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Assessment of Sport Area Electricity System Using a Resilience Energy System Framework

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ABSTRACT

Proper resilience metrics (RMs) for energy systems are necessary to be identified, evaluated, and implemented to improve energy system resilience. The proposed framework aims to be implemented as a tool, in the form of an energy resilience matrix, for energy system evaluation. The application of the engineering and infrastructure part of the framework was demonstrated in evaluation of a sport activity area located in Sweden. The results show potential to improve the resilience by installing solar cells and increase battery storage capacity in the area, connect with neighbouring area and utilize vehicle to grid.

Keywords: sustainability, renewable energy, reliability, energy security, resilience metrics, evaluation matrix

1. INTRODUCTION

According to the European Environment Agency 22.5% of total renewable energy sources (RES) was used in the EU in 2022. However, the new target is 42.5% of RES for 2030 [1]. Compared to other energy sources the disadvantage of RES is that they are intermittent as availability varies over time. In addition, transformation of energy use leads to a higher electricity demand, for example increased use of heat pumps in the building sector and electrified vehicles [2], [3]. These developments will impose new challenges to balance the electricity supply and demand in the European energy system.

To make the energy system resilient, the resilience of the system needs to be identified and quantified. Resilience is multi-dimensional and there is no universally accepted definition. A well-defined and structured Energy Resilience Framework (ERF) could provide an improved understanding of the assessment of resilience and contribute to a more stable and reliable energy system. The ERF can contribute to better knowledge on how to cope with disruptions from various events such as extreme weather, natural disasters, sabotage, equipment failure, or human error [3]. Besides, to ensure the continuity and functionality, an ERF can also contribute to achieving sustainability goals and business resilience [4]. Recent literature points out several research gaps in the field of energy resilience frameworks: i) lack of consideration of climate risks in energy system, [5]; ii) lack of clear indicators of energy resilience essential to demonstrate and modelling case studies [2]; iii) lack of considering dimensions such as social, policy and economic resilience [3-5]; iv) lack of a holistic approach [6]. In this paper we focus on ii) lack of clear indicators of energy resilience essential to demonstrate and modelling case studies, by investigating the engineering and infrastructure resilience of a defined city district, a sports activity area, in Sweden. This is a first step in the development of a holistic approach including also other dimensions utilizing the experiences from the engineering and infrastructure resilience dimension.

Energy-efficient and resilient sports facilities can contribute to environmental sustainability, lead to cost savings, ensuring continued operation during power outages or disruptions (important for facilities that host major events, where disruption could have financial and reputational implications) and contribute to the safety of sports facilities (for example, by ensuring that lighting and safety systems continue to operate during a power outage).

This paper aims to contribute to the development of a novel framework for measuring engineering and infrastructure resilience, by evaluating the electricity resilience of a sport activity area as a case study.

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2. METHODOLOGY

A novel framework with multiple dimensions where energy system resilience is measured and evaluated are proposed to be evaluated (see Fig. 1). Each dimension will be described by properties and measured by a set of resilience metrics (RMs). The suggested framework includes a holistic approach on energy resilience considering the entire energy system, from the origin of capturing the different characteristics of various energy carriers to end users' needs. The framework is aimed at being implemented as a tool, for energy system assessment.

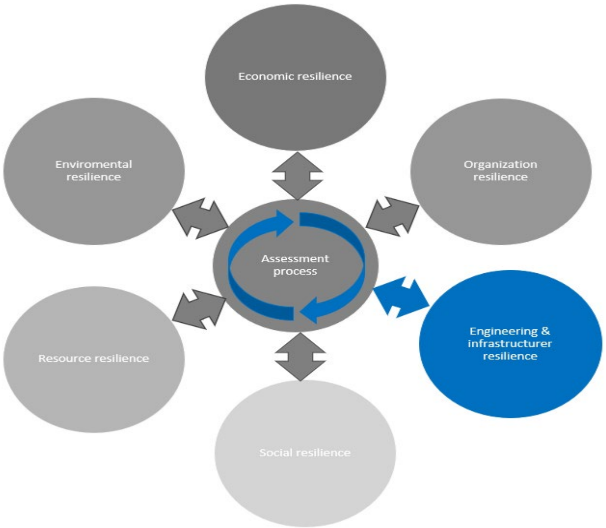


Fig. 1 Proposed energy resilience framework (ERF). In this study the application of the engineering and infrastructure dimension, marked in blue, is demonstrated.

