# SynErGame – Gamified Knowledge Building on Synchronizing Energy Supply and Energy Demand

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**Abstract:** Climate change is one of humanity's biggest challenges. With reference to power grids, there is a strong need for decarbonization alongside for a substantial increase in renewable energy generation. Keeping in mind that renewable energy sources are volatile – solar and wind power are heavily weather dependent – it is necessary to ensure the balance between power generation and power demand in the European power grid at all times. Significant deviations in grid frequency or bottlenecks could lead to a blackout. This raises the need for flexibility in the power grid substantially. An option so far relatively little explored is to make use of industrial demand-side flexibility. With a share in the power demand of about 45 per cent in Germany, industry could contribute significantly to power grid stability. While technologies for industrial demand-side flexibility have been comprehensively explored by the scientific community and (prototypically) implemented in industry, this knowledge has not spread to a broader audience. To foster knowledge on industrial demand-side flexibilization, we developed an approach using a serious game called SynErGame, synchronizing energy supply and demand. Within two game modes, one perspective macro-oriented and the other industry-oriented, a player learns about the benefits and challenges of using demand-side flexibility options to stabilize a power grid. The paper first introduces the topic of flexibilizing industrial power demand. Secondly, requirements are derived and the game design is outlined in detail. Thirdly, the paper shows how to make the game accessible via browser or app on mobile devices, such as smartphones and tablets. During ongoing use, SynErGame has proven particularly effective for audiences inclined to digital technologies, such as students.

**Keywords:** Climate Change; Demand-Side Flexibility; Serious Game

## 1. Motivation

Climate change is one of humanity's biggest challenges. Among the main contributors to climate change are greenhouse gases emitted by burning fossil fuels such as coal, crude oil and gas (European Commission, 2022). In 2015, approximately 190 states signed the United Nations Framework Convention on Climate Change agreement in Paris to meet the challenge of global warming. The long-term agreement goal is to limit global warming below 2°C as compared to pre-industrial values to reduce the risks and consequences of climate change (United Nations, 2015). Consequently, the European Union (EU) derived and updated its energy and climate targets, aiming at least for a reduction of 55% of greenhouse gas emissions compared to 1990, at least a 32% share increase in renewable energy generation and at least a 32.5% improvement in energy efficiency (European Commission, 2014). Member states in the EU still seek to increase these ambitious targets. For instance, by the Climate Protection Plan 2050 and even more by the new Federal Climate Change Act amended in 2021, Germany set the goal to achieve greenhouse gas neutrality by 2045 and foster renewable energy integration for electricity among others (Federal Ministry for the Environment, 2016; Federal Ministry of Justice, 2021). The associated transformation of the energy system into a secure, fair, and sustainable system to meet these targets faces several challenges (Gunningham, 2013). They are reflected in the target triangle of security of supply, energy justice, and environmental sustainability (Bauer et al., 2021). The challenge increases with global primary energy consumption continuing to rise and the need to cover economy and population energy demand at affordable prices. The war in Ukraine very clearly points out this dilemma and underlines the need for a rapid switch to renewable energy sources (Tollefson, 2022).

