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Deliverable report

Deliverable n°	D14.0
Deliverable name	Develop a resilience and sustainability concept for the urban context
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sweet swiss energy research for the energy transition

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List of Abbreviations

D	Deliverable
DSM	Demand Side Management
GHG	Greenhouse gas
GHGE	Greenhouse gas emissions
PV	Photovoltaic
SDG	Sustainable Development Goal
SFOE	Swiss Federal Office of Energy
SIA	Swiss society of engineers and architects
SPS	SURE Pathway Scenario
WP	Work Package

Summary

In Switzerland, a large part of the population lives in urban areas. Considering the increasing impact of climate change on cities in general, and the effects of geopolitical events on energy security, increasing the resilience and sustainability of the energy system is gaining importance for urban governance. Both aspects need to be considered in parallel, as they can enforce but also contradict each other. Deliverable D14.0 therefore proposes a resilience and sustainability concept for urban energy systems and its transformation, firstly to contribute to the literature and secondly to develop a basis for the upcoming case study with the city of Zurich.

The particular focus of our deliverable lies on the distinction between the national and urban levels of a resilience concept, complementing other SURE deliverables about the rural, regional and industrial levels. We argue that the relevance of shocks and thus the required strategies differ between these levels. To assess the relevance of shocks and corresponding resilience criteria, we develop a multi-step qualitative approach. First, we adapt a framework on energy resilience and sustainability. Then, we assess the relevance of shocks from the SURE project, based on our reflections, and interviews with stakeholders from the administration of the city of Zurich. Finally, we propose a set of resilience criteria, potential co-creational formats for assessing these criteria, and a method for increasing policy relevance, representation, and justice.

In the case study section, we apply the assessment of shocks and criteria to the context of the city of Zurich. Together with representatives of the city administration, we found that their main focus lies on heat and cold shocks and space availability considerations. However, other impacts are considered as part of overall resilience and sustainability strategies and plans. In contrast, societal change, financial shocks, and nuclear re-introduction are more likely to be of national and general relevance. This confirms our hypothesis that the relevance of shocks differs between urban and national contexts. Our proposed concept also provides an opportunity for the city of Zurich to continue integrating resilience and sustainability aspects to their development plans. In parallel, sustainability aspects such as reducing the carbon footprint should be considered to evaluate the resilience criteria.

Zusammenfassung

In der Schweiz lebt ein Grossteil der Bevölkerung in städtischen Gebieten. In Anbetracht der zunehmenden Auswirkungen des Klimawandels auf Städte im Allgemeinen und der Auswirkungen geopolitischer Ereignisse auf die Energiesicherheit, gewinnt die Erhöhung der Widerstandsfähigkeit und Nachhaltigkeit des Energiesystems für die städtische Verwaltung zunehmend an Bedeutung. Beide Aspekte müssen parallel betrachtet werden, da sie sich gegenseitig verstärken, aber auch widersprechen können. Deliverable D14.0 schlägt daher ein Resilienz- und Nachhaltigkeitskonzept für urbane Energiesysteme und deren Transformation vor, um einerseits einen Beitrag zur Literatur zu leisten und andererseits eine Grundlage für die anstehende Fallstudie mit der Stadt Zürich zu entwickeln.

Der besondere Schwerpunkt dieses Deliverables liegt auf der Unterscheidung zwischen der nationalen und der städtischen Ebene eines Resilienzkonzepts und ergänzt andere SURE-Beiträge zur ländlichen, regionalen und industriellen Ebene. Wir argumentieren, dass sich die Relevanz von Schocks und damit die erforderlichen Strategien zwischen diesen Ebenen unterscheiden. Um die Relevanz von Schocks und entsprechenden Resilienzkriterien zu bewerten, entwickeln wir einen mehrstufigen qualitativen Ansatz. Zunächst passen wir einen Rahmen für die Widerstandsfähigkeit und Nachhaltigkeit im Energiebereich an. Dann bewerten wir die Relevanz von Schocks aus dem SURE-Projekt, basierend auf unseren Überlegungen und Interviews mit Akteuren aus der Verwaltung der Stadt Zürich. Schliesslich schlagen wir eine Reihe von Resilienzkriterien, potenzielle Formate für die Bewertung dieser Kriterien und eine Methode zur Steigerung der Relevanz der Gesetzgebung, Repräsentation und sozialen Gerechtigkeit vor.

In der Fallstudie wenden wir das Bewertungsschema von Schocks und Kriterien auf den Kontext der Stadt Zürich an. Gemeinsam mit Vertretern der Stadtverwaltung haben wir herausgefunden, dass ihr Hauptaugenmerk auf Hitze- und Kälteschocks und Überlegungen zur Raumverfügbarkeit liegt. Andere Auswirkungen werden jedoch als Teil der allgemeinen Resilienz- und Nachhaltigkeitsstrategien und -pläne in Betracht gezogen. Gesellschaftliche Veränderungen, finanzielle Schocks und die Wiedereinführung der Kernenergie sind dagegen eher von nationaler und allgemeiner Bedeutung. Dies bestätigt unsere Hypothese, dass sich die Relevanz von Schocks zwischen städtischen und nationalen Kontexten unterscheidet. Das von uns vorgeschlagene Konzept bietet der Stadt Zürich auch die Möglichkeit, Resilienz- und Nachhaltigkeitsaspekte in ihre Entwicklungspläne zu integrieren. Parallel dazu sollten Nachhaltigkeitsaspekte wie die Reduktion des CO_2-Fußabdrucks bei der Bewertung der Resilienzkriterien berücksichtigt werden.

Résumé

En Suisse, une grande partie de la population vit dans des zones urbaines. En regarde de l'impact croissant du changement climatique sur les villes en général et de l'impact des événements géopolitiques sur la sécurité énergétique, l'amélioration de la résilience et de la durabilité du système énergétique devient de plus en plus importante pour la gestion urbaine. Ces deux aspects doivent être considérés en parallèle, car ils peuvent se renforcer mutuellement, mais aussi se contredire. Le delivrable D14.0 propose donc un concept de résilience et de durabilité pour les systèmes énergétiques urbains et leur transformation afin, d'une part, de contribuer à la littérature et, d'autre part, de développer une base pour l'étude de cas à venir avec la ville de Zurich.

Ce livrable met l'accent sur la distinction entre les niveaux national et urbain d'un concept de résilience et complète d'autres contributions SURE aux niveaux rural, régional et industriel. Nous soutenons que la pertinence des chocs et, par conséquent, les stratégies requises diffèrent entre ces niveaux. Afin d'évaluer la pertinence des chocs et des critères de résilience correspondants, nous développons une approche qualitative en plusieurs étapes. Tout d'abord, nous adaptons un cadre pour la résilience et la durabilité dans le secteur de l'énergie. Ensuite, nous évaluons la pertinence des chocs issus du projet SURE, sur la base de nos réflexions et d'interviews avec des acteurs de l'administration de la ville de Zurich. Enfin, nous proposons une série de critères de résilience, des formats potentiels pour l'évaluation de ces critères et une méthode pour augmenter la pertinence de la législation, de la représentation et de la justice sociale.

Dans l'étude de cas, nous appliquons le schéma d'évaluation des chocs et des critères au contexte de la ville de Zurich. En collaboration avec des représentants de l'administration municipale, nous avons découvert que leur attention se porte principalement sur les chocs liés à la chaleur et au froid et sur des considérations relatives à la disponibilité de l'espace. Cependant, d'autres impacts sont pris en considération dans le cadre des stratégies et des plans généraux de résilience et de durabilité. En revanche, les changements sociaux, les chocs financiers et la réintroduction de l'énergie nucléaire ont tendance à avoir une portée nationale et générale. Cela confirme notre hypothèse selon laquelle la pertinence des chocs diffère entre les contextes urbain et national. L'approche que nous proposons offre également à la ville de Zurich la possibilité d'intégrer les aspects de résilience et de durabilité dans ses plans de développement. Parallèlement, les aspects de durabilité tels que la réduction de l'empreinte carbone devraient être pris en compte dans l'évaluation des critères de résilience.

Sintesi

In Svizzera, gran parte della popolazione vive in aree urbane. Dato il crescente impatto dei cambiamenti climatici sulle città in generale e l'impatto degli eventi geopolitici sulla sicurezza energetica, l'aumento della resilienza e della sostenibilità del sistema energetico sta diventando sempre più importante per la governance urbana. Entrambi gli aspetti devono essere considerati in parallelo, poiché possono rafforzarsi ma anche contraddirsi a vicenda. Il deliverable D14.0 propone quindi un concetto di resilienza e

sostenibilità per i sistemi energetici urbani e la loro trasformazione, sia per contribuire alla letteratura che per sviluppare una base per il prossimo caso di studio con la città di Zurigo.

L'obiettivo particolare di questo deliverable è quello di distinguere tra i livelli nazionale e urbano di un concetto di resilienza, integrando altri contributi SURE sui livelli rurale, regionale e industriale. Sosteniamo che la rilevanza degli shock, e quindi le strategie necessarie, differiscono tra questi livelli. Per valutare la rilevanza degli shock e i corrispondenti criteri di resilienza, sviluppiamo un approccio qualitativo a più livelli. In primo luogo, adattiamo un quadro di resilienza e sostenibilità per il settore energetico. Poi, valutiamo la rilevanza degli shock del progetto SURE, sulla base delle nostre riflessioni e delle interviste con gli stakeholder dell'amministrazione della città di Zurigo. Infine, proponiamo una serie di criteri di resilienza, potenziali formati per la valutazione di questi criteri e un metodo per aumentare la rilevanza della legislazione, della rappresentanza e della giustizia sociale.

Nello studio di caso, applichiamo lo schema di valutazione degli shock e dei criteri al contesto della città di Zurigo. Insieme ai rappresentanti dell'amministrazione comunale, abbiamo scoperto che l'attenzione principale è rivolta agli shock da caldo e freddo e alle considerazioni sulla disponibilità di spazio. Tuttavia, altri impatti sono considerati come parte delle strategie e dei piani generali di resilienza e sostenibilità. I cambiamenti sociali, gli shock finanziari e la reintroduzione dell'energia nucleare, invece, sono di interesse più nazionale e generale. Ciò conferma la nostra ipotesi che la rilevanza degli shock differisce tra contesti urbani e nazionali. Il concetto che proponiamo offre anche alla città di Zurigo l'opportunità di integrare gli aspetti di resilienza e sostenibilità nei suoi piani di sviluppo. Parallelamente, gli aspetti della sostenibilità, come la riduzione dell'impronta di carbonio, dovrebbero essere presi in considerazione nella valutazione dei criteri di resilienza.

