of the designed new building structures in an innovative way. Until now, only individual existing structures were evaluated using this tool. A new possible use of this tool was noticed. The analysis of the results proved that the ELAS calculator is a relevant tool for analyzing urban energy efficiency parameters as well as can be used in an innovative way for comparing various design variant at an early design stage. This approach avoids unnecessary energy consumption and limits excessive carbon dioxide emissions into the atmosphere. Moreover, the approach proposed in this article simplifies the process of planning and optimization of a carbon neutral settlement.

The thesis that urban design in the first phase must also consider energy optimization has been verified by using a multi-level study. The conducted study showed the most likely scenarios approaches – commonly adopted by urban planners in the design process. This scenario was used to search for the urban scale elements that most influence energy optimization in early stage design phase. It is these elements that are crucial for others to continue and learn from.

The key finding are the identified urban scale elements that most influence energy optimization in early stage design phase. In the context of trend scenario energy consumption, the key elements influencing the final parameters in greatest extent were electricity consumption followed by inhabitant's mobility (mostly for leisure and vacation). Visibly smaller share was represented by heating demand. This demonstrates the need for optimization not only limited to a proper energy efficiency in building scale, but also in other categories. It is usually acknowledged that energy consumption in buildings in the largest part falls on heating and cooling. Considering urban factors, it turns out that with typical energy-saving design scenarios (scenarios 2, 3, and 4), aspects related to electricity consumption and mobility of residents also achieve the high percentage in final calculations. Only in the idealistic green scenario (scenario 5) the proportions between individual main categories: heating, mobility, electricity was evened and their final numerical values were significantly reduced compared to previous results. It may be a good clue for the future for researchers and designers to focus not only on aspects related to heating and cooling of buildings, but also on issues of electricity and mobility of residents while reducing energy demand. Figure 14 collects all the steps undertaken in the research and may constitute a recommendation for planners. This figure illustrates the constant need for continuous monitoring of energy optimizations.

The study also showed that the most likely design variant or with highest intensity or density will not always provide us with the optimal solution, as it was proved in the second stage of the study. Currently, the knowledge is well developed in terms of energy efficiency at the scale of individual buildings, but still deficient in terms of whole building complexes. What is probably most needed right now is a more holistic approach including all aspects of building complexes. For this reason, fundamental research about the relations between energy consumption, energy supply and residents in respect of mobility and lifestyles should be one of the main goals for future investigation. Based on the results from this investigation, the apparent conclusion is that the inhabitants living patterns, expressed in the type and amount of energy provision and mobility habits, along with building energy efficiency, can be one of the most important factors. They refer both to the type and efficiency of the building someone lives in, and their daily and long-term habits referring the type of transportation used.

