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ASSESSING THE PERFORMANCE AND RESILIENCE OF FUTURE ENERGY SYSTEMS AT NEIGHBORHOOD SCALE

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Abstract

This study compares the performance and resilience of future energy systems at neighborhood scale. Four urban design scenarios of a neighbourhood in Switzerland are evaluated. The energy systems of each scenario are modelled in EnergyPro. EnergyPro allows simulating hourly exchanges among vectors of demand and supply in buildings and electro-mobility. The performance of energy systems is evaluated according to costs, energy and carbon intensity. The resilience of energy systems is evaluated according to short-term and long-term responses to an electricity outage. The performance and resilience of energy systems are constrained to options of energy storage and on-site generation. Similarly, these options are constrained to land-uses and patterns of consumption in buildings. This paper builds new knowledge about the impacts of plans of urban development on the performance and resilience of energy systems.

Keywords:

Urban energy systems; life cycle assessment; resilience of power systems; sustainable development; neighbourhood scale

1 INTRODUCTION

In line with current targets for urban sustainability, cities need to build new knowledge about the impact of future patterns of development on the performance of energy infrastructure [1].

Most infrastructure systems in cities are highly reliant on energy systems for their operation. Mobility, water-supply, communication, healthcare, housing and banking are examples of systems highly dependent on a continuous supply of energy. This strong dependency supports concentrated efforts on building robustness and resilience of energy systems.

Vugrin et al. [2] define system's resilience as the capacity to absorb, adapt and restore its performance after affected by a disruption (e.g., electrical outage). The absorptive capacity is the degree to which a system can automatically absorb a disturbance and minimize the consequences with little effort. Concerning energy systems, this capacity is covered by backup systems.

On the other hand, the adaptive capacity refers to a system's capability of self-organization. It involves actions that require an extra effort in time. In relation to energy systems, on-site generation plays a key role as users without access to energy are prone to look for alternatives locally.

In contrast, the restorative capacity represents the ability of the system to be repaired exogenously. In the case of energy systems, this capacity mostly involves the efficacy of maintenance systems to prevent disasters or react quickly.

Recently, [3] assessed the environmental impact of future patterns of development of a neighbourhood in the city of Zug in Switzerland by 2030. For the urban scenarios of Fig. 1, [3] depicted the influence of land uses on the performance of district-scale energy systems. The Status Quo scenario (SQ) describes today's

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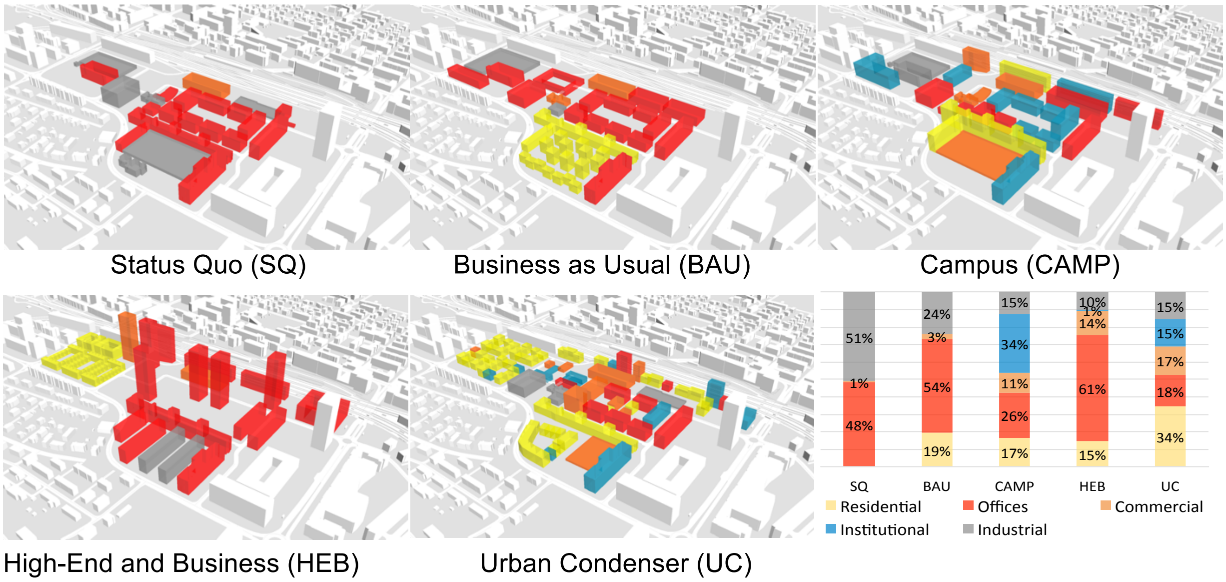