1 Introduction

The aims of this deliverable about urban energy resilience and sustainability are threefold. The first aim is to compare resilience on different levels of governance such as urban and national levels in Switzerland, and the second to combine resilience and sustainability in an urban context. Our final goal is to expand the literature by providing a comprehensive review and by proposing and applying a resilience assessment within a specific case, the city of Zurich, providing lessons learned for replicability in a new context.

1.1 Relevance on urban energy resilience

Increasing mitigation and adaptation to climate change (Yang, Ge, Liu, Li, & Zhang, 2022), as well as increasing energy resilience and sustainability has gained considerable attention in scientific and policy discourses. To meet national and international decarbonisation and sustainability goals (e.g., Paris Agreement or UN Sustainable Development Goals), current and future energy systems should be sustainable and maintain their sustainable aspects in the face of high stress or sudden, potentially unexpected events, so called shocks. Effects of climate change will most likely promote the occurrence of such shocks, for examples as heat waves and cold spells put the energy system under high stress, and as economic and societal changes affect companies[1], cities and nations alike.

Remarkably, the relevance of such shocks differs between levels of governance. On a national scale, some shocks are of concern because of national grid stability. In Switzerland this is becoming even more relevant following the past delays and final failure to negotiate an electricity agreement with the European Union[2]. In 2021 the Swiss Federal Electricity Commission expressed its concerns about Switzerland's ability to secure sufficient power supplies in the coming years. Tackling this issue is a responsibility of the national grid operator. In contrast, cities or urban energy systems have other needs, possibilities, and responsibilities that cannot be captured in a national approach. Due to the Swiss federal system and the principle of subsidiarity, creating a resilient urban energy system is first a municipal task. Therefore, one aim of this deliverable is to highlight the relative importance of shocks on the urban and national level. Our specific focus on urban areas in Switzerland also suggests itself due to the population structure: about three quarter of the Swiss population live in urban spaces (Figure 1).

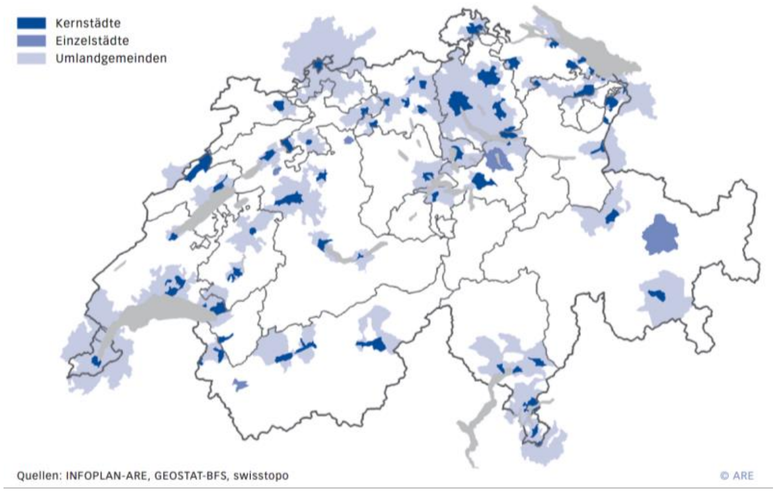

Figure 1: Overview of urban spaces in Switzerland in 2000 (ARE, 2009). Colours represent urban areas (dark blue: major cities; blue: cities; light blue: agglomeration).

[1] See D.15.4 relevance in industry and public mobility.

[2] See, for instance, **https://www.strom.ch/de/energiepolitik/stromabkommen** (accessed 23.2.23)

Another aim of this deliverable is to jointly consider sustainability and energy[3]. As illustrated by the energy supply issues of 2022/2023[4], the answers to dealing with shocks are not always “sustainable”. On national levels, this includes delaying the coal and nuclear plant phase-out in Europe, and on urban levels, allowing the continued use of oil for heating. Although such responses mitigate immediate effects, they put sustainability goals at risk. While this example illustrates a negative trade-off, resilience could also yield positive synergies with sustainability. For instance, adopting a broad portfolio of low-carbon energy sources would not only make the system more resilient against supply shocks but also reduce its carbon footprint. In conclusion a resilience *and sustainability* concept should explicitly consider sustainability criteria and goals like the net-zero targets of the cities in Switzerland.

1.2 Definitions and research goals

Existing definitions of sustainability and resilience build the foundation of this deliverable. We relate to **sustainable** development as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (WCED, 1987). In a resilient system four dimensions need to be considered: availability, accessibility, affordability, and acceptability (Sharifi & Yamagata, 2016). A resilient and sustainable system should be able to meet certain thresholds of these dimensions, even under high stress or sudden shocks. This applies to energy systems on various levels such as urban, rural, or national levels. For example, if energy prices spike or supply is unstable, sustainable alternatives to cover the populations’ needs at affordable prices should be available.

From an engineering point of view, **resilience** is the ability of a system to survive a shock and return to its equilibrium. However, in the context of urban energy resilience, we deem it more useful to consider resilience as the ‘ability to prepare and plan for, absorb, recover from, and more successfully adapt to’ any disruptions that may happen in the future” (Sharifi & Yamagata, 2016). Considering the sustainability aspects, the city should be able to do this while perpetuating its sustainability goals.

Furthermore, we understand resilience as a concept that is applicable to systems and processes. Resilience of the **system** against shocks is arguably the more common concept. In systems, criteria evaluate how a current or future state is affected if a shock occurs and how to recover from it. In contrast, resilience of **the transition process** describes whether shocks would derail the transition towards a sustainable and resilient end state. Research about socio-technical energy system transitions should therefore consider the resilience aspect along the transition pathway (Binder, Mühlemeier, & Wyss, 2017a).

The general relevance, definitions, and our scope cumulate in general research questions for D14.0:

1. How do urban sustainability and resilience measures and goals interact?
2. What are relevant shocks and stresses, an urban energy system may have to face and mitigate?
3. Which shocks are of national relevance that also affect the urban sector, and vice-versa?

To answer these questions and to show how a resilience concept for urban energy systems could be defined and implemented for the Swiss context, we first adapt insights from the literature to develop a general concept. We then link the general concept to previous work of the project SWEET SURE. For this, a selection of national shocks is adapted from the project and from own considerations. We then apply it to the specific case of Zurich. With relevant stakeholders from the government of Zurich, these shocks are discussed in detail and evaluated.

[3] Our explicit focus lies on *energy* resilience in these sectors and the investigated cases. E.g., flood resilience, among other areas, is out of scope unless the energy grid is affected.

[4] See **https://www.elcom.admin.ch/elcom/de/home/dokumentation/medienmitteilungen.msg-id-90036.html** (accessed 23.2.23)

1.3 Case study selection and outlook to WP14

Our deliverable builds the foundation for the corresponding WP 14, which has two main objectives: 1st, the objectives, concepts and approaches of SURE are applied to the urban environment and it is demonstrated how an energy system can be (re)designed in a sustainable and resilient way. 2nd, insights from an in-depth analysis of the specific urban challenges are fed into the cantonal and national part of SURE. Resilience is investigated at various levels, both with regard to the transformation phase up to 2050 and with regard to the operating phase of the future “target” energy system of energy supply, distribution and use. The resilience of the urban system will be assessed om the technical level as well as on the socio-economic, policy and legal level. That is, the resilience of the transformation process and the (impact of) the measures to be taken (e.g., energy planning) is investigated, with special attention to urban-**specific indicators.**

With the case of Zurich, these concepts are assessed in the largest city of Switzerland. It complements existing work in the area such as recent resilience analyses about the critical infrastructure (EBP, 2021).

The remainder of this deliverable is structured as follows: this section introduces the problem, research question and general approach, as well as the case study selection. Section 2 gives an overview of literature in the field, and specifically of useful frameworks to build upon. In Section 3, the general concept is illustrated, and relevant principles, criteria and shocks are introduced, furthermore, a link to previous work in SURE is established. In Section 4, the resilience concept is applied to specific case study with the city of Zürich.

2 Background on resilience

We present the current state of knowledge related to resilience in urban energy systems and general resilience studies of the power system in Section 2.1 These studies tend to be fragmented, targeting specific aspects of resilience. Nevertheless, comprehensive frameworks, which combine this knowledge, exist. We present relevant ones in Section 2.2. Section 2.4 lays a foundation to evaluate the social justice of urban resilience concepts, and thus, increase their legitimisation. All of this background highlights the need and provides the basis for our resilience concept about urban energy in Switzerland.

2.1 Urban energy resilience in literature

While energy-, electricity- and gas-grid reliance or disaster resilience has received considerable attention for quite some time (Bueno, Bañuls, & Gallego, 2021; Dyson & Li, 2020; Jasiūnas, Lund, & Mikkola, 2021; Mola, Feofilovs, & Romagnoli, 2018; Rusco, 2021; Saboo, Morari, & Woodcock, 1985; Sharifi & Yamagata, 2016; Tchórzewska-Cieślak & Pietrucha-Urbanik, 2018), literature on *urban energy resilience* is more fragmented and scarcer. Specific studies on the urban level, compared to studies on the national and regional levels, are still less numerous (Mola et al., 2018).

Table 1: Categorisation of literature relevance for the Swiss context, and our evaluation of an application in it.

Relevance score	Application to Switzerland	Description
1	Direct application	Directly relevant for urban areas in Switzerland.
2	General relevance	General relevance or concept.
3	Partial mapping needed	Presents a general concept but applies it two a case outside Switzerland.
4	Full mapping needed	Assessed specifically for other cities or countries and thus mapping needed.
5	Not applicable	Not or only applicable to a minor degree.

Table 2 provides our own overview of sampled studies in the field of energy resilience. For this, we skimmed and categorised literature that may have a potential application in the context of energy resilience in Switzerland. We then assigned a relevance score according to **Error! Reference source not found.**.We deem literature sources with a relevance score of 1 or 2 and an urban level to be particularly worth reading as a background for the Zurich case study because they either directly address Swiss urban areas or concepts applicable to Swiss urban context.

While we do not claim to cover the entire literature, the overview underlines the fragmented character of literature, which deals with various aspects of resilience and shocks, varying degrees of applicability to a Swiss urban or national context.

Table 1: Categorisation of literature relevance for the Swiss context, and our evaluation of an application in it.

