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# SWEET Call 1-2020: SURE

# Deliverable report

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sweet swiss energy research for the energy transition

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## Acronyms and abbreviations

| | |
|---|---|
| DB | Deutsche Bahn |
| ENTSO-E | European Network of Transmission System Operators for Electricity |
| HP | Heat pump |
| HTHP | High Temperature Heat Pumps |
| GHG | Greenhouse gas |
| GHGE | Greenhouse gas emissions |
| IWB | Industrielle Werke Basel |
| OEM | Original equipment manufacturer |
| ÖBB | Österreichische Bundesbahnen |
| NG | Natural Gas |
| PtH | Power-to-Heat |
| PtG | Power-to-Gas |
| SFR | Swiss Federal Railway |
| SFOE | Swiss Federal Office of Energy |
| SPS | SURE Pathway Scenario |
| UPS | Uninterruptible power supply |

**Summary**

The manufacturing industry and the national public transport are a significant part of the Swiss energy system. These sectors not only have decarbonisation goals, but also need to be prepared against sudden energy supply and demand disruptions. However, the implementation of sustainability and resilience goals proves to be a challenge. Here, we propose a general resilience and sustainability concept for these sectors and apply it to concrete cases. Depending on the sector (industry or transport), resilience and sustainability concepts of the main stakeholders, the industry in Basel and Swiss Federal Railways (SBB), are at different stages of their development. First, we review the literature and develop a concept, consisting of resilience principles that are reflected in measurable and concrete resilience measures, as well as a sustainable development framework. In the second step, we link the concept to selected shocks from the SWEET SURE project. Finally, we apply the concept to specific cases in Switzerland by identifying relevant shocks, proposing concrete measures, and summarising existing resilience and sustainability concepts of specific cases.

The specific cases are the heat-intensive manufacturing industry in Basel, for instance chemical industries, and SBB. First, the industry has a large potential to decarbonise heat, using options such as high-temperature heat pumps (HTHP). Shocks affect energy demand and prices, as well as capital costs. Resilience measures identified focus on energy supply and operational dimensions. An interview with an HTHP manufacturer has revealed the relevance of a first set of measures to increase resilience. Second, SBB aim at a carbon-neutral operation by 2030. Their efforts to increase energy efficiency may significantly promote the decarbonization of the overall energy sector. Although, they operate a challenging and volatile electricity system with rapid transients, their resilience is improved by a full control of all power plants and assets, flexible connections to the Swissgrid network and established emergency procedures. This deliverable lays the foundation for the deeper case study between the SURE consortium, the industry and SBB. In upcoming deliverables, we will further identify relevant measures and resilience indicators against shocks and energy supply issues.

**Zusammenfassung**

Das verarbeitende Gewerbe und die nationalen öffentlichen Verkehrsmittel sind ein wichtiger Teil des Schweizer Energiesystems. Diese Sektoren haben nicht nur Dekarbonisierungsziele, sondern müssen auch auf plötzliche Unterbrechungen der Energieversorgung und -nachfrage vorbereitet sein. Die Umsetzung von Nachhaltigkeits- und Resilienzzielen erweist sich jedoch als eine Herausforderung. Wir schlagen hier ein allgemeines Resilienz- und Nachhaltigkeitskonzept für diese Sektoren vor und wenden es auf konkrete Fälle an. Je nach Sektor (Industrie oder Verkehr) befinden sich die Resilienz- und Nachhaltigkeitskonzepte der Hauptakteure, der Industrie in Basel und der Schweizerischen Bundesbahnen (SBB), in unterschiedlichen Entwicklungsstadien. In einem ersten Schritt wird die Literatur gesichtet und ein Konzept entwickelt, das aus Resilienzprinzipien, die sich in messbaren und konkreten Resilienzmassnahmen niederschlagen, sowie einem Rahmen für nachhaltige Entwicklung besteht. In einem zweiten Schritt verknüpfen wir das Konzept mit ausgewählten Schocks aus dem SWEET SURE-Projekt. Schliesslich wenden wir das Konzept auf spezifische Fälle in der Schweiz an, indem wir relevante Schocks identifizieren, konkrete Massnahmen vorschlagen und die bestehenden Resilienz- und Nachhaltigkeitskonzepte für spezifische Fälle zusammenfassen.