Fig. 1: Urban design scenarios. Legend: Mix of Land uses.

condition of an industrial site of 25ha. A large manufacturer in the light industry sector owns and predominately occupies the site. At the moment, there is no residential use on-site. The Business-As-Usual scenario (BAU) focuses on the industrial legacy of the site with a small expansion to residential uses. The Urban Condenser scenario (UC) presents a balanced mix of industrial, residential and commercial uses. The UC scenario is a socially-inclusive strategy to increase the livability of the area. It offers housing close to job opportunities and open spaces for leisure and recreational activities. The High-end Business scenario (HEB) drives the light industry out of the area and populates it with high-rise buildings in the services sector. This scenario responds to economic growth observed in the area. The Campus scenario (CAMP) describes a university environment with laboratories, housing, and catering services. In this area, students, residents, and workers meet with big parcels of open space, which evoke pedestrian mobility. More information of these scenarios can be found in [3]

This paper expands the approach of [3] to address how future patterns of development could influence the capacity of their energy systems to adapt and absorb a disturbance.

Section 2 describes a general methodology for such assessment. Section 2.1 and 4 present a comparison between descriptive variables of performance and resilience. Section 5 concludes.

2 METHOD

2.1 Data collection and processing

For the urban design scenarios of [3] information was collected about:

- Number of users per land use and target group (i.e., students, workers in industry, services and institutional sectors, residents, visitors) [3]
- Transportation modes (e.g., private, public [bicycle, train, bus]) and shares per target group [3]
- Energy demand patterns (i.e., total hourly heating, cooling and electrical demand) [4]
- Optimal energy systems configurations (i.e., capacities of equipment for generation storage and distribution of energy) [1]
- Key performance indicators (KPI's) of optimal systems (i.e., greenhouse gas emissions [GHG], non-renewable primary energy [PEN_{nr}] (Include embodied energy and grey emissions of buildings and energy infrastructure.) and total annualized energy costs [TAC] per unit of heated space) [1]

The electrical storage capacity of vehicle-to-grid electro-mobility (V2G) of every scenario was determined according to [5]. For this, the next assumptions were considered:

- A density of 0.30 private vehicles per resident in BAU and HEB scenarios [6]
- A density of 0.25 private vehicles per worker in SQ, BAU and HEB scenarios [6]
- A density of 0.10 private vehicles per worker/visitor/resident in CAMP and UC scenarios [6]
- An electrical storage capacity of 50 kWh/veh,
- A density of 0.05 private vehicles per student in CAMP and UC scenarios [6]
- 20% penetration of V2G in private automobile use

2.2 Resilience assessment.

The resilience of the energy system is calculated for a long-term electricity outage. For this, the hourly operation of the energy system of each scenario (Table 1) was simulated in EnergyPro

Property	SQ	BAU	CAMP	HEB	UC
Energy consumption (GWh/yr)					
Heating	13.5	13.2	16.7	16.9	14.3
Cooling	4.6	5.5	3.9	6.1	5.1
Electricity	17.9	22.1	15.2	24.4	16.4
Energy intensity (kWh/m^2.yr)	271	237	159	188	192
Heating capacity (MW)					
NG-fired boiler	10.2	-	12.7	-	11.5
Heat pumps	-	6.8	5.2	6.2	6.5
PV-T	-	14.6	11.1	14.2	8.4
Cooling capacity (MW)					
Lake water pumps	0.3	0.4	0.3	0.5	0.4
Electrical capacity (MW)					
PV	-	0.4	-	-	-
PV-T	-	3.68	2.8	3.29	2.2
Local grid (step-down transformer)	10	15	15	15	15
Storage capacity (MWh)					
Hot thermal storage	9.3	7211	5939	7470	5309
Cold thermal storage	5.8	5.8	5.8	5.8	5.8
Backup Diesel	1.3	1.3	1.3	-	-
Electrical battery	0.5	0.5	0.5	-	-
Electro-mobility batteries	0	18.7	10.7	30	9
PV Generation (GWh)					
Generated	-	3.0	2.8	3.6	2.2
Potential available	5.8	1.6	3.9	0.8	4.2
Renewable energy (%)	11	52	39	46	38

Table 1 Characteristics of energy system configuration per scenario.

v4.1. For this, the next assumptions were considered:

- Maximum discharge rate of 50%/veh and charging/discharging capacities of 10 kW/veh (semi-fast charging cars) [7]
- Parking hours in the area between 9:00 and 18:00 during weekdays for vehicles in commercial, industrial and institutional sectors
- Parking hours between 22:00 and 9:00 during weekdays and Saturdays, and between 00:00– 24:00 during Sundays for the residential sector

Two descriptive variables of resilience were evaluated: the minimum reserve margin (RM_{peak}) [8] and the minimum potential resource margin (PM). The last is introduced as part of this study. RM_{peak} addresses the absorptive capacity of the energy system and represents the available power capacity at peak time (including electrical storage, backup capacities and interaction with batteries in V2G electro-mobility) as a percentage of the demand.