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Table 2: Overview of literature focusing on energy resilience. Evaluation according to our own consideration and skimming of a sample of papers and studies. Level: Nat.: National; Urb.: Urban. Relevance to Swiss urban context is categorised as described in the main text.

Source	Resilience topic	Level		Events covered by resilience concept	Research goal and findings	Relevance in Swiss context
		Nat	Urb			
(Kendziorski et al., 2022)	Security of energy supply	X		Technical failure and intermittent renewables	Analyse the resilience and reliance of the Swiss electricity system given different energy supply scenarios with nuclear energy and renewables	1: directly applicable
(Mühlemeier, 2018)	Energy System		X	Transformation of the Energy System	Analyzes the importance of utility companies in the energy system transformation and how they can promote urban resilience.	1: directly applicable
(Arafah & Winarso, 2017)	Smart city		X	Various unexpected events.	Review the importance of considering energy resilience in smart city concepts.	2: general relevance
(Bai et al., 2018)	Urban development		X	Climate Change	Present the six most important points policy makers should consider when designing new urban structures and resilience concepts	2: general relevance
(Binder, Mühlemeier, & Wyss, 2017b)	Energy Systems		X	Climate Change	Conceptualize and operationalize resilience for energy systems in transition regarding both social and technological aspects.	2: general relevance
(Chelleri et al., 2012)	City development		X	Population growth, urbanization	Discuss the three main challenges when cities transform towards a more sustainable and resilient structure.	2: general relevance

(Esfandi, Rahmdel, Nourian, & Sharifi, 2022)	Urban spatial structure		X	General risks and vulnerabilities.	Discuss the impact of spatial structure on energy resilience and proposes a globally applicable framework for energy planers, including a composite index.	2: general relevance
(Jasiūnas et al., 2021)	Resilience of the entire energy system.	X		Extreme weather and cyberattacks.	Provide a detailed overview of the specific threats and discusses strategies to reinforce resilience such as digitalization.	2: general relevance
(Martišauskas et al., 2022)	Energy system resilience	X	X	Natural hazards, technical accidents, intentional threats.	Present aggregated indicator to evaluate the resilience of an energy system.	2: general relevance
(Nik, Perera, & Chen, 2021)	Urban energy		X	Extreme climate events.	Provide an overview and insight into the progress that has been made in urban energy system resilience, particularly extreme weather events. Sees need to better consider climate events in energy models.	2: General relevance
(Sharifi & Yamagata, 2016)	Urban energy		X	Various threats and vulnerabilities	Propose a comprehensive conceptual framework for assessing urban energy resilience.	2: General relevance
(Yang et al., 2022)	Power grid resilience	X		Natural disasters; cyber intrusion.	Provide a better definition for multi energy systems that are prone to physical- or cyber-attacks. It provides a methodology for finding the key constraint factors.	2: general relevance
(Anderson et al., 2018)	Energy System		X	Natural Disaster Sever weather events	Present a methodology that quantifies the value of resiliency when incorporating renewable energy hybrid systems into the energy system and ways to monetize on the increased resilience.	3: partial mapping needed
(Hossain, Roy, Mohammad, Nawar, & Dipta, 2021)	Electricity grid.	X		Natural disaster.	Characterize the grid resilience and reliability of areas in to a four-tier system based on the emerging electricity infrastructure.	3: partial mapping needed
(Mutani & Todeschi, 2018)	Modelling energy resilience		X	General risks and vulnerabilities.	Propose a flexible methodology to analyze energy sustainability and resilience. Model can be used to improve policies and practices for sustainability and resilience.	3: partial mapping needed

(Mutani, Todeschi, & Beltramino, 2020)	Energy system		X	General impacts on energy systems.	Present a dynamic energy model to calculate the energy demand of buildings and increase energy resilience.	3: partial mapping needed
(Ribeiro & Bailey, 2017)	Energy supply system and the local community		X	Service disruptions; pollution; high energy bills, and others.	Discuss the intersection of energy resilience and living in US communities. Proposed resilience indicators consider social, economic, and environmental impact in the valuation of the energy system resilience.	3: partial mapping needed
(Röder, Mitzinger, Thier, Wassermann, & Dunkelberg, 2020)	Heat supply		X	Unknown unknowns.	Evaluate resilience promoting factors in the context of heat supply if a German urban area. Usage of waste and river water increases diversity in the heat supply.	3: partial mapping needed
(Byfield, 2017)	Focus on electricity, but also, heat, gas, and communication grids.	X		Sabotage and attacks on the grid; natural disaster; scarcity of resources; failing infrastructure.	Considers four scenarios for Germany caused by different developments and presents ten measures to prevent associated negative consequences.	4: full mapping needed
(Chu, Richardson, & Rogowska, 2014)	Thermal grid	X	X	Energy supply interruptions	Discuss how the implementation of a thermal district heat grid increases the resilience of urban spaces in Canada.	4: full mapping needed
(Dyson & Li, 2020)	Electricity grid	X		Natural disaster; cyber and physical attacks; electromagnetic or geomagnetic events	Assess current strategies to improve resilience in the US and then introduces new elements that improve the evaluation of resilience and introduces resilience interventions that improve the process.	4: full mapping needed
(Ribeiro et al., 2015)	Urban energy and interaction with other systems (water, air, health, and economy).		X	Extreme weather; economic volatility; aging infrastructure.	Explore the role of and connection between energy efficiency and resilience, considering the whole community and its aspects.	4: full mapping needed
(York & Jarrah, 2022)	Community resilience.		X	Climate change risks, challenges and disruptions.	Assess extent and quality of energy initiatives including efficiency and renewable energy	4: full mapping needed

2.2 System resilience - sustainability and resilience frameworks

Sharifi & Yamagata (2016) propose a comprehensive conceptual framework for assessing urban energy resilience (Figure 2). According to the framework, an urban energy system is resilient if it is capable of "planning and preparing for", "absorbing", "recovering from", and "adapting to" any adverse events that may happen in the future. Integrating these four abilities into the system would enable it to continuously address "availability", "accessibility", "affordability", and "acceptability" as the four sustainability related dimensions of energy. The general dimensions can be applied apply to specific cases, but their importance vary from context to context, for example policymakers may want to stronger emphasis acceptability in democratic systems such as Swiss cities.

From a vast body of fragmented literature, Sharifi & Yamagata have then identified and collected a set of principles which underly a resilient system. These principles must then be assigned to criteria which are measurable and implementable to increase the resilience of a system. While their focus lied on urban energy resilience, most of these principles are also general principles, e.g., for resilience in industry (see D15.4).

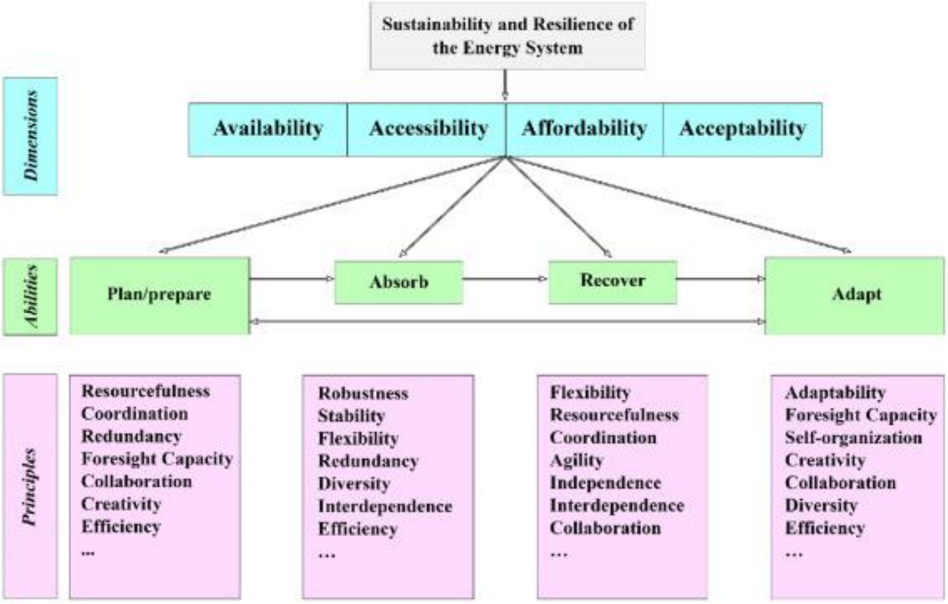

Figure 2: Sustainability and resilience framework for energy systems by Sharifi & Yamagata (2016) .

Other work has focused on quantitatively assessing resilience and aggregating various criteria to compound indices. One such example is the urban resilience index (Suárez, Gómez-Baggethun, Benayas, & Tilbury, 2016) or other studies applying aggregated indices (Esfandi et al., 2022; Martišauskas et al., 2022). Finally, overarching national concepts and roadmaps for resilience and decarbonisation have been proposed (David, Mathiesen, Averfalk, Werner, & Lund, 2017; Pilpola, Arabzadeh, Mikkola, & Lund, 2019). In this deliverable, we apply the Sharifi & Yamagata framework[5] and associated resilience measures to the cases study of Zurich.

2.3 Process resilience - socio-technical transitions

Transition studies are a useful stream of literature for understanding and assessing resilience, highlighting the increasing importance of adopting decentralized energy generation technologies. In particular,

[5] Which is licensed as open access, by the CC BY license v4, allowing us to share and adapt its content under attribution. We indicate if changes are made to the content (e.g., to criteria descriptions) in the corresponding parts.

the energy supply in regions and cities, which both tend to rely on decentralized systems, is a major focus of this stream (GEA, 2012).

Special attention is drawn to making the process of the transition, rather than only the status-quo or a sustainable end-state, more resilient against disruptions (Binder et al., 2017a). Binder et al. propose diversity and connectivity as two core principles of a successful and resilient transition process. In the social sphere, this boils down to including a diverse set of actors in decision processes, and to foster collaboration. With this, the transition will be accepted by various stakeholders. In the technical sphere, a well-balanced energy plant portfolio consisting of different technology groups may be essential. A good connection ensures an efficient operation. Binder et al. propose six indicators to measure the resilience of the process under various constellations. They find that an ideal regional energy governance system should both promote high diversity and connectivity.

The concept of resilient transition processes is also related to the shock concept in the SURE project, in which they differentiate between transient and disruptive shocks. A disruptive shock does not only affect the current system state but also the long-term transition pathway (Figure 3).