The integration of renewable energy sources such as wind and solar contributes to higher fluctuations in energy supply, specifically in the power grid. A power grid requires a constant balance between power supply and demand monitored by its frequency (Haes Alhelou et al., 2019; Papaefthymiou et al., 2018). Failing to balance supply and demand provokes deviations in the power grid's frequency beyond its nominal operation limits, as experienced in severe incidents e.g., in 2018 and 2021 within Europe. In 2018, the frequency deviation caused by power deviations in the control area of Serbia induced in EU a six-minute delay in electric clocks, steered by the grid power frequency (ENTSO-E, 2018). In 2021, a higher flow than expected caused an overload in Croatia, resulting in the busbar tripping and, consequently, the split of the continental synchronous area in Europe into two parts (ENTSO-E, 2021). If these frequency deviations had become even greater, the power grid would have threatened to collapse in a so-called blackout with possibly far reaching consequences (Eckert and Eberlein, 2020; Haes Alhelou et al., 2019). These consequences include massive restrictions for all areas of daily life, such as food supplies, health system, and communications infrastructure (Petermann et al., 2011). Hence, flexible demand by modifying the demand pattern based on input signals arises as a complement to traditional solutions. This is meant to mitigate supply and demand fluctuations and is contributing to a stable and reliable power supply (Roesch et al., 2019). Demand Response (DR), a method to synchronize power supply and demand by adjusting power demand, can thus contribute to power grid stability (Murthy Balijepalli et al., 2011; Siano, 2014). Industrial consumers offer substantial potential to contribute to flexible demand, since they account for 25.6% in the EU's and 25.1% in Germany's total final energy consumption as well as 44.7% of Germany's power consumption in 2019 (eurostat, 2022; International Energy Agency, 2022).

Although the concept of DR is key to energy transition and therefore has been intensively explored by the scientific community and implemented (prototypically) in industry, the concept is still little known to the public. To foster knowledge on the topic, we developed an approach using a serious game called SynErGame – synchronizing energy supply and demand. In section 2 of this work, the approach and the design of SynErGame are outlined, followed by its implementation in section 3. Section 4 describes the application of SynErGame. Section 5 summarizes the work and gives an outlook on future research.

## 2. Game Design

To simultaneously facilitate learning and increase the motivation of learners, game-based approaches are suitable. So-called educational games or serious games, for example, show clear signs of typical game design elements and allow for entertaining mentor amusement while also supporting learners in improving skills or understanding new subjects (Abele et al., 2017). Empirical studies have shown that game-based learning approaches achieve higher learning outcomes than the comparatively passive conventional method of frontal teaching (Pivec and Dziabenko, 2004; Prensky, 2003).

Game-based learning approaches are well known and commonly used in manufacturing, especially with lean manufacturing and digitalized manufacturing (Teichmann et al., 2020; Yesilyurt et al., 2019). Regarding the energy sector, there are games on policy issues (Suzuki et al., 2021), renewable energy generation (Ouariachi et al., 2019), and power grid operation (TenneT, 2020). However, these games focus on power supply, while power demand is only considered to a small extent. Therefore, a game-based learning approach is needed focusing on the power demand fostering knowledge on industrial DR.

SynErGame has been developed using an iterative approach inspired by the information system research framework with its inherent cycles (Hevner, 2007). Therefore, developers have worked together closely with domain experts to incorporate their knowledge and experience into the game design next to findings from relevant literature on industrial DR. The first step defines the requirements for the game that were further refined in the course of development. In the second step, during actual development of the game's approach and design, semi-structured interviews of domain experts were regularly conducted, processed, and the results integrated into the further development.

### 2.1 Requirements

The overall target of the game is to foster knowledge on how industrial DR can support the transition to renewable energies as well as the associated challenges. To this end, entry barriers need to be low to appeal to a broad target group. Therefore, the game must be comprehensible without a technical background and without time-consuming preparation. Implementation as a highly platform-independent electronic game allows it to be run on a variety of different devices. In terms of content, the game needs to simplify and illustrate the complex processes and how they interdepend in the power grid and in companies offering DR potential. The game, therefore, aims at the fundamental background, principles, and goals of industrial DR. Players can become familiar with possible changes, effects, challenges, as well as advantages in an appealing manner. By playing an active role in the game, each player learns about the implications and consequences of specific actions at both grid and company level.

