Serious game for modelling neighbourhood energy supply scenarios

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Abstract. Scientific evidence suggests that in developing neighbourhoods, which are under-serviced by centralised energy distribution grids, the reasonable solution is a mix of grid and off-grid energy provision, as well as a mix of fossil fuels and renewable energy sources. The assumption shapes a theoretical foundation for a serious game, Energy Game, which emerged as a result of an international interdisciplinary student collaboration. The aim of the Game, on the one hand, is the simulation of user behaviour choosing between various energy options based on their cost efficiency, and on the other hand, the education of design and engineering students, as well as other interested parties, about neighbourhood energy production and delivery. The outcome of the Game represents a distribution of various energy options across the neighbourhood, and may potentially inform planning decisions about neighbourhood energy provision. The results of game sessions with students indicate the viability of the Game for education, energy demand and supply modelling, as well as highlighted the requirements for enhancing the playfulness of the Game and, apart from costs, the need to include the environmental impact of energy provision options into game mechanics.

Abbreviations
DES - distributed energy systems; DH - district heating; DHW - district hot water; FF - fossil fuels, GHG - greenhouse gases; GSHP - ground source heat pump; LCA - life cycle assessment; LCC - life cycle costing; MG - micro-grids; NG - natural gas; RES - renewable energy sources.

1 Introduction
The share of DH in EU is 10 percent, with uneven distribution across the member countries [1]. In Northern and Eastern Europe DH is a default option in urban environment, with 60 percent of households in Denmark and 90 percent of residents in Finnish big cities living in district-heated buildings [2,3]. In Central and Southern Europe DH is almost non-existent, and residential buildings are heated with off-grid devices, such as condensing hot water boilers, wood stoves, GSHP, etc. [1]. In contrast to heating, electricity in EU (and in Western developed economies) is produced centrally and distributed via nation-wide grids, expanding an exurban environmental footprint [4]. The European
energy mix is heavily dependent on FF, with 58 percent of energy in 2016 coming from oil and natural gas, 13 percent - from RES, and the rest covered by solid fuels and nuclear energy [5].

The policy shift towards sustainability urges EU member countries to cut energy consumption and gradually transition to RES [5, 6]. The policy shift sparked scholarly discussions about the most environmentally friendly strategies for energy provision [3, 4, 7, 8]. Scientific evidence suggests that some energy production options from RES have greater environmental footprint, than those from FF [7, 9], whereas off-grid energy provision options in certain contexts are more efficient in terms of costs and emissions than grid options [2, 3].

Evidence from case studies which contradicts EU policies indicates the inefficiency of universal guidelines for energy issues, and suggests the demand for context sensitive solutions. Ref. [10] demonstrates the potential efficiency of spatiotemporal contextual approach towards energy generation and distribution, whereas ref. [11] highlights the importance of social acceptance of newly emerging energy technologies. The current article presents a serious game - Energy Game, which is an attempt to combine context sensitive spatiotemporal approach with education and experimentation in a playful way. The Game emerged as a collaboration between students in urban planning, environmental engineering and game design from Tallinn University of Technology (Estonia), Riga Technical University (Latvia) and Albert College (Latvia).

The aim of the Game is twofold, on the one hand, the Game educates design (architecture, landscape architecture, planning) students and other interested parties (residents, professional planners, representatives of environmental agencies) about neighbourhood energy supply, on the other hand, the Game simulates user behaviour choosing between various energy provision options based on their cost efficiency. The Game allows free experimentation and exploration of choices and their spatial and financial implications over time. The result of the Game represents a distribution of various energy provision options across the neighbourhood, and may potentially inform planning decisions about energy generation and distribution. The Game is contextualised based on the currently developing Skanste neighbourhood in Riga, Latvia.

The following section of the article discusses the state of the art in scholarly research related to games and energy provision. The third section introduces the context of the case study, whereas the forth section - describes the Game, its underlying assumptions and outcomes. The fifth section discusses the results of game sessions with students. The article concludes with educational and environmental benefits of the game, as well as with its planning related limitations.