The sport activity area in this study includes several ice rinks and multi-arenas for football, a riding house with a riding school and large outdoor facilities. There are several exercise tracks for running in the summer and skiing in the winter. During winter, there is a 2.5 km long snow track which is complemented with artificial snow whenever needed. The demand includes electricity used in buildings (ventilation, lighting), cooling demands for making the snow for the tracks when needed and EV charging on the parking lots [7]. Supply includes connection to the Swedish electricity grid, solar installation within the sport activity area as well as in neighbouring areas and battery storage

The battery storage, enable storage of excess energy during low-demand periods and supply of it during high-demand periods or emergencies. Energy storage also facilitates the integration of intermittent renewable energy sources and can assist in stabilizing the grid. The battery storage at the sport activity area is a modular, lithium-ion battery system, with an output of up to 220 kW and a usable energy capacity of 320 kWh. The battery is expected to mitigate some of the peak loads and relieve the local power grid when charging electric cars by over 80% [8]. For the simulations, the HOMER Grid® was used. The Homer software is used to evaluate redundancy, energy security and resilience improvements. The demand of the area, installed solar capacity, electric vehicle charging points capacity and day-ahead electricity prices are used as input parameters to the simulation. The simulations give the current electricity profile and the energy mix of the area. Further, the possible changes of the resilience when (suggested options) reinforcing interconnection with neighbouring area roof mounted solar cells, installing more solar cells and providing vehicle to grid possibilities were evaluated.

2.1 Proposed framework

According to Fig. 1., the proposed overall framework will be divided into six main dimensions, to have a holistic approach when describing the energy resilience of the energy system. Each dimension is described through properties and key performance indicators (KPI). Based on those, stakeholders can forecast the status of the energy system, characterize the risks and come up with strategy development plans. In this paper the focus is on the dimension of engineering and infrastructure resilience. In literature different metrics and KPIs to evaluate resilience are proposed but none of those measure the resilience on the system level. The novelty of the framework presented here is the suggested measurements of the resilience of the energy system for comparison of resilience improvements in different applications.

2.2 Assessment of the engineering and infrastructure resilience (only considering electricity system) in the sport activity area.

In this study the assessment of the electricity resilience of the engineering and infrastructure dimension of the energy system for the case of a sport activity area has been done to demonstrate the application of the proposed ERF. First, resilience properties, considered as the most important ones for the area, are identified. Based on those a set of KPIs, to be used to measure the properties of the selected system, are designed. Selecting the suitable properties should be done after analysing the area boundaries, local energy balance, infrastructure development and type of business. To measure the electricity resilience of the selected area for this study the properties' reliability, redundancy, energy security and affordability were used. In Fig.2. the selected properties and the KPIs for the given case are summarized.

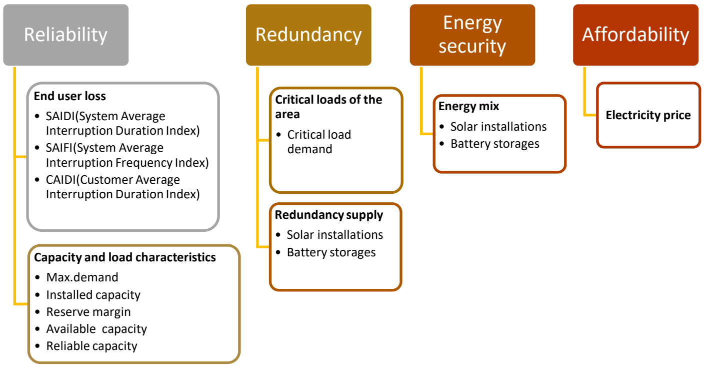


Fig. 2 Resilience properties and KPIs used in the assessment of the sport activity area