### 2.2 Structure and Gameplay

The processes of industrial DR are well described in literature (Papaefthymiou et al., 2018; Roesch et al., 2019; Sauer et al., 2019). However, for a broad audience with a non-technical background, they are way to complex and need to be simplified to make them easy to experience. Therefore, SynErGame is organized in three modules. The introductory module explains the fundamental background, principles, and goals of industrial DR. The explanation is text-based and supported by optional deep-dive videos. To address both technically proficient and non-proficient players alike, the introductory module can be skipped quickly. The two game modules differ in their focal point. The first module focuses on a power grid level with the player being responsible for the power grid's stability in a fictional city. The second module gives the player the responsibility of an entrepreneur to enable economic manufacturing despite fluctuating energy costs. The two modules also represent two different game modes the player can choose from (see Figure 1). Since the basics of industrial DR have been explained in the introductory module, the focus at the beginning of the game modes can shift to a tutorial on how to play the specific game mode. This way, the elements of the game mode are explained, and the player is set up to experience the game.

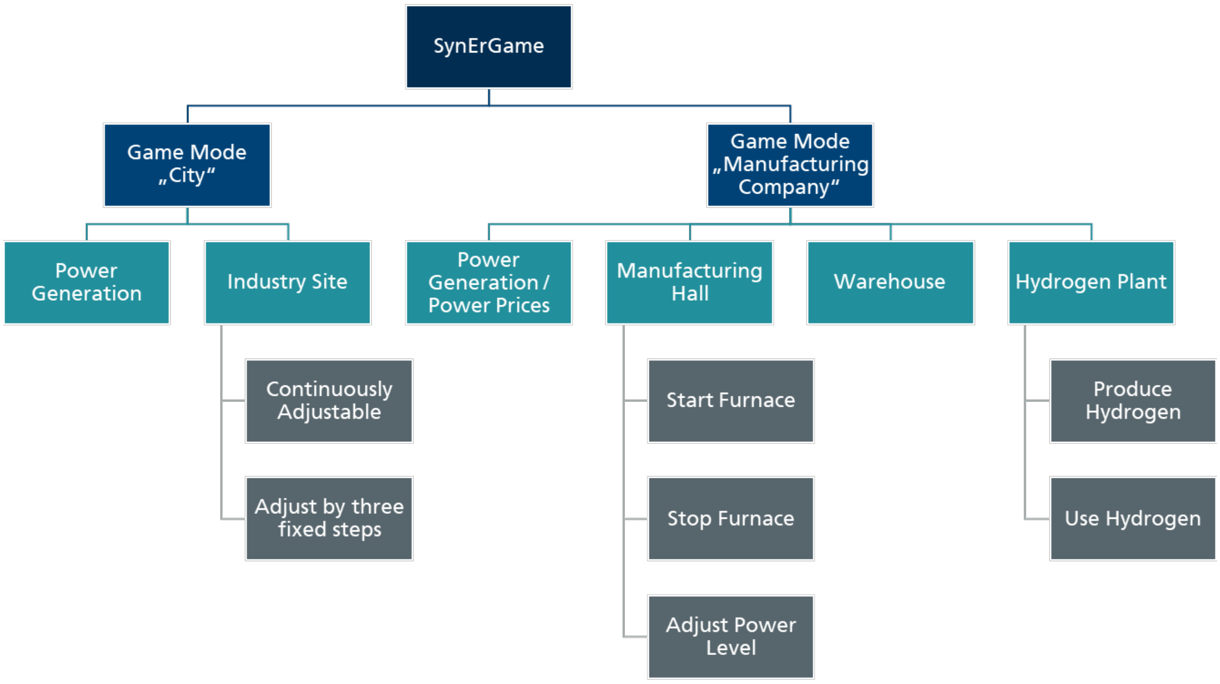


**Figure 1**: Structure of SynErGame including two game modes and respective elements and actions

#### *2.2.1 Game Mode "City"*

The aim of the game mode "city" is to show how industrial DR can contribute to stabilizing the power grid. For this purpose, a fictional city is designed comprising infrastructure, housing, and industry - the power consumers. Furthermore, there is power generation from renewable energies, i.e., wind turbines and solar panels. The gameplay is round-based. At the end of each round, a balance of power generation and power demand is calculated. If these match, the frequency remains the same while the power grid is in balance. The player receives points for this achievement. If power generation and power demand deviate from each other, the frequency of the power grid changes and the player receives penalty points. If the deviations are too significant, the power grid collapses, a blackout occurs, and the game is over. After a selectable number of rounds, the game ends regularly, and the player scores depending on the points won or lost for the power grid's frequency state at the end of each round. Therefore, it is of great importance for the player to observe the grid frequency displayed at any time, as well as the current power generation and power demand.