On the other hand, PM addresses the adaptive capacity of the system. It is equal to the ratio between the potential energy available from local resources and the non-attended portion of the electrical demand after a long-term disruption. This margin is an indicator of the alternatives that users have to change their energy supply and subsequently adapt to on-site generation over time. If the possibility of using fossil fuels is neglected for this end (with the exception of emergency systems), the unexploited solar potential is the only source included in this assessment. For scenarios with solar generation, this potential refers to the fraction of solar energy sold to the grid and that could be otherwise stored.

3 RESULTS

Fig. 2 presents the performance of the energy system of each scenario. In this diagram, a target area describes the Swiss benchmark for sustainable development (the 2000-Watt / 1 ton CO2 Society standard) [5].

Similarly, Fig. 3 presents the resilience of the energy system of each scenario. In this diagram,

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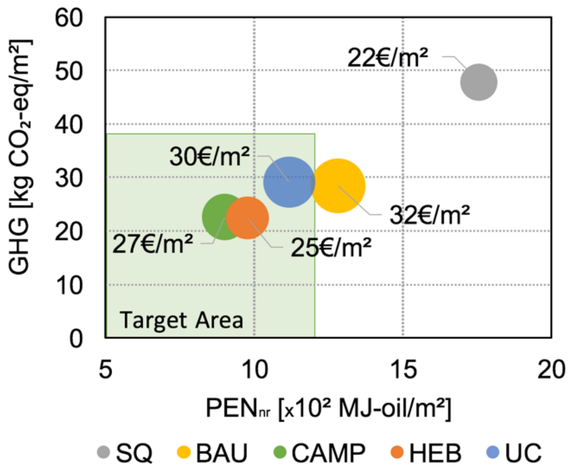

Fig. 2 The performance of energy systems. In this figure, the size of the bubble represents the TAC of each scenario.

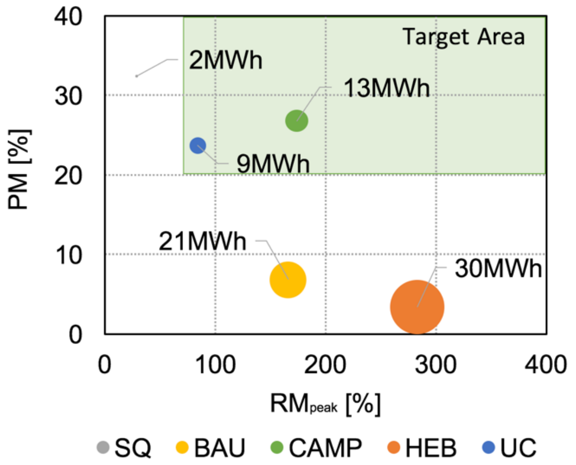

Fig. 3 The resilience of energy systems. In this figure, the size of the bubble represents the total electricity storage per scenario.

a target area represents the minimum robustness desired for the area. These values are estimated in a $RM_{peak} \geq 80\%$ and $PM \geq 20\%$.

4 DISCUSSION

The performance of energy systems could increase as a consequence of three factors:

- A general decrease of the energy intensity per scenario (from -13% to -41%)
- A general increase in the penetration of renewable energy sources (from 2.4 to 3.7 times) subjected to costs between 22% to 46% higher than today
- A resulting reduction of emissions and primary energy consumption (from 40% to 57%)

In the long-term, electrical storage could contribute to increase the performance of systems as it enables higher penetrations of renewable energy.

The resilience of energy systems for the area of study could be affected both positively and negatively, especially in scenarios with more than 50% of office space (BAU and HEB).

- Positively, as a consequence of higher electrical storage capacities (from 18MWh to 30 MWh). These capacities are attributed to industry on site (backup systems) and high V2G attracted by costumers in the commercial sector.
- Negatively, by a high penetration of local resources (close to 50%) in today's energy mix. This situation could limit future opportunities for on-site generation.

5 CONCLUSION

This study presented an assessment of the performance and resilience of energy systems under future patterns of development at neighborhood scale.

For the case study, the performance of the energy system could increase as a result of building retrofits and on-site generation. In the long-term, electrical storage could contribute to increasing the performance of the systems.

On the other hand, the resilience of the system could be constrained to the existence of high fractions of V2G (attracted by office space), backup systems in industry and the potential for on-site generation. The last aspect is highly constrained to the building intensity of the area.

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