The end user loss and capacity and load characteristics are calculated with Eq. (1) to (3) and Eq. (4) and (5), respectively.

$$\mathrm{SAIDI} = \frac{\text{Total minitues of customer}}{\text{Number of all customers}} \tag{1}$$

$$\mathrm{SAIFI} = \frac{\text{Total number of interruptions for a group of customers}}{\text{Number of all customers}} \tag{2}$$

$$\mathrm{CAIDI} = \frac{\text{Total minutes of customer}}{\text{Total number of interruptions}} \tag{3}$$

$$\text{Reserve margin ratio} = \frac{\text{Total installed capacity} - \text{Peak Deamd}}{\text{Peak Demand}} \tag{4}$$

$$\text{Reliable capacity ratio} = \frac{\text{Available capacity} - \text{Peak Deamd}}{\text{Peak Demand}} \tag{5}$$

3. RESULTS & DISCUSSION

The main aim of this case study is to evaluate the engineering and infrastructure resilience of the electricity system in the sport activity area and how it can be improved. The results are presented in Table 2 and further explained below.

3.1 Results of the assessment of the engineering and infrastructure resilience

3.1.1 Reliability

Reliability is the ability of the system to supply customers with the energy needed without any disruption. To measure the reliability of the electricity system in the sport activity area two KPI's are used. Those are end user loss and capacity and load characteristics.

3.1.1.1 End user loss.

The statistics Sweden [9], electricity interruption data for past five years is used to evaluate the current state of the power outages in the sport activity area. Tables 1 shows the SAIDI, SAIFI and CAIDI values for Sweden from 2017 to 2021.

Table 1 End user loss analysis for the sport activity area [9].

Year	SAIDI (minutes per year)	SAIFI (times per year)	CAIDI (minutes per interruption)
2017	44	0.97	45.36
2018	55	1.11	49.54
2019	43.5	0.75	58.00
2020	27.34	0.47	58.14
2021	54.52	1.02	53.45

3.1.1.2 Capacity and load characteristics.

The customers electricity demand must be met when it is needed, by the amount of electricity supplied. To calculate eq. (4) & (5) these steps are followed.

Nominal installed capacity: The installed capacity is the maximum power that can be fed into the energy system, which can be higher than the maximum demand. In this case study the maximum demand can be considered to always be met.

Reserve margin: Reserve margin is necessary to cater for any loss of supply capacity due to faults or planned maintenance and refurbishment. For the Swedish national grid, the reserve capacity is calculated to be 70% based on the peak demand that occur during winter. The level of reserve margin is connected to the maximum electricity demand and is dependent on the size of the power system and the reliability level required. The higher the need for reliability in a power system, the higher the percentage reserve margin. Typically, the reserve margin recommended by the International Energy Agency (IEA) is 20% to 35% [10].

$$\text{Reserve margin} = \frac{45600 - 26600}{26600} = 70\%$$

Total installed capacity [11] = 45600 MW

Peak load in winter [12] = 26600 MW

Available capacity: The available capacity means the maximum power supply capacity remaining available in the energy system. The availability factor [12] of each source varies depending on the season and other factors. The availability of a power plant varies greatly depending on the different factors such as the design of the plant, climate, energy prices and how the plant is operated. Considering these factors the actual available capacity of the system can be calculated. The Swedish energy system does have 562 MW [12] as power reserve capacity.

$$\text{Reliable capacity in the grid} = \frac{(26697 + 592) - (26600)}{26600} = 3\%$$

Maximum demand of studied area: The maximum demand is the highest aggregated electricity demand of all end users that needs to be supplied at the same time. The maximum measured demand of the studied sport activity area is 2000 kW. The sport activity area mainly depends on the grid and the reliability level is maintained by the grid. It means the reliability level of the sport activity area has the same reliability level as the grid. Applying the grid reliability factor 0.03 into the studied area, means assuming that when there is a sudden electricity consumption increment during the wintertime in the whole Sweden, then the grid can only supply additional 60 kW to the studied area.