Being dependent on the weather, the power generation of the wind turbines and solar panels cannot be controlled by the player. However, weather forecasts enable the player to decide whether power demand must decrease or increase in the following round. By decreasing and increasing power demand with industrial DR measures, the player can influence the power grid's frequency. To do so, two industrial DR measures according to VDI (2020) have been implemented and can be triggered by the player using industry sites in the city. One industrial DR measure is continuously adjustable, though affecting the following round. For example, if power demand is increased in the current round, it cannot be further increased in the subsequent round. The second industrial DR measure goes without such dependencies on subsequent rounds but can only be adjusted in three fixed steps. The difficulty for the player is to balance power generation (with its prediction via weather forecast) and power demand (taking into account the characteristics of the different industrial DR measures) at all times. At the same time, this allows the player to experience how industrial DR, even specific measures, affects the frequency of the power grid.

#### *2.2.2 Game Mode "Manufacturing Company"*

The game mode "manufacturing company" aims to show how industrial DR challenges or benefits a manufacturing company's site. It is modelled on a fictional company, manufacturing silicon wafers for semiconductors. As the manufacturing process is very energy-intensive, it is important to maintain the company's competitiveness by using the cheapest possible power in the face of volatile power prices resulting from volatile power generation by renewable energy sources. The gameplay is continuous, and the player tries to use power as cheap as possible to manufacture wafers. The quantity of wafers to be produced in a given period is predefined, and so is turnover. The player may influence the costs at which power is purchased for manufacturing the wafers. Accordingly, the company's profit increases or decreases in inverse proportion to the cost of power. The game is lost when the company's assets are depleted, or its inventory of saleable wafers drops to zero. The game is won if sufficient profit is generated to be able to implement four expansions of the company. The two central tools of the player are, therefore, a graph showing the current power demand of the company and the power price forecast for a certain period into the future, as well as extensive statistics on the company's performance.

At the beginning of the game, the company consists of a manufacturing hall with four melting furnaces, a warehouse with limited capacity, and a hydrogen plant:

- Manufacturing hall: The manufacturing hall comprises four melting furnaces for the actual wafer manufacturing process. Each melting furnace can be switched on or off discretely. The power consumption profile of the furnace is known to the player and can be compared with the expected power prices in this period.
- Warehouse: After being manufactured, wafers are stored in the warehouse. From there, they are sold automatically. So the player can only control the inflow to the warehouse. The outflow happens automatically. It is important that the stock level does not drop to zero. At the same time, if the stock is full, no more wafers can be manufactured. So, if the stock is full, cheap power cannot be exploited.
- Hydrogen Plant: The hydrogen plant allows for producing hydrogen by means of electrolysis - which requires a lot of power. In turn, power can be generated from the hydrogen via fuel cells. This creates a storage possibility that allows the player to use more power when it is cheap and less power when it is expensive.

If the cost-effective wafer manufacturing has generated sufficient profit, five company expansions can be implemented:

- Power controller: With a power controller, the melting furnaces in the manufacturing halls can not only be switched on and off but also operated on five power levels. Although this does not change the total power required to manufacture the wafers, it can change their timing by adapting power consumption profiles.
- Warehouse expansion: An expansion of the warehouse allows for storing more wafers.
- Hydrogen plant expansion: An expansion of the hydrogen plant will allow a larger amount of power to be stored in the form of hydrogen.
- Building a manufacturing hall: By building an additional manufacturing hall, the company's capacity for wafer manufacturing can be expanded by four additional melting furnaces.
- Building a hydrogen plant: By building an expensive additional hydrogen plant, the capacity of the company to synthesize and use hydrogen for their power supply can be extensively expanded.