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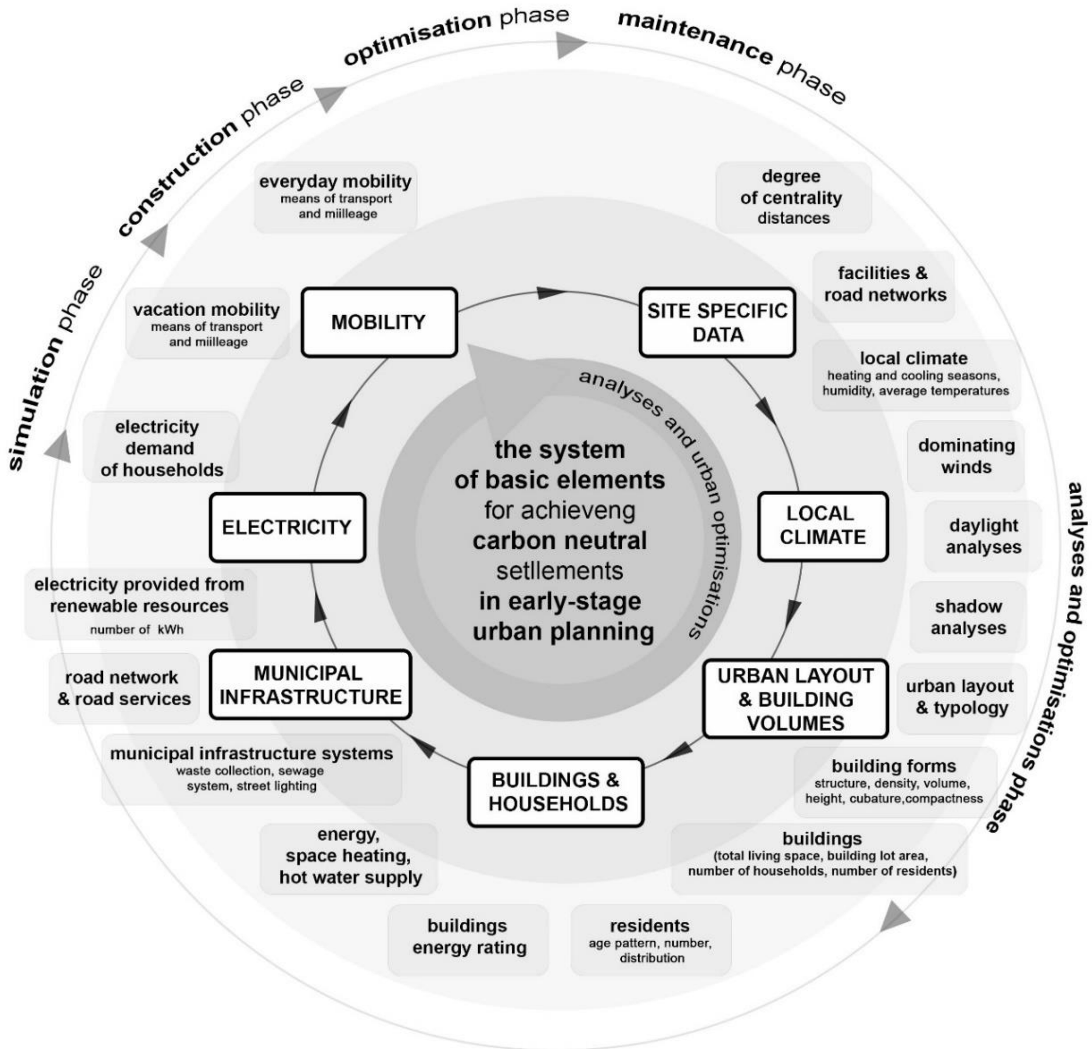
Figure 14. Steps for achieving carbon-neutrality in early-stage urban design: the urban scale elements that most influence energy optimization in early stage design phase"



Source: Authors' elaboration.

However, the most prominent and meaningful aspects are those referring to urban scale optimizations of a dwelling complex. The most remarkable result to emerge from the research is that urban optimizations conducted in the early-stage design phase may distinctly improve the results of energy consumption, carbon dioxide emissions and ecological footprint, respectively, by 33, 69 and 75 percent (scenario 5) in comparison to the standard planning approach represented by scenario 1. The investigation proved the hypothesis on the importance of early-phase design optimizations, which resulted in significantly improved final parameters. Such kinds of improvements can be identified not only by percentage, but also directly calculated as economic benefits. The difference between the most beneficial planning scenario and the worst one is ca. 12.6 GWh annually, which can be expressed as 1.1 million Euro savings annually (current state for May 2020). Therefore, working on balanced design models can lead to carbon neutral development of future cities. The reduced energy consumption and environmental impacts which were proposed in scenario 5 are possible to achieve and lead to decreased pollution and a reduced negative impact on the natural environment.

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To a large extent, the designers are also responsible for the issues of ecological footprint and carbon neutrality. The planners directly influence them by selecting the urban parameters, location, geometry and orientation of the buildings as well as the materials and construction technologies. Although the results were conducted at a local scale, quantitative measurement was used, so repeatable research is possible in other contextual conditions. The percentage comparison of final outcomes enabled comparison between scenarios and can be imaginable also in other locations. Nonetheless each of the design plots should be treated individually, so such results will never be fully transferable and will need certain local adaptations.

User behavior is also crucial in the energy assessment of the dwelling complexes. The study confirmed the theses of other researchers regarding the importance of behavior and ways of obtaining and saving energy by individual residents. Research has shown that individual lifestyles are key both in architectural and urban evaluation of energy consumption.

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Authorship

Conceptualization, and methodology the first and second authors; software, second author; formal analysis, first and second authors; investigation, resources, and data curation, second author; writing-original draft preparation, second author; writing—review and editing, first and third authors; visualization, second author; and supervision, first and third authors.

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