3.1.2 Redundancy

Currently the area doesn't have a redundancy supply, or the supply is not prioritized. Redundancy supply should be able to back up the critical loads for unexpected electricity outages and minimize the commercial loss due to electricity disruption.

Critical or minimum load in the studied area: The critical load is the minimum load that needs to be supplied for emergency and uninterruptable functions of the area [13]. The critical or minimum demand in the sport activity area during the winter was 80 kW and in summertime it decreased to 55 kW in the year of 2022.

Redundancy supply for critical minimum loads: Currently the sport activity area has 500 kW solar installation and 320 kWh battery storage capacity. Redundancy power is provided in summer by solar energy and battery storage. According to the Table 2 the area has experienced maximum one hour power outage. It means that during the summertime the installed solar supply and battery storage can work as a redundancy electricity supply to the area. In the wintertime battery storage can work as a redundancy electricity supply to the area.

3.1.3 Energy security

Energy mix: Currently, the sport activity area has solar power and the national grid as the main electricity supply. The energy mix (annual basis) of the area in average is 94% of electricity from the grid and 6% from the solar system installed inside the sports activity area. It means the locally provided renewable fraction in the area is in average 6%. Fig.3 shows the variation of the energy mix during the year.

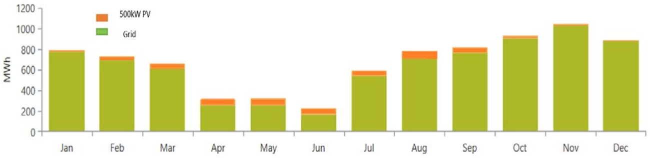


Fig. 3 Monthly total electricity consumption in the sport activity area.

3.1.4 Affordability

To examine the affordability of the area, industry users' electricity prices, was assumed to be valid for the sport activity area studied. Statistics Sweden [9] was used as the data source for the price analysis.

3.2 Scenarios for improved electricity system resilience in studied area.

After measuring the current electricity resilience level in the sport activity area. The second part of this paper is to analyse the electricity system resilience improvement strategies. Three options have been proposed in this paper.

3.2.1 *Increase flexibility by connecting to local electricity production in nearby areas using micro-grid concept.*

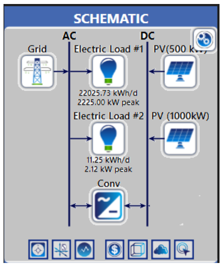
An option to increase the flexibility for the sport activity area is to connect nearby residential area assuming utilisation of possible areas for rooftop mounted solar panels on the residential buildings. When a sudden disturbance occurs in the grid the neighbourhood area and sport area become interconnected and works as an island mode operation area. The option is to help to improve the resilience of the area without increasing the grid capacity or reliability factor of the current existing grid.

Assuming 100 single family buildings with the assumed electricity demand 2213 MWh/yr [14] in the nearby residential area with roof mounted systems of 10 kW connected to the sport activity area. 1000 kW solar panels can produce 1015 MWh/yr., which means 12% of the total consumption of the sport activity area. The addition can decrease the power outages of the system. The maximum supply profile, with all the produced electricity from the solar panels in the nearby area exported to the sport activity area, is shown in Fig. 4.

When connecting this additional 1000 kW we can increase the sport activity area reliable capacity by 7% for the summertime.

Table 2 Summary of the resilience characteristics improvement/change of the area.