The difficulty for the player is to maintain the necessary wafer manufacturing at all times while achieving competitive costs by sourcing power as cheaply as possible. The interrelationships within the company are complex and characterized by a wide range of possible actions. At the same time, this allows the player to experience the impact of the use of industrial DR in a manufacturing site.

### 2.3 Findings for Players

Since the primary purpose of SynErGame is to foster knowledge on industrial DR among a broad audience, gaining experiences and findings is most important for the players. Therefore, an essential part of both game modes is to explain why the game was won or lost. In the game mode “city”, this is explained using the power grid frequency; in the game mode “manufacturing company”, it is explained using the statistics and how power costs affect the profitability of companies. Players can use this information to understand the consequences of their actions and how to act better next time.

## 3. Implementation

SynErGame was implemented as an iterative process and in close cooperation between developers and domain experts. In the first phase, domain experts and developers had to decide which scenes and industries to include in the game and what to allow the players to do. As outlined in section 2.1 for the game mode “city”, it was chosen to depict a whole city with several different companies. This was meant to give players an overview of the topic of industrial DR and the general challenges it brings without the limitation of only looking at one specific industry or manufacturing process. This context had to be combined with the usual approaches and rules of games, for example, regarding navigation and control. Despite the complexity of the topic to be transported, the game should be simple, easy to learn and understand, especially regarding controls. With the serious and real-life message behind it, the target groups of the game differ from casual or entertainment games. Therefore, entry barriers to step into the game should be as low as possible. The game mode “manufacturing company” was created to allow players a closer look at the specific challenges a modern manufacturing company with its individual manufacturing process steps faces with industrial DR (see section 2.2). However, the same challenges regarding game and graphics design had to be dealt with when creating this game mode. The input possibilities and controls, especially when developing applications for mobile devices with touch input, needed to be considered for every step of design and development. There are restrictions and limitations regarding touch input, especially on small displays of mobile devices, while the game has to make sure that all necessary control elements (like menus, arrows, or other actions) are displayed at all time without taking too much space. Thus, creating and adjusting user interfaces for different aspect ratios (e.g., browser vs. smartphone) was one of the biggest challenges for game and graphics design during development.

The fundamentals of the graphic design were created to generate a friendly and inviting environment. For the game mode “city” for example, bright and appealing colors were chosen, and the city is depicted with a river and sunshine. For both game modes, we included as many graphical details as possible to aim for a realistic and appealing look. The game mode “manufacturing company” also had the aspiration of a modern appearance, in look as well as in content, being another reason why a company for manufacturing wafers for the semiconductor industry was chosen.

For actually implementing SynErGame, we used two main tools: Blender (blender, 2022) to create graphics assets and Godot (godot, 2022) as a game engine for bringing all components together, and building and extracting a functioning game. Godot is a lightweight game engine suitable for developing browser games, but its framework also allows for creating apps for mobile devices, which, for example, influences the final download size of the game. The technical possibilities and capacities of both browsers and mobile devices are limited, especially when compared to a gaming computer or a gaming console, which had to be considered during implementation. In a learning environment with as many potential users as possible, the goal for the game must be to work on as many browser versions and mobile devices as possible, including not only high-end but also low-end devices. We had to consider and limit the graphical complexity of the scenes regarding graphical effects or special effects, for example, so as not to push the limits of lower-end hardware and devices. For the game mode “city” the overall technical workflow was to create the city in the 3D tool Blender in the form of several individual tiles (= pieces of the city with houses, streets, etc.), each modelled and created separately. Each tile was created in several versions to have different day times and lighting moods included in the final game. Furthermore, the game mode “city” was created in multiple tiles to allow for a dynamic effect of the icons and control elements. The individual tiles were rendered in Blender, different overlays (arrows, lightning bolts, controllable menu elements, etc.) were created, and tiles and overlays were placed and pictured on top of each other inside the Godot game engine (see Figure 2).