2 Theoretical foundations

2.1 Serious games

Originally games were tight to practical activities, namely, to the art of war, e.g. the strategy games, such as chess and go, or the ancient Olympics, where athletes competed in wrestling and chariot racing [12]. In the 20th century with the rise of commercial video games, gaming became associated mainly with entertainment [13]. As a counter reaction to this phenomenon the concept of serious games emerged, which indicates the return to gaming origins [14]. Serious games are characterised by satisfying other goals beyond entertainment, such as education, training or social change [15, 16].

Serious games entered the planning domain in the 1960s, and remain prominent methods for spatial modelling and simulation, as well as for civic engagement [17, 18]. Early serious games, such as CLUG (Allan G. Feldt, 1960s) and Metropolis (Richard D. Duke, 1964), focused on land-use and budgeting issues, and were intended for educating planning students and local government representatives. Later serious games emphasised role-play, dialogue and the development of shared understanding among players, and were successfully applied in the domain of community participation [19]. Today, as the focus of planning policy shifts towards sustainable development and mitigation of environmental footprint, serious games tend to focus on energy transition (Energy Safari by Play!UC,
2016), circular economy (In the Loop by Katherine Whalen, 2016), scenario building for sustainable development (Port of the Future by Deltares, 2016), and similar topics (for the extended database of urban related games refer to gamesforcities.com).

Discussing the factors, which stimulate players to engage in gameful activities, scholars distinguish between extrinsic (external) and intrinsic (internal) motivation [20]. Extrinsic motivation relates to the reward systems, such as points and badges, which are employed in competitive games [21, 22]. Intrinsic motivation relates to non-competitive activities, such as enjoyment from taking part in core activity (e.g. citizen science) [22], learning by doing [23] or the opportunity for experimentation without (undesirable) real-life consequences [24].

The design of serious games is a complex task, which requires the convergence of pedagogy, game design and domain knowledge in a compatible and complementary way [16]. While designing a serious game, ref. [16, p. 1014] suggests “designing, prototyping and play-testing” to check if the game functions as envisioned and, then, iterating back to design and adjusting the prototype accordingly based on the experiences gained from play-tests. Due to the interdisciplinary nature of serious games contributions from multiple experts are often required, resulting into co-design. Co-design emerged within product design and in recent years gained popularity, also, in game design [25].

Co-design with the potential end users is often applied in the early stages of design to provide inspiration for designers or in the late stages — to provide feedback [26]. Involving users during the design process yielded contradictory results, depending on the co-design method employed and the type of users involved [26, 27]. The requirements for co-designer profiles vary depending on the design stage and feedback they are expected to give. In the early stages the expert contributions regarding the narrative of the game are essential, whereas in late stages — potential end user (laymen) contributions concerning the playability, learning and fun aspects are indispensable [26, 27].

2.2 Neighbourhood energy supply

In Europe buildings account for ca. 40 percent of the total energy consumption [1, 7]. In response to sustainability challenges EU developed a set of policies aiming at minimising energy consumption in the built environment applying regulations for newly built or renovated buildings [1]. However, achieving low, zero or plus energy buildings is a challenging task, as the impacts from the built environment surrounding the building may substantially influence its energy performance. For instance, urban heat island effect increases energy consumption for cooling in warmer climates, whereas shading effect in dense neighbourhoods decreases the solar potential of the rooftops [28]. Therefore, ref. [28] suggests to manage energy issues on district, rather than building, level. Furthermore, managing energy production and consumption on district level allows to balance supply and demand between multiple individual buildings, rather than within an individual building, avoiding the oversizing of energy systems, and thus saving the resources [28].