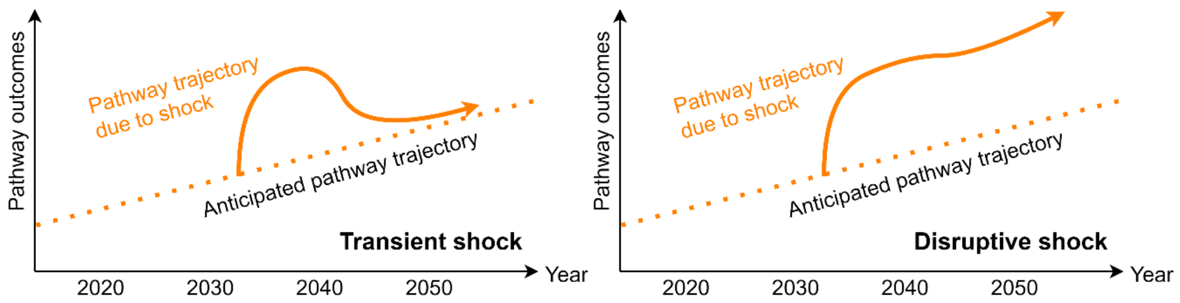

Figure 3: Comparison between a *transient shock* and a *disruptive* shock. Based on Panos et al. (2022).

2.4 Legitimization and social justice

While literature on urban energy resilience is gaining attention from the scientific community and policy makers, some criticise that such concepts need to better consider social justice. In a co-creational process, science and policy makers should ask themselves the five “Ws of urban energy policy”. This means, for whom, what, when, where and why is urban resilience relevant (Meerow & Newell, 2016). Meerow and Newell argue that a resilience concept that does not take the five Ws into consideration has a general lack of meaning, can’t properly depict the scalar dimensions, trade-offs, is inherently conservative and doesn’t change the status quo enough (Meerow & Newell, 2016). The meaning of the five Ws is:

- **Who** designs the resilience concept, to whose benefit the concept is made and who is included in the concept. The outcome of a resilience concept is dependent on the worldview and priorities of their creators, the urban circumstances can be quite variable based on the definition of the urban area, e.g. is the surrounding suburban area also considered in the concept or not.
- **What** will be made resilient to what threat. Furthermore, to which extent enables the concept to differentiate between different shocks and their consequences. Can a compromise between different threats be made to achieve a more wholistic resilience strategy?
- **When** is resilience considered, differentiating between its short term and long-term perspective. Is the goal of the concept to be resilient to a short-term threat like a cold spell or should it be resilient to a long-term shock like climate change? Should it react to a past event or anticipate a future development?
- **Where** is the resilient concept implemented. Cities are always linked to their surroundings and to the overarching conditions on a national and global scale.

- **Why** is a resilience concept established. This prevents an unnecessary retention of the status quo. Should a system just revert back to its prior state after a shock or could it be rebuilt differently?

In summary, a Swiss urban energy resilience and sustainability concept should consider the political circumstances, trade-offs, interconnections, multiple scales, and social justice. We propose to ask the 5Ws during a co-creational workshop (see in Section 3.2), including stakeholders from the city of Zurich and the administration, relevant private sector and general public. Using such an approach also increases the process resilience by including a diverse set of collaborating actors (see Section 2.3 above).

3 General resilience concept

The main research goal of this deliverable is to propose a resilience concept for the specific context of urban energy in Switzerland. The task builds upon the respective shock concept developed by SURE for the national scale. We adapt existing frameworks from scientific literature (see 2.2) to highlight the principles which a resilient system should follow, and suggest which indicators are relevant and need to be measured in the context of urban energy resilience. A special emphasis is put on operational aspects, in other words, on the examination of criteria relevant and useful for the Swiss urban context and on data needed to implement the concept at the urban level. The relevance will be identified through stakeholder involvement, referring to "five Ws" of Urban Resilience. Part of this deliverable is dedicated to the definition of a set of different types of shocks which will be used in the following tasks to assess the resilience performance.

3.1 The resilience and sustainability concept

We base the sustainability and resilience concept on a qualitative procedure inspired by the previously mentioned framework. Using a stepwise approach, we identify relevant resilience and sustainability dimensions, evaluate the robustness of a system to shocks and propose criteria and measures related to the principles to counteract these shocks. Finally, the sustainability of these measures needs to be analysed. Ideally, the process includes relevant stakeholders.

Table 3: Proposal of the general concept to appraise the resilience and sustainability. Own consideration. We give examples for the application in the case of Zurich (see also next Section for workshop design).

Task	Description of task	Application in case study for Zurich
1: Build on an existing **framework**.	A framework facilitates the identification of principles and criteria.	See this deliverable.
2: Evaluate **shock** relevance.	Evaluate the relevance of shocks for the specific system (potentially brainstorm measures to tackle them).	First talks with stakeholders hold, further results from workshop.
3: Select and evaluate **criteria**.	Measurable and specific criteria are selected and applied to the context and relevant shocks.	First measured identified, further results from workshop,
4: Consider **sustainability**.	Appraise the sustainability implications of resilience criteria (e.g., associated GHG-emissions, implications on SDGs and circle indicators, see Section 5).	Discuss resilience criteria in the context of Zurich's strategy, e.g. the SDG.
5: Aggregate **indicators**.	Measurable criteria / indicators are combined to an index to evaluate overall resilience and sustainability.	Appropriate indexes depend on the workshop outcomes.
6: Discuss **social justice and policy**.	Discuss the 5Ws of urban resilience and design policies to implement the resilience strategy.	As part of final discussion

In this deliverable, we focus on steps 1-3, mainly based on literature review, but also on own considerations and stakeholder inputs. We here present a set of criteria and measures. However, we have not yet assessed all of the relevant criteria, an aggregate index or the effects on sustainability (steps 3-5). In future work related to WP14, we will however conduct a workshop with relevant stakeholders to tackle, among other goals, the indicator evaluation/aggregation, the sustainability assessment., and potentially the social justice discussion. Potential outcomes can be a city heat-supply resilience index.

3.2 Workshop design and stakeholder input

To increase political relevance and legitimisation, we suggest that the resilience concept should be evaluated during a co-creational process. Appropriate methods include interviews, workshops, focus groups or the world cafe method. We recommend the workshop format, as it enables deep and collaborative work. Potential stakeholders are professionals from the local energy administration, energy planning offices, utilities, and people from the general public.

The aim of the workshop is to identify and appraise shocks and criteria for the urban energy context in the investigated urban region, here Zurich. In the first part of the workshop, shocks and threats are presented, for example the shocks defined by SURE. Other relevant shocks may come up. Stakeholders discuss their relevance and evaluate them (see Section 3.3). Then, resilience principles are shown for information purposes (see Section 3.4), and stakeholders evaluate relevant criteria and map them to the previously identified shocks (see Section 3.5).

Between the sessions, the researchers aggregate the knowledge to a tentative resilience strategy, presenting the consensus about what criteria and measures should be implemented to improve the resilience against the most relevant shocks. If possible, the researchers assign indicators and calculate an aggregate index to facilitate further discussions. In the second part of the workshop, the political legitimisation of the concept is discussed. We suggest applying the “5Ws of urban resilience” (see Section 2.4). Finally, potential policy measures could be assessed.

In this deliverable we present the outcomes of in-depth interviews with stakeholders from the energy and security administration of the city of Zurich (see Section 4.1). In the interviews, we have received general context information about current resilience strategies and validated the relevance of shocks in the urban context. In a future amendment to this deliverable, we may present the results of the workshops described in this section.

3.3 Shock and threats

Shocks are sudden events that affect the pathway trajectory of a system state or the transition towards a certain goal. In the scope of urban energy, the shock concept is useful to assess “the sustainability, robustness and resilience of the energy transition to a carbon-free economy in 2050” (Panos et al., 2022). With a well-rounded resilience concept, a system will be enabled to either bounce back to its original pathway or follow a new one, depending on the characteristics of the shocks (i.e., whether it is a transient or disruptive shock, see Section 2.3).

Table 4 provides an overview of potentially relevant shocks and their general effects. We argue that the shocks and their effects need to be considered separately for the national and urban energy systems due to different needs and preconditions.

Table 4: Shock descriptions and their effects (relevant in Switzerland), adapted from the SURE project (Panos et al., 2022), the framework (Sharifi & Yamagata, 2016), own/stakeholders’ considerations. Effects for general context, for differentiation on urban and national level see Section 4.1.

Shock	Description	General effects
Shocks identified by the SURE project		
1: Financial shock	A deterioration of exchange rates between Asia and Switzerland affects import prices.	- Relevant if dependent on global market. - Affects energy prices.

		- Technology and decarbonisation costs increase. - Potential need for financial support
2: Heat wave	High temperatures and low precipitation, leading to heat island effects.	- Puts the energy system under stress. - Security of hydropower supply under stress. - Higher electricity demand due to air-conditioning - Heat exchange of air-conditioners and power plants impaired. - Heat accumulation impairs the efficiency, well-being and health of residents.
3: Cold spell	Sudden cold wave and dry fall.	- Puts the energy system under stress. - Security of hydropower supply under stress - Problem for peak-load management. - Higher electricity demand due to heating needs in public transportation. - Only low quantities of energy can be imported because of general European demand.
4: Societal change	Sudden population growth in Switzerland due to geopolitically or climate-change induced refugee crisis.	- Uncoordinated response may lead to disputes, nationally and internationally. - Increase of demand for energy, food, goods and building materials.
5: Nuclear power reintroduction	A political decision around 2030 to keep currently running nuclear power plants and introduce new ones to the Swiss power mix.	- Potentially stranded assets of renewables. - More centralised energy supply. - Long-term energy planning needs to be adapted.
Shocks identified by TEP and the administration of Zurich		
6: Denial of usage rights	Conflicts of interest impede the installation of district heat stations or other technologies unless alternative locations are available.	- May slow down the energy system transformation. - Affects costs.
7: Opposition	Sudden public resistance against certain technologies (e.g., tapping renewable energy from lake, rivers, ground water) or against ambitious energy and climate policy.	- Potentially stranded investments. - May slow the energy transition.
8: Legal barriers	Unexpected legal barriers (e.g., restricting technological, commercial or policy approaches).	- Slows the energy transition in specific areas.
9: Technological "game changers"	New mature energy technologies appear.	- Stranded investments. - Potential benefits.
10: Energy shortage	Energy shortage ("Energiemangellage") caused by various technical or geopolitical reasons	- Reduction of the energy demand. - Controlled blackouts
11: Cyberattacks	Attack of the IT infrastructure. Risk increases with higher digitalisation and electrification (such as smart meters, electric vehicles).	- Partial or full failure of the affected services.