We applied a similar approach for the game mode “manufacturing company”, where a 3D scene was created for each process (manufacturing hall, warehouse, and hydrogen plant) and rendered in several 2D planes that were placed on top of each other. With this approach, animations and movements could be included requiring less performance than actual 3D assets and scenes because the different planes could be moved in parallel with the screen, thus creating an animation (see Figure 3).

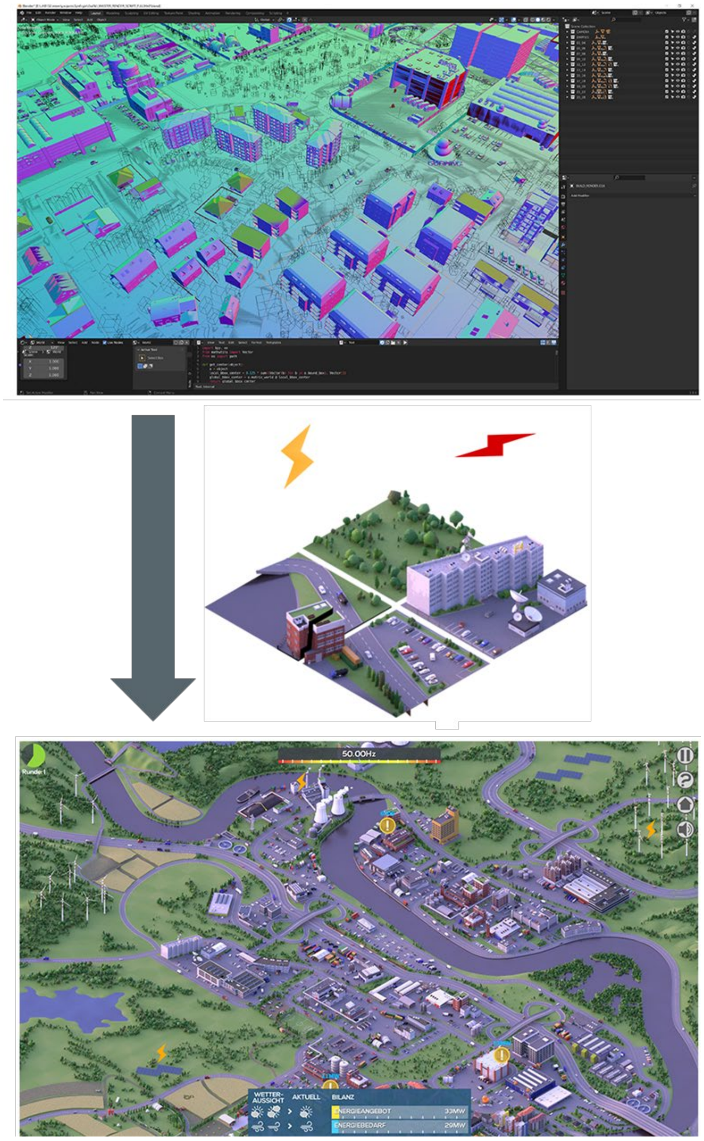


**Figure 2:** Conversion of 3D artifacts into segmented 2D images for a performant display in the application

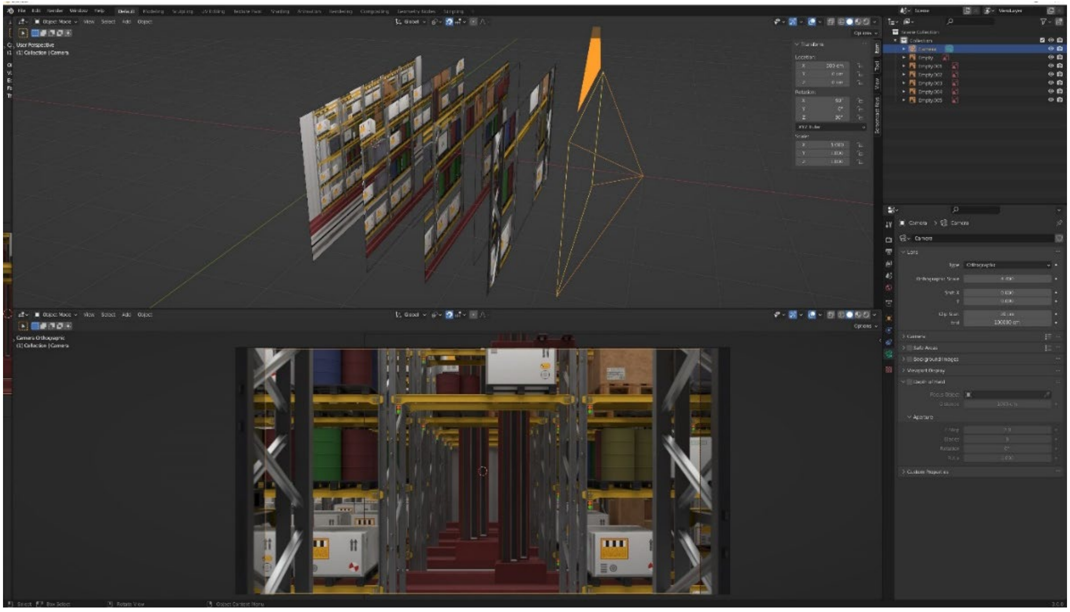

**Figure 3:** Image layers of an interior scene in which individual layers can be animated parallel to the camera

The same approach was used for the overview map connecting both game modes, where, for example, small vehicles are moving across the map. These 3D assets were rendered in several 2D planes, placed on top of each other, and then moved parallel to the screen to create movement (see Figure 4).

**Figure 4:** Individual images to animate the rotation of the vehicles on the overview map

SynErGame is available online as a browser game as well as a mobile app for Apple iOS and Google Android (SynErgie Project, 2022).

## 4. Application

As described in the requirements (see section 2.1), the entry barriers for SynErGame have to be low for being applicable for a broad audience. So far, SynErGame has been applied in lectures and seminars with students, as an opening for workshops with manufacturing companies, and for demonstration purposes at trade fairs. First insights gained from interviewing players afterwards are promising for SynErGame's further application:

- Students from two different universities emphasized the fun aspect of the game. Learning the subject matter worked almost incidentally; afterwards, major conclusions could be reproduced by the students.