State policies pursue the transition from FF to RES (e.g. Dutch [27] and Danish [2] energy transition ambitions), with the aim to decrease the carbon footprint of the built environment and mitigate the climate change. However, mitigation of environmental impacts related to combustion of FF, such as GHG emissions, ocean acidification and photochemical smog, may increase other environmental impacts, stemming from the production of infrastructure or equipment for certain types of RES, such as the depletion of resources (metals) and human toxicity [9]. The case studies reported in ref. [3, 7, 8, ] support the conclusions outlined in ref. [9].

The LCA of DH systems, which are considered to be more efficient than individual heating systems [3, 7] indicates, that DH has a substantial ecological footprint, with neighbourhood system (CHP plant, trench works, service pipes) and dwelling systems (heat exchangers) being major contributors into ozone and abiotic depletion, acidification, eutrophication and human toxicity [7, 8]. Comparing FF based DH versus GHP in Finnish context ref. [3] concluded that in a long term perspective, from 25 to 100 years, GHP performs better in terms of costs and GHG emissions than DH. Ref. [2] performed similar analysis in Danish context, assuming future DH transition to RES, such as biomass. The
analysis indicated that in the perspective from 2020 to 2060 individual outdoor air and ground source heat pumps perform similar to DH in terms of costs, GHG emissions and fuel efficiency [2].

The review of DES in electricity indicates that a mix of MG and large scale grids contributes to network resilience in case of failures, which is essential in case of crucial city services, such as hospitals, fire and police stations, emergency centres [4]. Furthermore, the proliferation of MG in cities reduces the dependency on energy import, and, hence, an exurban ecological footprint [4].

Taking into account environmental impacts and costs ref. [2] and [7] concluded that the most reasonable solution is the combination of DH and off-grid energy provision devices, with gradual transition from FF to RES in the future. The proportion of grid versus off-grid systems depends on the density and the provision of centralised infrastructure in the neighbourhood [10].

3 Case study

3.1 Planning context

In Riga urban development de jure is controlled by the local government. Master plans for certain areas are initiated by either the local government or the land owner, and are usually developed by private planning offices. Upon completion plans undergo public discussion procedure and, if there are no substantial objections from the public, are ratified by the local government [29, 30].

Centralised utility infrastructure, such as cold water, sewage, DH and electricity is a tool to limit urban sprawl and encourage densification of inner city areas [31]. In the city centre the development of utility infrastructure is substantially subsidised by public money, whereas in the periphery land owners have to finance the utility infrastructure from their own pocket, which leads to proliferation of individual (off-grid) utility devices.

3.2 Energy provision

The area of Riga is well-serviced by DH, NG and electricity grids. The grid energy is provided by three stock companies “Rīgas Siltums” (DH), “GASO” (NG) and “Latvenergo” (electricity). The shares of “Rīgas Siltums” and “Latvenergo” belong to the state and/or the city, whereas the shares of “GASO” belong to private shareholders [32, 33, 34]. Utility network is usually developed in the land which either belongs to or is managed by the local government (e.g. an easement), thus, pipes follow the street pattern.

Thermal and electrical energy for grids is produced by co-generation (electricity and heating) plants; a share of thermal energy is produced by small and medium sized hot water boilers. Co-generation plants operate using hydroelectric power and combustion power from the combustion of natural gas and wood chips. The share of renewable energy in DH and DHW is ca. 30 percent (wood chips), and in electricity ca. 75 percent (hydropower) [33, 35]. In 2014 76 percent of the heat demand in Riga was covered by DH [36].

There is no statistics about the share of off-grid energy devices. There are a few pilot projects, which use solar PV for electricity, solar thermal collectors for hot water, GHP for heating and cooling [36]. A few large companies use co-generation plants operating on gas and/or wood chips, and may operate either in island or in grid modes [36]. Air-to-air and air-to-water heat pumps as auxiliary heating and cooling devices are common in non-residential and industrial buildings, whereas wood chip boilers are common in public and residential buildings [36].