The shock concept is an essential component of the SWEET SURE project, in which five shocks were selected for deeper investigation (Panos et al., 2022). The *SURE shocks* are based on stakeholder inputs and will be modelled also in other work packages as part of the SURE scenario concept. They relate to sudden global and regional events that potentially affect the decarbonisation pathways of Switzerland, or their costs.

However, these five shocks are only a selection of potential threats and vulnerabilities; literature lists several other such peak oil, volatility of global energy markets, old infrastructure, technical failures and lock-ins or privatisation (Sharifi & Yamagata, 2016). In the context of this case study, we also consider public resistance against technologies and policies, as well as legal barriers and technological “game changers” as relevant shocks. Furthermore, with stakeholder involvement, we have identified other shocks relevant for the urban level, namely the situation that space is limited or that usage rights would be denied.

It should be noted that the shocks defined in this deliverable are not *inherently* negative. For instance, opposition, nuclear power re-introduction or the denial of usage rights are likely the results of political or democratic processes. However, in the scope of the energy transition, we regard them as stepping-stones affecting the current pathway trajectory towards a decarbonised economy. Some actors such as the municipal administrations or energy utilities may consequentially be faced with adverse effects such as stranded investments if previous plans suddenly change (e.g., regarding heat infrastructure and energy plant investments). Ultimately, any adversities or opportunities associated with the shocks depend on the point of view.

3.4 Resilience principles

According to the literature, resilience principles serve as a general “compass” to assess the ability of a system to prepare and plan for, absorb, recover from, and more successfully adapt to any disruptions. They are useful to categorise practical measures and obtain an overarching strategy. We base our concept on a selection of urban energy resilience principles proposed by (Sharifi & Yamagata, 2016). Evaluating all of their 17 principles (see Figure 2), associated criteria and indicators goes not only beyond the scope of this deliverable, but is probably infeasible for most policymakers, and therefore, we focus on the four most relevant criteria. These are, as suggested by Sharifi & Yamagata, “efficiency”, “diversity”, “adaptability” and “redundancy”. In Table 5, we compile these principles and describe their relevance for urban energy.

Table 5: Principles of a resilient system which apply to urban energy systems as adapted from the literature review by Sharifi & Yamagata (2016). (For primary sources, please see the corresponding review article.)

General principles	Description	Example for the city of Zurich
Redundancy	- Availability of components with similar functions to enhance adaptive capacity. - The failure of one component would thus not result in failure of the system. - Negative impacts on system efficiency and costs.	- The use of ring pipelines for district heating to provide redundant heat supply.
Diversity	- Hedge against supply disruptions by having multiple options available. - Diverse land and infrastructure use, knowledge, economy and demographic structure and different supply providers.	- Ensuring the availability of different low-carbon fuels to hedge against supply disruptions of natural gas.
Adaptability	- Ability to learn from shocks and improve urban systems - Adapt to changing conditions.	- Continuous resilience monitoring and management
Efficiency	- Reducing energy intensity and demand for inputs, while maintaining the same output.	- Foster building insulation

3.5 Resilience criteria

To fulfil the resilience principles, specific and more concrete criteria need to be fulfilled. The Sharifi & Yamagata framework suggests a large set of design criteria which belong to five themes: (i) infrastructure; (ii) resources; (iii) land use, urban geometry and morphology; (iv) governance; and (v) sociodemographic aspects and human behaviour (see Appendix 8 for a full overview). These criteria are implemented by appropriate measures and should be measurable by indicators. With the application of existing criteria to the case study in Zurich, we contribute to the literature; Sharifi & Yamagata state the necessity to apply their work to actual cases.

A central aspect of our resilience concept, developed hereafter, is to identify, select and evaluate relevant criteria for the specific case, for instance Zurich. This selection process enables policymakers to focus on the most relevant aspects and facilitates the development of measures and indicators.

For each shock, different criteria may be more or less relevant. To evaluate their relevance in the context of specific shocks, we suggest to following a procedure. We illustrate this procedure with an exemplary set of criteria about the urban infrastructure theme:

1. **Pre-selection of criteria** that are applicable to an urban context in Switzerland, specifically Zurich. For this we have rated the relevance of each criterium from 1 to 5 based on general considerations such as the applicability (e.g., criteria aimed at arid regions or less developed countries do not apply), whether a criterion is feasible in Zurich (e.g. large wind-power plants have low potential), and if there is a need to promote the criteria or measures (e.g. LED already highly diffused). Furthermore, a focus on energy resilience will exclude measures aimed at other topics such as flooding.

2. **Limiting the number of criteria** to those with a general relevance score of at least three (highlighted in orange). This step limits the number of criteria to a more manageable amount, which is particularly useful in a workshop setting, but also in regard to policy implementation. Special attention is advised if too many criteria are considered relevant. It may be necessary to set an upper limit for the number of considered criteria.

3. **Evaluation of the relevance** of the remaining criteria in context of the shocks. The main question is whether the criteria increase the resilience against the specific shocks.

4. **Identify potential trade-offs** between the criteria and associated measures.

While our evaluation below is only a tentative result, we suggest applying the procedure during a stakeholder workshop. In the workshop, participant with appropriate system knowledge will conduct the evaluation from various perspectives. A workshop participant may want to take notes of the reasoning underlying the final ratings.

3.5.1 Tentative and exemplary criteria evaluation

Table 6 depicts an example evaluation of selected criteria for three of the SURE shocks, namely the heat wave, cold spell and financial shock. As the heat wave affects electricity prices and the stability of the power grid (due to the increased cooling demand), criteria related to urban infrastructure are relevant. On site energy production and diversification of energy supply lowers international dependence, providing additional stability and lower costs. Concrete means to cool such as solar absorption cooling are an option. Furthermore, local storage facilities (ln28) or parks to lower the urban temperatures (ln35), as well as other criteria listed in the Appendix Section 8., are worth considering.

As for the case of the financial shock, to increase resilience against higher energy prices, criteria related to energy and urban governance are relevant (see Appendix). If the supply chains are mainly abroad, the shock also affect technology costs, leading to higher decarbonisation and policy support cost (Hoggett, 2014). The criteria *market liberalisation (G039)* captures the need to have a more resilient and adaptable supply chain.

Table 6: Illustration of the criteria appraisal concept based on tentative data. Relevance ratings: 1 (very low) to 5 (very high). Positive ratings denote that the measure mitigates the shock, while negative ratings increase the vulnerability to the shock. Fields highlighted in orange are those with a relevance score over 3 for the Zurich case study. Criteria are adapted from the Sharifi & Yamagata framework

Crite-rium	Description of the criterium	Relevance for CH	Relevance for shock		
	Supply, transmission, distribution		Financial	Heat wave	Cold spell
In3	Diversification of energy supply (fuel mix, multi-sourcing, type of generation)	5	4	3	5
In5	Energy production near point of use (colocation of supply and demand)	3	-3[1]	3	3
In6	On-site energy production (photovoltaics, micro combined heat and power, tri-generation, thermal panels, small wind turbines mounted at the corners of the roof)	3	3	4	4
In7	Solar absorption cooling	3	0	4	0
In8	Large wind turbines located outside the built-up area	2			
In9	Large solar thermal collectors	1			
In12	Ground source heat pumps	4	3	4	2
In13	Waste heat or biomass-fueled combined heat and power plants	3	3	2	3
In15	Biomass supply chain, wood pellet systems	2			
In17	Regular maintenance	4	2	2	2
In18	Generation, transmission, and distribution efficiency (leakages, etc.)	2			
In19	Age of the fleet (feeder lines, etc.)	1			
In20	Phasing out obsolete and/or damaged assets and introducing new and more efficient technologies	3	2	2	2
And more… (see Appendix)					
Notes (to be completed for other criteria): 1) Energy production near point of source requires capital investments which may be more expensive in the context of a financial shock, however, rooftop PV are an advantage for other shocks.					

4 Application of resilience for urban energy in Zurich

4.1 Shock resilience in the context of urban energy

Based on our own considerations and the interviews with the stakeholders from the city of Zurich, we have assessed the relevance and effects of the proposed shocks, as well as possibilities and measures to tackle the shocks (overview in Table 7 and details in the subsections). As SURE shocks have been devised in a workshop with a national viewpoint, our special focus lies on comparing their relevance on the urban and national level. Our current findings show that there are considerable differences between the relevance of shocks on these levels.

The shocks include SURE shocks and other potential threats such as cyberattacks, as well as shocks discussed during the stakeholder interview (Section 3.3). In a potentially upcoming workshop, other shocks may be identified and evaluated, or current shocks revaluated; these will be part of a future amendment of this urban resilience concept.

Table 7: Tentative evaluation of shock relevance for urban and national energy systems. Urban relevance according to stakeholder input, national relevance according to own consideration. The relevance of all national SURE shocks is assumed to be at least "mid". N.a. = not assessed.

	Shock	Relevance on national Level	Relevance on urban Level
1	Financial shock	Mid	Low
2	Heat wave	Mid	High
3	Cold spell	Mid	High
4	Societal change	Mid	Low
5	Nuclear power re-introduction	Mid	Low
6	Denial of usage rights	Low	High
7	Opposition	N.a.	Mid
8	Legal barriers	N.a.	N.a.
9	Technological game changers	unclear	unclear
10	Energy supply shortage	N.a.	N.a.
11	Cyberattacks	N.a.	N.a.

4.1.1 Resilience against financial shocks (shock 1)

A financial shock, e.g., caused by higher exchange rates in Asia, may lead to higher capital costs and affects the energy prices, particularly if supply changes are affected. The city of Zurich argues that these effects concern all of Switzerland, and hence have higher relevance on the national and international level, such as the federal state and the European Union. The city does not see considerable room for action for cities to mitigate these shocks; measures like mid to short term storage on an urban scale would not considerably affect this shock. The potential space in the city to install seasonal gas and water storage tanks is limited. Overall, these factors render the shock a concern on the national level, and the city does not currently have a dedicated strategy to increase resilience against international financial shocks.

Nevertheless, Zurich sees a general need to make the system less vulnerable and more efficient. This will be achieved by decarbonising the power and heat supply in Zurich, and by substituting various fossil energy carriers with regional electricity and heat production (e.g., using river water, wood, waste water heat). Therefore, the dependence on foreign energy supply, and hence potential effects of exchange rates should be lowered.