- In workshops with manufacturing companies, the game was used with participants from different backgrounds (e.g., manufacturing managers with no energy background, energy managers with a strong energy focus). It has been shown that SynErGame is particularly suitable when only limited background knowledge is available. If an extensive background knowledge exists, the game is quickly reduced to the fun aspect and outperforming each other.
- At trade fairs, SynErGame has been used as an eye-catcher for the topic of industrial DR. The audience there was much more inhomogeneous compared to the students and workshops. It worked very well for game-affine and digital-affine visitors eager to get more information and stay in touch. However, with visitors non-affine and without appropriate background knowledge, starting a conversation was even harder since they possibly regarded industrial DR itself as a game.

An empirical evaluation of the game with quantified results is part of future work, as described in the next section.

## 5. Conclusion and Outlook

Within this paper, we proposed the approach and design of SynErGame as well as its implementation as a browser and mobile game. Building on the concept of industrial DR, an easy-to-use browser, and mobile gaming, our approach fosters knowledge of industrial DR among a broad audience. First insights show that SynErGame is well accepted by a game-affine audience and an eye-catcher for more in-depth information on the topic.

For further work, an empirical evaluation of the game using the approach by Draghici et al. (2020) is planned. The evaluation results can be incorporated into further development. This includes a more detailed elaboration of target groups and their specific requirements. In addition, various levels of difficulty are planned to be created, for example by integrating further flexibility measures into the game mode “manufacturing company”.

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