Energy issues are covered by Sustainable energy action plan for the smart city of Riga 2014 - 2020, which uses CO₂ emissions as an indicator for environmental footprint [36]. Neither the Sustainable energy action plan, nor the forthcoming Master plan include spatial dimension of energy production and distribution [36, 37].
3.3 Skanste - urban area in focus

Although Energy Game can be adapted for any neighbourhood, current version is contextualised based on 228.4 ha large Skanste neighbourhood (Riga, Latvia), which has been under development and, hence, in the spotlight of public attention since the mid-2000s (figure 1). Until 20th century Skanste was a livestock pasture and garden area. In the 20th century a cargo railway and a hippodrome were added. Currently, the area is a mixed use area, dominated by housing, offices and large brownfield areas. Local government has designated the area as a priority development [31] and commissioned a master plan for the area, which was ratified in December 2017. The master plan [38] envisages public functions (or anchor objects), such as a transportation hub, museum of modern art, concert hall, international conference centre and alike.

The south-east fringe, which borders housing areas, is well developed and supplied with DH, NG and electricity grids. The north-west fringe borders industrial areas and houses rail-yard and some industrial buildings. The street pattern of the area is underdeveloped, and the energy grids either do not exist or their pattern and capacity does not suit newly planned functions (figure 2, a, b, c). According to the master plan [38] industrial buildings and the rail-yard are going to be torn down, and the new street and land plot pattern is going to be established. The newly planned land plots are large and belong to a few land owners (which are often developers). The area is supposed to be fully serviced with public utility infrastructure, which follows street pattern, and apart from cold water and sewage grids includes DH, NG and electricity networks (figure 2, d, e, f). Alternative energy provision options, such as off-grid devices or devices operating on RES, are not considered by the plan.

4 Energy Game

In Skanste neighbourhood DH is planned parallel to electricity and NG grids, therefore, newly constructed housing and office blocks have an opportunity to connect to any of the energy grids (figure 2, d, e, f). However, heating can be generated from electricity and/or gas, and gas can provide electricity and heating. Furthermore, electricity and heating can be generated locally, using off-grid devices. Thus, it is unnecessary to develop extensive DH, electricity and NG grids parallel to each other within one neighbourhood. The underdeveloped DH, electricity and NG grids, as they are now (figure 2, a, b, c), are already excessive, as some segments of these grids remain unused or used only partially. For instance, existing housing development in the south-east fringe of the area has the

Figure 1. Skanste neighbourhood in the city context (author; Bing Maps © 2019 Microsoft).
Figure 2. Existing DH (a), NG (b) and electricity (c) grids (author based on [38]); planned DH (d), NG (e) and (f) electricity grids (author based on [38]); in-game mix of grid and off-grid energy production and distribution devices for heating (g, h), electricity (i, h) (author).
opportunity to connect to either DH or NG, but is connected solely to DH. Therefore, existing NG grid in the south-east fringe is unused (figure 2, a, b, c), and will, probably, remain unused in the future, as the structure of the buildings does not allow connection to NG without major reconstruction.

The excessive provision of energy grids stems partially from local government strategy, which recognises centralised energy production and distribution via city wide grids as the most efficient and environmentally friendly solution [36]. However, recent research in the energy field challenges this assumption. As already mentioned in Section 2.2, in the neighbourhoods with underdeveloped energy grids the reasonable solution is a mix of grid and off-grid energy systems, as well as a mix of systems operating on FF and RES, with the gradual transition from FF to RES in the future. Energy Game described below is an endeavour to illustrate this statement by means of simulation-gaming approach.

In the Game players take on the roles of developers, who have to buy land plots, built houses and supply them with energy, namely, electricity and heating. If the house is supplied with energy, developers, who are at the same time landlords, earn revenues. Installation of an off-grid device and connection to the grid allow generation of additional revenues by selling energy to the grid. The aim of each landlord is to earn as much revenues as possible. During 30 in-game years (rounds) landlords face additional challenges, such as changes in fiscal policies, fluctuations in energy and fuel market, failures of grids and off-grid devices caused by natural and anthropogenic disasters.