4.1.2 Resilience against heat waves (shock 2)

Due to climate change, heat waves will occur more frequently (IPCC, 2018). This affects the electricity demand and the supply of energy for cooling and heating purposes (e.g., less water in hydro storage, low flow in rivers), and hence, electricity prices and the stability of the power grid. Criteria related to power grid stability should be considered. Redundancy is an essential resilience principle, which translates to having backup power generation available.

To deal with energy demand and supply fluctuations, the main possibilities in Zurich lie in daily storage measures and demand side management (DSM). Through smart meters, a shift of power usage to times of low demand would be a possibility. Regarding large scale seasonal storage, the possibilities of the city are more limited.

The municipality of Zurich is trying to combat the heat island effect, in other words the accumulation of heat in urban areas. With its current plan, the city has identified a toolbox consisting of eight fields of action (e.g., green and open water spaces, streets, buildings, etc.) and 13 measures (e.g., greening of roofs, albedo on streets, other materials, etc.) to mitigate and adapt to urban heat (Stadt Zürich, 2020). One strategy currently considered by the municipality is active air conditioning, in which the lake would act as a sink for the heat exchange.

However, there are barriers to the active cooling of existing buildings, particularly related to the distribution. First, cold cannot be easily distributed in existing buildings without add-on retrofit measures (due to potential water condensation issues at radiators). Second, space may be a limiting factor. Third, the conventional district heating grid may not be an option either. In contrast, for newly built or retrofitted areas, Zurich is already actively considering the current and future cooling demand.

Finally, as in the case for a financial shock, the availability of energy resources is an issue. The strategy of Zurich is to diversify their energy sources. For instance, synthetic or biogases burned in conventional boilers or combined heat and power plants are options to cover demand in peak hours.

4.1.3 Resilience against cold spell (shock 3)

To tackle cold spells, existing planning criteria such as the norms of the Swiss society of engineers and architects (SIA) have been useful and successful. According to the stakeholder, there is thus no urgent need to fundamentally revise these tools as different guidelines promote the use of efficient and low-carbon heating options. To foster the adoption of district heating and decentralised heat pumps, support mechanisms exist both on the city and cantonal levels. Nevertheless, ensuring the availability of conventional boilers, low carbon fuels, and storage capacity remain relevant resilience measures on the urban level, particularly if the heat supply is being electrified. On the national level, larger seasonal storage is relevant, as well as international coordination to decarbonise the European energy system.

To deal with energy demand and supply fluctuations, the main possibilities in Zurich lie in daily storage measures and possibly DSM. Through the use of smart meters, a shift of power usage to low demand times would be a possibility. Regarding seasonal storage, the possibilities of the city are more limited.

The use of wood needs to be reviewed. Wood pellets, for instance, are a means to cover peak load, and are storable. Currently, the City of Zurich and the Canton of Zurich are net importers. However, wood is part of the decarbonisation strategies of various countries, and hence, the supply may be an issue in the future. Current studies, on behalf of the city of Zurich, investigate the use of wood in the energy system.

4.1.4 Societal change and nuclear power re-introduction (shock 4 & 5)

Major societal changes might affect the demand for products and energy, and the availability of new workforce in the industry, which are potentially positive outcomes. Currently, Zurich is not actively pursuing an energy- or climate-focused strategy to buffer a sudden influx of refugees. Past experiences have shown that the urban energy system in Zurich can handle increased demand, and general energy-related measures will already contribute to making the grid more reliable. However, it needs to be considered that the immigration rate is likely to increase due to climate change. Therefore, the stakeholder in Zurich speaks in favour of a national long-term strategy.

Regarding shock 5, a potential nuclear power re-introduction is not a current concern for the city. The opinion of the stakeholder is that the deployment of renewables needs to be increased, regardless of the risk.

4.1.5 Denial of usage rights and opposition (shock 6 & 7)

First, a relevant issue is the lack of space for the energy transition in Zurich. For instance, district heating plants, as well as heat exchangers of (air/water) heat pumps can have considerable space requirements. This is particularly relevant in an urban area because space is limited. The associated shock is the denial of usage rights, caused by conflicts of interest and political decisions in the administration. Resilience against this shock is established by considering alternative locations during scouting, and by using a multi criteria analysis.

Second, Zurich does currently not consider opposition against the use of lake or groundwater as a significant risk. These topics are currently not very prominent on the political agenda and in the general public. On the other hand, more visible changes, e.g., in the area of the Limmat, could be a potential risk.

4.1.6 Cyberattacks. technological game changers and energy supply shortage (shock 9, 10 & 11)

The risk assessment and resilience against cyberattacks is the responsibility of the energy utility (i.e., EWZ). We have not yet assessed its relevance on the urban scale.

Insights about the effect of game changing technologies are speculative. On the one hand, new technologies and energy carriers could lower costs of the energy transition. For instance, the current district heating system requires space, which may be reduced if low-carbon fuels conquered the market. On the other hand, stranded investments may be an issue, particularly if investment have not been paid-off. Overall, the relevance for the urban and national level needs to be further investigated.

Finally, potential measures to tackle an energy supply shortage have been publicly communicated in 2022[6]. These include, among other measures frugal heating, reduction of hot water consumption, reduction of electronic appliance use. In addition, heating oil has been stored for up to 1 month to uphold the district heating grid.

4.2 Resilience analyses in Zurich

Until 2022, the city of Zurich and EBP have conducted various workshops and analyses to assess relevant risks and threats to the critical infrastructure (EBP, 2021). While they build on existing risk and threat assessments, their current approach takes a more holistic approach. “In contrast to conventional hazard analyses, the resilience approach focuses on the functionality of the city and not on individual hazard-specific damages” (Blaser & Meile, 2019). In general, continuous resilience monitoring and management, consisting both of strategic and operational tasks, builds the foundation of their resilience concept. The strategic phase consists of analyses of resilience, risks and threats, while the operational one is about identifying and prioritising measures.

In conclusion, they deem that resilience is essential for the city Zurich (Blaser & Meile, 2022). They identified 91 potential measures such as introducing a business continuity management, continuous management efforts, and periodical exercises. These also include specific measures such as promoting the use of ring pipelines for district heating. Furthermore, they mention several remaining issues: first, the focus on few energy carriers like electricity (for the decarbonisation of mobility), second, the lack of measures to ensure an uninterrupted power supply, and third, a missing definition about what the basic supply of heat and cold entails. Our upcoming workshops in WP14 can help take a step further to address these issues, and to improve the resilience of Zurich.

5 Sustainability goals, assessment, and application in Zurich

While a well-rounded urban energy resilience concept should address the sustainability dimensions “availability”, “accessibility”, “affordability”, and “acceptability”, more specific goals and indicators have been proposed in order to plan for and assess sustainability.

To promote a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (WCED, 1987), we suggest following the guidelines of the 17 Sustainable Development Goals (SDG), one of the most prominent sustainability frameworks.[7] Although not all of the goals are equally important for the urban energy context in Switzerland, cities still have untapped potential regarding various energy-related goals (Figure 4), for instance, affordable and clean energy (7), infrastructure (9) sustainable cities (11), responsible consumption (12), climate action

[6] See https://www.stadt-zuerich.ch/energie/de/index/energiepolitik/energieversorgung.html (accessed 23.2.23)

[7] See https://sdgs.un.org/goals

(13). Urban areas may want to act on these goals, while also considering the wholistic picture, in other words, the interrelationship with the other goals and the resilience measures (see Section 3.5).

Figure 4: 17 SDGs of the United Nations

To measure sustainability and reach these goals, cities in Switzerland can follow the federal system “cercle indicateurs”, consisting of 32 sustainability indicators. Alongside the “Strategy Zurich 2035” and the 2000-Watt-Society, Zurich is already considering both the SDGs and the indicators (see Section **Error! Reference source not found.**). We deem these frameworks and the current strategies to be comprehensive and will thus not propose a new concept. However, we do suggest that sustainability goals and indicators should be part of the resilience concept.

This strategy has impacts on the resilience of the city. For instance, while the planned shift from internal combustion engine vehicles will reduce the carbon footprint of Zurich (given the low-carbon electricity mix), it decreases resilience against various shock that affect power production (EBP, 2021). Although there may also be fossil fuels supply shortages, gasoline is better storable. Therefore, it is essential to consider sustainability and resilience aspects in parallel.

6 Conclusion and Outlook

In this deliverable, we have illustrated the relevance and need for a resilience and sustainability concept for urban energy systems in Switzerland, applied a framework to the Swiss context, and assessed shocks and their relevance in an urban context. Furthermore, we highlight the need to differentiate between the resilience of a system state and of the transition process.

Our review has revealed a broad body of literature focusing on specific aspects of resilience. Comprehensive frameworks combining the current knowledge have been proposed, notably the one by Sharifi & Yamagata. With this deliverable, we suggest that this framework is applicable to the concrete case of the city of Zurich. Following a qualitative procedure involving several steps, such a framework may build the foundation of a future stakeholder workshop. Upcoming work should therefore apply the proposed procedure to further develop a resilience and sustainability concept for Zürich. Result will potentially be amended to the current deliverable.

Furthermore, we have identified relevant shocks and discussed these with stakeholders from the city of Zurich. The preliminary results show that the relevance of several shocks, also those identified in the SURE project, vary between urban and national governance levels. For some of these shocks, such as heat and cold waves, the city of Zurich has already considered appropriate measures. Nevertheless, fundamental resilience questions remain, for instance related to the heat supply. Quantifying the effect of measures to tackle such issues, and conducting workshops to legitimise the measures could be next steps. For the continued work in WP14, a potential focus could lie on assessing and modelling the future heating system of Zurich with different carriers. Resilience principles such as redundancy and diversity provide a basis to inform such analyses, for instance through self-sustained neighbourhoods.

7 References

Anderson, K., Laws, N., Marr, S., Lisell, L., Jimenez, T., Case, T., … Cutler, D. (2018). *Quantifying and Monetizing Renewable Energy Resiliency*. *Sustainability*, *10*(4), 933. https://doi.org/10.3390/su10040933

Arafah, Y., & Winarso, H. (2017). *Redefining smart city concept with resilience approach*. *IOP Conference Series: Earth and Environmental Science*, *70*, 012065. https://doi.org/10.1088/1755-1315/70/1/012065

ARE. (2009). *Monitoring urbaner Raum Schweiz*. Bundesamt für Raumentwicklung (ARE).