Property	KPIs	Current characteristics	Option 1		Option 2		Option 3	
				Improvement /Change		Improvement/Change		Improvement/Change
Reliability	End user loss (CAIDI and SAIDI/SAIFI)	53.45 min (from 2022)	50 min	6%	52 min	3%	49 min	8%
	Capacity and load characteristics (Available capacity and Reliable capacity in the grid)	60 kW (from 2022)	140kW	133%	130 kW	116%	281 kW	368%
Redundancy	Critical loads 80 kW (winter) 55 kW (summer) (from 2022)	Solar capacity 60 kWh & Battery storage 350kWh	Solar capacity 146 kWh	143%	Solar capacity 131 kWh	118%	EV discharging capacity 281 kWh	368%
Affordability	Area electricity levelized cost based on new balance between import and export from and to the grid	109 EUR/MWh (from 2022)	96 EUR/MWh	11%	102 EUR/MWh	6%	106 EUR/MWh	3%
Energy security	Solar installation Or EV to grid and % contribution of solar energy to the electricity demand	500 kW & 6%	1500 kW	200%	1000 kW	100%	721 kW	44%



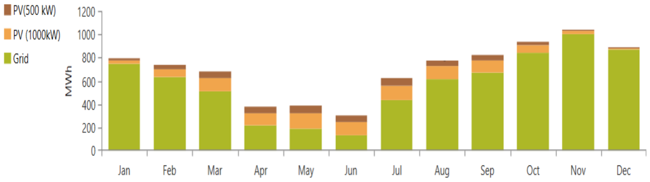


Fig. 4 Maximum supply profile after connecting the neighbouring PV supply into sport activity area.

3.2.2 Increasing install PV capacity

The second option address changing the energy mix inside the area without applying any microgrid concept which can be done by installing more solar panels and a battery storage system (220 kW) within the sport activity area.

Installing 500 kW (2,3670 m^2) solar panels inside the area can improve the current 6% to 12% renewable fraction of the sport activity area demand. It decreases the 6% grid dependency of the sport activity area. The supply profile shown in Fig.5.

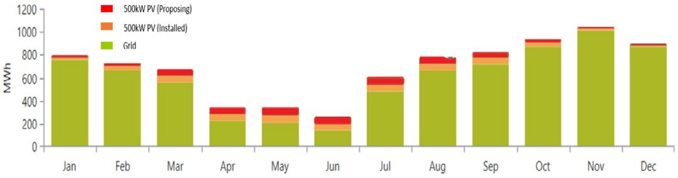


Fig. 5. Supply profile after installing more solar panels in the sports activity area.

3.2.3 EVs to grid.

Another feasible option is to utilise EVs to the grid and improve the resilience of the system. This option can be used when there is a sudden demand rise in the area and when solar electricity production can't fulfil the demand. The average capacity of an electric car battery is around 40 kWh [15]. The vehicle to grid option can be used to improve the resilience of the system. According to the website "Charge finder" [16] there are six charging points including five 22 kW and one 111 kW, in total 221 kW and efficiency of about 70% [17] vehicle to grid that can be used for charging in the sports activity area.

4. CONCLUSION

With a framework for defining dimensions, properties and key performance indicators the resilience of a system can be measured and evaluated. The assessment of resilience is both complex and multidimensional, which is a challenge in defining, retrieving data for and calculations of the proper KPI: s.

This case study shows how the proposed framework can be applied and how to measure the engineering and infrastructure electricity resilience in the selected sports activity area. Changers presented in Table 2 only consider the percentages of the absolute values, which indicates the improvements of the sport activity area. Different options for further development of the energy system of the area were evaluated with the ERF.

The three evaluated improvement options (1) Increase flexibility by connecting to local electricity production in nearby areas, 2) Installing more solar panels, 3) EV to grid), all show possibilities for improvement of the resilience of the studied area. In this paper we implemented a suggested evaluation framework for a real area and illustrated the complexity and challenges and the need for further development. Future work will also include development of the ERF with evaluation of more additional dimensions.

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