Key assumption of the Game is different from the real-life context outlined in Section 3.1, as the landlords cover the development of energy grids fully from their own budget, without any public subsidies. The connection from an individual land plot to the main energy line (NG grid, DH, electricity) is expensive compared to the installation of an off-grid device (GSHP, solar PV, solar thermal, small-scale wind turbine, etc.), as the former requires an engineering project, trench-works, pipes, pumps, taps and meters. Thus, the prices of land plots vary depending on the distance from main energy lines. The closer is the land plot to main energy lines, the lower is the price of connection, the higher is the price of a land plot (figure 3). Landlords have to balance between the prices of land plots, connections to grids and installation of off-grid devices. The prices of land plots, connections to grids, installation of off-grid devices, revenues from renting out the houses, etc., are based on real-life prices (provided by Maksims Feofilovs).

The Game mechanics potentially limits the excessive development of energy grids and stimulates the installation of off-grid devices. By the end of the Game a pattern of diversified energy provision options emerges, which contains a mix of grid and off-grid devices, as well as a mix of systems operating on FF and RES (figure 2, g, h, i). Figure 2 (h) shows the potential development of the NG grid in the south-east fringe.
grid, which may transition from NG to biogas in the future. The land plots connected to the grid co-generate electricity and heat from gas, whereas land plots disconnected from the grid take advantage of existing DH and electricity grids, or off-grid devices. Thus, a minor extension of the NG grid and installation of off-grid devises fully supplies the neighbourhood with energy, and there is no need for extensive DH and electricity grids.

5 Findings and discussion

5.1 Pen and paper prototype

The idea of the game was initially tested as a pen and paper prototype with a group of design students (architecture, landscape architecture, urban design) during the Baltic International Summer School organised by HafenCity University (Hamburg, Germany) in 2017. The calculations of expenditure and revenues were done manually in Excel sheets, which substantially slowed down the gameplay and decreased the “fun” element, indicating the need for automation.

Pen and paper prototype was tested with students, who did not have any expertise in energy field. Before the game session students were given a brief introduction about the topic and several preparatory tasks: (1) mapping utility infrastructure in Hamburg HafenCity; (2) assessing utility infrastructure risks; (3) finding an image of their dream house. Dream houses had to be placed in suitable urban contexts within the area in focus. Some locations were better serviced with energy grids, than other. Students, who placed their houses close to main energy lines, invested, in the first place, in connections to energy grids, as connection costs and monthly fees were relatively low. After the houses were secured with the energy from the grids, students invested in off-grid energy production devices to diversify the energy supply. Students, who placed the houses further from main energy lines, had no choice, but to invest in off-grid devices, as the costs of connections to energy lines surpassed substantially the prices and installation costs of off-grid devices.

The most popular grid options among students were grid electricity and NG heating, whereas off-grid options were solar PV and windmills for electricity and solar thermal for heating. Students
ignored such options as DH due to its higher costs compared to NG heating, as well as hydropower for electricity and biogas and GSHP for heating due to the lack of knowledge about these technologies.

Due to the slow pace of the gameplay, the game session had only 4 rounds (in-game years). In the short-term (4 years) grid connections were financially more beneficial, than off-grid devices, as the latter required larger initial investments. During the game session there was no opportunity to find out if the off-grid devices pay off in long-term. However, the comparative LCA and LCC analysis of DH versus GSHP performed by ref. [3] suggests, that in 10 years the total costs of DH surpass the total costs of geothermal heat pump.

5.2 Digital prototype

The game was digitalised by a group of Albert College (Riga, Latvia) students in game design from February 2018 to December 2018. The game was developed using Unity game engine for gameplay, Illustrator for two-dimensional and Blender for three-dimensional graphics. The digitalised prototype was presented publicly and tested with students in game design in January 2019.