Bai, X., Dawson, R. J., Ürge-Vorsatz, D., Delgado, G. C., Salisu Barau, A., Dhakal, S., … Schultz, S. (2018). *Six research priorities for cities and climate change*. *Nature*, *555*(7694), 23–25. https://doi.org/10.1038/d41586-018-02409-z

Binder, C., Mühlemeier, S., & Wyss, R. (2017a). *An Indicator-Based Approach for Analyzing the Resilience of Transitions for Energy Regions. Part I: Theoretical and Conceptual Considerations*. *Energies*, *10*(1), 36. https://doi.org/10.3390/en10010036

Binder, C., Mühlemeier, S., & Wyss, R. (2017b). *An Indicator-Based Approach for Analyzing the Resilience of Transitions for Energy Regions. Part I: Theoretical and Conceptual Considerations*. *Energies*, *10*(1), 36. https://doi.org/10.3390/en10010036

Blaser, L., & Meile, M. (2019). *Wie resilient ist die Stadt Zürich? Transforming Cities*, (4), 52–55.

Blaser, L., & Meile, M. (2022). *Resilienz als Erfolgsfaktor für Zürich*. *Transforming Cities*, (2), 42–45.

Bueno, S., Bañuls, V. A., & Gallego, M. D. (2021). *Is urban resilience a phenomenon on the rise? A systematic literature review for the years 2019 and 2020 using textometry*. Elsevier Ltd. *International Journal of Disaster Risk Reduction*, *66*. https://doi.org/10.1016/j.ijdrr.2021.102588

Byfield, S. (2017). *Das Energiesystem resilient gestalten* .

Chelleri, L., Olazabal, M., Kunath, A., Minucci, G., Waters, J., & Yumalogava, L. (2012). *Multidisciplinary perspectives on Urban Resilience*.

Chu, T., Richardson, M., & Rogowska, M. (2014). *The Importance of District Energy in Building Resilient Cities*. Canadian Academy of Engineering. In C. Bowman & R. Marceau (Eds.), *Canada: Becoming a Sustainable Energy Powerhouse* (Preprint edition, pp. 169–186).

David, A., Mathiesen, B. V., Averfalk, H., Werner, S., & Lund, H. (2017). *Heat Roadmap Europe: Large-Scale Electric Heat Pumps in District Heating Systems*. *Energies*, *10*(4), 578. https://doi.org/10.3390/en10040578

Dyson, M., & Li, B. (2020). *Reimagining Grid Resilience*.

EBP. (2021). *Resilienzanalyse Stadt Zürich (unpublished)*.

Esfandi, S., Rahmdel, L., Nourian, F., & Sharifi, A. (2022). *The role of urban spatial structure in energy resilience: An integrated assessment framework using a hybrid factor analysis and analytic network process model*. *Sustainable Cities and Society*, *76*, 103458. https://doi.org/10.1016/j.scs.2021.103458

GEA. (2012). *Global Energy Assessment - Toward a Sustainable Future*. Cambridge.

Hoggett, R. (2014). *Technology scale and supply chains in a secure, affordable and low carbon energy transition*. *Applied Energy*, *123*, 296–306. https://doi.org/10.1016/j.apenergy.2013.12.006

Hossain, E., Roy, S., Mohammad, N., Nawar, N., & Dipta, D. R. (2021). *Metrics and enhancement strategies for grid resilience and reliability during natural disasters*. *Applied Energy*, *290*, 116709. https://doi.org/10.1016/j.apenergy.2021.116709

IPCC. (2018). *Global Warming of 1.5°C*. *Journal of Chemical Information and Modeling*, *53*(9), 1689–1699. https://doi.org/10.1017/CBO9781107415324.004

Jasiūnas, J., Lund, P. D., & Mikkola, J. (2021). *Energy system resilience – A review*. *Renewable and Sustainable Energy Reviews*, *150*, 111476. https://doi.org/10.1016/j.rser.2021.111476

Kendziorski, M., Weyhing, C., Dupke, R., Kemfert, C., von Hirschhausen, C., Weinhold, R., … Zozmann, E. (2022). *Resilienz in der Schweizer Energieversorgung auf dem Weg zur Klimaneutralität - Ein modell-basierter Szenarienvergleich für 2035*.

Martišauskas, L., Augutis, J., Krikštolaitis, R., Urbonas, R., Šarūnienė, I., & Kopustinskas, V. (2022). *A Framework to Assess the Resilience of Energy Systems Based on Quantitative Indicators*. Multidisciplinary Digital Publishing Institute. *Energies 2022, Vol. 15, Page 4040*, *15*(11), 4040. https://doi.org/10.3390/EN15114040

Meerow, S., & Newell, J. P. (2016). *Urban resilience for whom, what, when, where, and why?*. Routledge. *Urban Geography*, *40*(3), 309–329. https://doi.org/10.1080/02723638.2016.1206395

Mola, M., Feofilovs, M., & Romagnoli, F. (2018). *Energy resilience: research trends at urban, municipal and country levels*. *Energy Procedia*, *147*, 104–113. https://doi.org/10.1016/j.egypro.2018.07.039

Mühlemeier, S. (2018). *Grosse Stadtwerke – theoretische und empirische Exploration eines besonderen Akteurs in der Energiewende Deutschlands und der Schweiz*. *Zeitschrift Für Energiewirtschaft*, *42*(4), 279–298. https://doi.org/10.1007/s12398-018-0237-z

Mutani, G., & Todeschi, V. (2018). *Energy Resilience, Vulnerability and Risk in Urban Spaces*. *Journal of Sustainable Development of Energy, Water and Environment Systems*, *6*(4), 694–709. https://doi.org/10.13044/j.sdewes.d6.0203

Mutani, G., Todeschi, V., & Beltramino, S. (2020). *Energy Consumption Models at Urban Scale to Measure Energy Resilience*. *Sustainability*, *12*(14), 5678. https://doi.org/10.3390/su12145678

Nik, V. M., Perera, A. T. D., & Chen, D. (2021). *Towards climate resilient urban energy systems: a review*. *National Science Review*, *8*(3). https://doi.org/10.1093/nsr/nwaa134

Panos, E., Kober, T., Fragkiadakis, K., Paroussos, L., Cellina, F., Maayan, J., … Trutnevyte, E. (2022). *SWEET Call 1-2020. SURE Deliverable report- 1st scenario protocol capturing the definition of pathway and shock scenarios.*

Pilpola, S., Arabzadeh, V., Mikkola, J., & Lund, P. D. (2019). *Analyzing National and Local Pathways to Carbon-Neutrality from Technology, Emissions, and Resilience Perspectives—Case of Finland*. *Energies*, *12*(5). https://doi.org/10.3390/en12050949

Ribeiro, D., & Bailey, T. (2017). *Indicators for Local Energy Resilience*. Washington.

Ribeiro, D., Mackres, E., Baatz, B., Cluett, R., Jarrett, M., Kelly, M., & Vaidyanathan, S. (2015). *Enhancing Community Resilience through Energy Efficiency*.

Röder, J., Mitzinger, T., Thier, P., Wassermann, T., & Dunkelberg, E. (2020). *Analyse und Bewertung der Resilient urbaner Wärmeversorgungskonzepte - Methodenentwicklung und Anwendung*. Bremen.

Rusco, F. (2021). *Electricity Grid Resilience- Climate Change Is Expected to Have Far-reaching Effects and DOE and FERC Should Take Actions*.

Saboo, A. K., Morari, M., & Woodcock, D. C. (1985). *Design of resilient processing plants—VIII. A resilience index for heat exchanger networks*. *Chemical Engineering Science*, *40*(8), 1553–1565. https://doi.org/10.1016/0009-2509(85)80097-X

Sanchez, A. X., Osmond, P., & van der Heijden, J. (2017). *Are Some Forms of Resilience More Sustainable than Others? Procedia Engineering*, *180*, 881–889. https://doi.org/10.1016/j.proeng.2017.04.249

Sharifi, A., & Yamagata, Y. (2016, July 1). *Principles and criteria for assessing urban energy resilience: A literature review*. Elsevier Ltd. *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2016.03.028

Stadt Zürich. (2020). *Fachplanung Hitzeminderung*. Stadt Zürich. Zürich.

Suárez, M., Gómez-Baggethun, E., Benayas, J., & Tilbury, D. (2016). *Towards an Urban Resilience Index: A Case Study in 50 Spanish Cities*. *Sustainability*, *8*(8), 774. https://doi.org/10.3390/su8080774

Tchórzewska-Cieślak, B., & Pietrucha-Urbanik, K. (2018). *Approaches to Methods of Risk Analysis and Assessment Regarding the Gas Supply to a City*. *Energies*, *11*(12), 3304. https://doi.org/10.3390/en11123304

WCED. (1987). *Our Common Future*.

Yang, B., Ge, S., Liu, H., Li, J., & Zhang, S. (2022). *Resilience assessment methodologies and enhancement strategies of multi‐energy cyber‐physical systems of the distribution network*. *IET Energy Systems Integration*, *4*(2), 171–191. https://doi.org/10.1049/esi2.12067

York, D., & Jarrah, A. (2022). *Community Resilience Planning and Clean Energy Initiatives: A Review of City-Led Efforts for Energy Efficiency and Renewable Energy*. Washington.

8 Appendix

Table 8 shows the findings from the literature. Various of these criteria are applicable in the context of this study.

Table 8: Criteria for urban energy resilience from the framework of Sharifi & Yamagata (2016).