The digital prototype represents a three-dimensional environment with pop-up windows urging players to perform certain actions, such as buying a land plot, building a house, supplying a house with heating and electricity (figure 4). The digital prototype has three significant modifications compared to the pen and paper prototype, namely, (1) due to scripting considerations the digital prototype is single-player; (2) it includes information about available grid and off-grid options with the description of their benefits and limitations, (3) land plot prices change dynamically, following the extension of the energy network. Figure 5 shows that the price of land plots along the newly built energy line increases.

The digital prototype was tested with students, specialising in game design. The game encouraged students to experiment with grid and off-grid options, finding the best strategy for gaining revenues. Students in game design expressed the need for “fun” elements, such as competition, which requires playing either against a computer or other players, and an appealing, “cartoonish”, interface. Additional challenges, such as changes in fiscal policy and disasters, were represented as a strip of text in the upper part of the screen and reflected in the revenues, and students paid little attention to them. Students pointed out that the challenges had to be better articulated graphically.

The feedback received from students during game sessions generally aligns with studies performed by ref. [20] and [22] who found out that different player groups derive “fun” from different activities. Players who identify themselves as “gamers”, are motivated by the competitive nature of serious games, the gameful part, whereas the non-gamers find pleasure in target activities of serious games, the serious part [20, 22], such as learning, scenario building, interaction with other players, etc.

Figure 5. The dependency between land plot price and the distance from main energy lines (author).
6. Conclusions and directions for further research

6.1 Educational benefits
The purpose of the Energy Game is twofold, firstly, to model the distribution of energy provision options across the neighbourhood depending on the choices made by landlords, and, secondly, to educate students, planners and residents about energy production and distribution. The involvement of students in early game design stages revealed the benefits and the shortcomings of the Game. On the one hand, Energy Game is a viable tool for educating students about neighbourhood energy supply. On the other hand, the Game prototype has to be improved by introducing competitive (or collaborative) elements and new challenges, as well as by developing a more appealing interface.

6.2 Energy and environmental benefits
The preliminary results of game sessions show, that in urban environment in short-term connecting to energy grids is more profitable for landlords than installing off-grid energy production devices. However, in long-term some off-grid devices might be cheaper then DH, which is the most expensive grid option compared to NG and electricity. Diversification of energy provision by including both grid and off-grid options is essential for the objects of strategic importance only, such as hospitals, emergency response centres, etc., where the failures in energy supply might lead to consequences extending beyond the losses in revenues.

In short- and long-term off-grid energy production devices operating on RES have a lower carbon footprint than energy grids, due to the dependency of the latter on FF. With the gradual transition of grids to RES by 2050-2060s the difference between grid and off-grid options should vanish. If carbon footprint indicator is complemented by other environmental impact indicators, such as toxicity and resource depletion, grids operating on FF might perform “cleaner” than some off-grid devices operating on RES.

Current prototype of the Game focuses solely on expenditure and revenues related to energy provision, thus, players are driven mainly by financial considerations, which are reflected in the distribution pattern of grid and off-grid energy options across the neighbourhood. For environmental purposes the Game should, also, include environmental impacts, which might substantially alter the distribution pattern of energy options. Environmental impact might be introduced, e.g. as an environmental tax, which affects the prices and fees related to energy options depending on how environmentally friendly they are.

With financial aspects and environmental impacts incorporated, the Game might serve as a tool for energy provision modelling and assessment on neighbourhood level. The game allows to find and optimum mix between grid and off-grid, as well as between FF and RES based, energy options, which delivers the maximum financial and environmental benefits at lowest cost.

6.3 Limitations
Similar to other simulation games, such as SimCity, Cities:Skylines, etc., the Game contains “black box” bias, namely, game results reflect the assumptions underlying in the game algorithm, which are not necessary true in real-world [39]. Additionally, game results reflect the intentions of player, who might aim for free experimentation and fun, rather than for serious outcomes.

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The author declares no conflict if interests.

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