Area	Nr.	Criterion
Urban Infrastructure		
	Supply, transmission, distribution	
	In1	Fortification and robustness (physical security)
	In2	Operational system protection (e.g. system relief, circuit breakers)
	In3	Diversification of energy supply (fuel mix, multisourcing, type of generation)
	In4	Spatially distributed generation (and critical facilities)
	In5	Energy production near point of use (colocation of supply and demand)
	In6	On-site energy production (photovoltaics, micro combined heat and power, tri-generation, thermal panels, small wind turbines mounted at the corners of the roof)
	In7	Solar absorption cooling
	In8	Large wind turbines located outside the built-up area
	In9	Large solar thermal collectors
	In10	Smart micro-girds fed by micro-turbines and solar panels (photovoltaics, building integrated photo-voltaics) and storage facilities
	In11	Building integrated photovoltaic/thermal for recovery of heat loss from photovoltaics and building integrated photovoltaics
	In12	Ground source heat pumps
	In13	Waste heat or biomass-fueled combined heat and power plants
	In14	Biofuel energy ("food waste", "second generation cellulosic biofuels", "third generation using algae" etc.)
	In15	Biomass supply chain, wood pellet systems
	In16	Interdependency and interconnection of infrastructures and their networks
	In17	Regular maintenance
	In18	Generation, transmission, and distribution efficiency (leakages, etc.)
	In19	Age of the fleet (feeder lines, etc.)
	In20	Phasing out obsolete and/or damaged assets and introducing new and more efficient technologies such as LEDs

	In21	Type of feeder lines (overhead/underground cables; looped/interconnected or radial configuration)
	In22	Natural gas distribution: continuous (grid) VS discontinuous (propane tanks)
	In23	Alternative and safer energy sources for critical infrastructure such as parking gates, traffic lights, sub-ways, etc.
	In24	Intelligent ICT infrastructure and its cyber security for maintaining grid operation
	In25	Flexible network architecture
	In26	Number and configuration of nodes and links in the transmission and distribution grid
	Backup and storage	
	In27	Back-up energy sources and stocks of energy
	In28	Energy storage facilities (involving electro-chemical batteries, flow batteries, hydrogen, etc)
	In29	Distributed storage
	In30	Connectivity of generation and storage infrastructure
	In31	Back-up data of the utility infrastructure (information networks, data sharing, etc.)
	In32	"Spare capacity and reserve margins" (resources, transmission lines, etc.)
	In33	Installed/ready redundant components (generators, pumps, etc.)
	In34	Vehicle to Grid and Vehicle to Community (selling surplus power)
	Green infrastructure	
	In35	Parks and open spaces, bioswales, etc. (attention to regular trimming of trees)
	In36	Indigenous (native) vs invasive plants
	In37	Deciduous trees for cold climates
	In38	Xeriscape for hot and arid climates
	In39	Urban agriculture (vacant lands, marginal lands, etc.)
	In40	Green area ratio (building envelope)
	In41	Green wall (vegetative covering, green fagade)
	In42	Green roof (living roof)
	Blue infrastructure	
	In43	Rainwater harvesting, decentralized water harvesting systems
	In44	Water conservation
	In45	Heat recovery and energy generation from sewage
	In46	Separation of used water into grey and black flows

	In47	Removing and recovering ammonium and phosphate from wastewater
	In48	Waterscape as a natural heat sink
	In49	Roof pond
	Buildings and neighborhoods	
	In50	Redesign and refurbishment (retrofit)
	In51	Glazing
	In52	Net-zero and net-positive energy buildings
	In53	Insulation and dynamic insulation of buildings
	In54	"Cut-off of air conditioning waste heat discharge"
	In55	Net zero energy neighborhoods
	In56	Pooling of the built environment (shared walls)
	In57	District energy systems ("using low-temperature heat from renewable sources" and "industrial waste heat")
	Transportation	
	In58	Infrastructure for active transportation modes
	In59	Modal split
	In60	Size of cars
	In61	Fuel efficiency of cars
	In62	Supporting promotion of hybrid vehicles and Installing electric vehicle plug-ins in locations where multiple use can be achieved.
	Innovation	
	In63	Enhancing energy efficiency through innovation and technology (building, industry, transportation)
	In64	Fuel flexibility of the grid, appliances, automobiles, etc.
Resources		
	Energy	
	Re1	Energy/Carbon intensity of generation
	Re2	Efficient resource use
	Re3	Energy conservation
	Re4	Energy self sufficiency
	Re5	Energy cycling
	Re6	Waste management and waste incineration

	Re7	Environmental and socio-economic impacts of energy system
	Water— energy nexus	
	Re8	Reducing energy footprint of water production
	Re9	Using water saving shower head
	Re10	Installation of low-flush toilets
	Re11	Using low-energy cloth washing and dish washing machines
	Re12	Installation of tankless water heaters (demand-type or instantaneous)
	Re13	Use of greywater for irrigation and toilet flushing
	Re14	Smart consumption of freshwater
	Re15	Provision of less energy intensive rainwater harvesting systems in buildings
	Re16	Reclaim and treatment of used water for public drinking water supply
	Re17	Use of "municipal wastewater
	Re18	Improvement of water infrastructure to reduce water loss
	Re19	Water and energy resource coupling
	Re20	Reducing energy footprint of wastewater collection, treatment and discharge
	Re21	Storing water (in aquifers) as insurance against the impact of future droughts
	Re22	Reducing water footprint of energy production and transmission
	Re23	Improving the efficiency of energy production by enhancing water quality
	Re24	Understanding the water intensity of fuels used for electricity generation
	Re25	Less water-intensive technologies for cooling purposes in thermoelectric plants
	Re26	Use of natural gas for steamed turbines and combined cycle plants
	Re27	Use of wet "cooling towers instead of once-through cooling"
	Re28	Knowing groundwater implications of energy (technologies
	Food—water—energy nexus	
	Re29	Food waste (harvesting
	Re30	Energy intensity of agriculture
	Re31	Local food production
	Re32	Best management practices in irrigation
	Re33	Efficient irrigation technologies

Land use, urban geometry and morphology		
	Land use	
	La1	Multi-functionality of urban space
	La2	Mixed-use development
	La3	Housing-job proximity
	La4	Co-location of enterprises that can use each other's waste or byproducts
	La5	Defensible urban spaces that reduce the need for mechanical surveillance
	Urban morphology	
	La6	Development pattern (sprawl, compact, suburbanization, infill, brownfield, greenfield, etc.)
	La7	Density (housing, population)
	La8	Connectivity (number of intersections, etc.)
	La9	Street systems (grid, curvilinear, hybrid, etc.)
	Urban geometry	
	La10	Size of urban blocks
	La11	Size of the housing unit
	La12	Sky View Factor; Obstruction angle
	La13	Surface (facades plus roof) to volume ration of buildings
	La14	Urban horizon angle
	La15	Aspect ratio (H/W height of the opposite buildings divided by the canyon width)
	Passive design	
	La16	Surface albedo enhancement (walls, pavements)
	La17	Surface albedo enhancement (cool roofs)
	La18	Surface emissivity
	La19	Radiative and evaporative passive cooling
	La20	Passive heating (thermal storage wall, Trombe wall, direct gain storage, Sunspace, etc.)
	La21	Shading
	La22	Size and orientation of buildings (daylighting)
	La23	Roof lights, atria
	La24	Phase change materials for cooling and heating

	La25	Earth air tunnels
	La26	Wind environment, Natural vs mechanical ventilation and cooling
	La27	Wind towers
	La28	Cistern (for cooling water in hot and arid regions)
Urban governance		
	Monitoring and assessment	
	Go1	Surveillance (manned and/or automated)
	Go2	Early discovery of the intervention and stopping its propagation
	Go3	Performance evaluation and monitoring
	Go4	Smart metering and visual display technologies to inform occupants of consumption patterns and
	Go5	obtain their feedback Fine-scaled, site-specific, and updated database (generation, emissions, consumption, etc.)
	Go6	Planning and Decision making based on decision support systems and simulation models
	Go7	Certificates, labeling, and rating tools
	Planning and management	
	Go8	long-term vision
	Go9	Scenario-based energy planning and risk management
	Go10	Ability to prioritize tasks at the time of disaster
	Go11	leadership qualities to initiate and sustain innovative energy experiments
	Go12	Flexible governance to respond to changes
	Go13	Preparation (contingency plans, response & recovery plans)
	Go14	Forecast and event warning broadcast
	Go15	Risk communication and energy response
	Go16	Training and communication for raising awareness
	Go17	Visual tools and visualization methods to raise awareness
	Go18	Availability of trained repair personnel
	Go19	Transparent planning
	Go20	Harmonization of bottom-up initiatives with top-down engagements
	Go21	Participatory governance
	Go22	Self-governance and governance by enabling

	Go23	Community involvement and/or ownership of renewable energy generation
	Go24	Knowledge networks based on inter-organizational collaboration for information communication
	Go25	and knowledge sharing Cross-scale collaborations and partnerships/ jurisdictional mismatches
	Go26	Institutional coordination on water, food, health and energy nexus
	Go27	Reliance on imports
	Go28	Reliance on nuclear energy
	Go29	Travel demand management
	Go30	Regular publication of energy planning documents and statistics
	Go31	Fuel substitution
	Go32	Social barriers to adoption of modern and innovative technologies
	Go33	Market competitiveness and investment risk of decentralized renewable energy
	Go34	Connections between renewable energy industry and building industry
	Regulatory basis and law enforcement	
	Go35	Building code (development, enforcement and update)
	Go36	land-use and zoning bylaws (development, enforcement and update)
	Go37	Parking requirements
	Go38	Solar easements
	Go39	Market liberalization
	Go40	Requirement for suppliers to source a proportion of electricity from renewables
	Go41	Legal and regulatory frameworks to encourage technological development and transition towards
	Go42	energy resilience Measures against electricity theft
	Pricing	
	Go43	Carbon pricing
	Go44	Road pricing and congestion charging
	Go45	Time-varying rates and prices (electricity)
	Go46	Pre-payment electricity, rationing, etc.
	Go47	Funding for research and technology development
	Go48	Attracting private sector's investment in low carbon development
	Go49	Financial mechanisms and incentives for: promoting green products and renewable energy technologies and enhancing affordability

	Go50	Non-financial mechanisms and incentives for: promoting green products and renewable energy technologies and enhancing affordability
Socio-demographic aspects and human behaviour		
	Demographics, health and equity	
	So1	Household size
	So2	Reproductive education and family planning
	So3	Gender equality
	So4	Social-class equality
	So5	"Access to birth control methods and reproductive health services"
	So6	Universal energy access (energy poverty)
	So7	Upgrading slums and informal settlements
	So8	"Externalization of impacts"
	So9	Safety of energy production, transmission, and distribution (accidents, etc.)
	Behavioral aspects	
	So10	Car use frequency
	So11	Driving behavior
	So12	Dietary patterns
	So13	Respecting, utilizing, and learning from local culture, knowledge and traditions
	So14	Willingness to pay upfront costs of renewable technologies
	So15	Communal solutions for social cohesion and energy saving
	So16	Energy consciousness of the public and consumption behavior / demand side management
	So17	"Smarter selection of the mode of operation of appliances"
	So18	Load matching to obtain maximum value for on-site energy generation
	So19	Switching off lighting, air conditioning, etc. in unoccupied rooms
	So20	Doing activities (e.g. watching TV) in the living room VS separate rooms
	So21	Acclimatization