Bei den konkreten Fällen handelt es sich um das wärmeintensive verarbeitende Gewerbe in Basel, z.B. die chemische Industrie, und die SBB. Erstere wurde gewählt, weil sie über ein großes Potenzial zur Dekarbonisierung der Wärme verfügt, indem sie Optionen wie Hochtemperaturwärmepumpen (HTHP) einsetzt. Schocks wirken sich zudem auf die Energienachfrage und -preise sowie auf die Kapitalkosten der Industrie aus. Die ermittelten Resilienzmaßnahmen konzentrieren sich auf die Energieversorgung und betriebliche Aspekte. Ein Interview mit einem HTHP-Hersteller hat die Relevanz einer ersten Reihe von Maßnahmen zur Erhöhung der Widerstandsfähigkeit aufgezeigt. Die SBB wurde ausgewählt, da sie bis 2030 einen kohlenstoffneutralen Betrieb anstrebt. Ihre Bemühungen zur Steigerung der Energieeffizienz können die Dekarbonisierung des gesamten Energiesektors erheblich fördern. Obwohl

die SBB ein anspruchsvolles und volatiles Stromsystem mit schnellen Transienten betreiben, wird ihre Widerstandsfähigkeit durch eine vollständige Kontrolle aller Kraftwerke und Anlagen, flexible Verbindungen zum Swissgrid-Netz und etablierte Notfallverfahren verbessert. Diese Arbeit legt den Grundstein für die vertiefte Fallstudie zwischen dem SURE-Konsortium, der Industrie und der SBB. In den nächsten Beiträgen werden wir weitere relevante Maßnahmen und Indikatoren für die Widerstandsfähigkeit gegenüber Schocks und Energieversorgungsproblemen ermitteln.

**Résumé**

Le secteur manufacturier et les transports publics nationaux constituent une partie importante du système énergétique suisse. Ces secteurs ont non seulement des objectifs de décarbonisation, mais doivent également être prêts pour des interruptions soudaines de l'approvisionnement et de la demande en énergie. Cependant, la mise en œuvre d'objectifs de durabilité et de résilience s'avère être un défi. Nous proposons ici une approche générale de la résilience et de la durabilité pour ces secteurs et l'appliquons à des cas concrets. Selon le secteur (industrie ou transport), les concepts de résilience et de durabilité des acteurs principaux, l'industrie à Bâle et les Chemins de fer fédéraux suisses (CFF), se trouvent à différents stades de développement. Dans un premier pas, nous passons en revue la littérature et développons un concept composé de principes de résilience, qui se traduisent par des mesures de résilience mesurables et concrètes, ainsi qu'un cadre de développement durable. Dans un deuxième pas, nous associons le concept à des chocs sélectionnés dans le cadre du projet SWEET SURE. Enfin, nous appliquons le concept à des cas spécifiques en Suisse en identifiant les chocs pertinents, en proposant des mesures concrètes et en résumant les concepts de résilience et de durabilité existants pour des cas spécifiques.

Les cas concrets sont l'industrie de transformation à forte consommation de chaleur à Bâle, par exemple l'industrie chimique, et les CFF. Le premier a été choisi parce qu'il dispose d'un grand potentiel de décarbonisation de la chaleur en utilisant des options comme les pompes à chaleur haute température (HTHP). Les chocs ont également un impact sur la demande et les prix de l'énergie, ainsi que sur le coût du capital dans l'industrie. Les mesures de résilience identifiées se concentrent sur l'approvisionnement en énergie et les aspects opérationnels. Un entretien avec un fabricant de HTHP a permis de mettre en évidence la pertinence d'une première série de mesures visant à accroître la résilience. Les CFF ont été choisis parce qu'ils visent une exploitation neutre en carbone d'ici 2030. Leurs efforts en matière d'efficacité énergétique peuvent favoriser considérablement la décarbonisation de l'ensemble du secteur énergétique. Bien que les CFF exploitent un système électrique exigeant et volatile avec des transitoires rapides, leur résilience est améliorée par un contrôle total de toutes les centrales et installations électriques, par des connexions flexibles au réseau Swissgrid et par des procédures d'urgence bien établies. Ce travail constitue la base de l'étude de cas approfondie entre le consortium SURE, l'industrie et les CFF. Dans les prochains articles, nous identifierons d'autres mesures et indicateurs pertinents pour la résilience aux chocs et aux problèmes d'approvisionnement en énergie.

**Sintesi**

Il settore manifatturiero e il trasporto pubblico nazionale sono una parte importante del sistema energetico svizzero. Questi settori non solo hanno obiettivi di decarbonizzazione, ma devono anche essere preparati ad affrontare interruzioni improvvise della domanda e dell'offerta di energia. Tuttavia, l'attuazione degli obiettivi di sostenibilità e resilienza si rivela impegnativa. Proponiamo qui un approccio generale alla resilienza e alla sostenibilità per questi settori e lo applichiamo a casi concreti. A seconda del settore (industria o trasporti), i concetti di resilienza e sostenibilità dei principali attori, l'industria di Basilea e le Ferrovie Federali Svizzere (FFS), si trovano in diversi stadi di sviluppo. In una prima fase, esaminiamo la letteratura e sviluppiamo un concetto composto da principi di resilienza, che si traducono in misure di resilienza misurabili e concrete, e da un quadro di riferimento per lo sviluppo sostenibile. In una seconda fase, colleghiamo il concetto a shock selezionati dal progetto SWEET SURE. Infine,

applichiamo il concetto a casi specifici in Svizzera, identificando gli shock rilevanti, proponendo misure concrete e riassumendo i concetti di resilienza e sostenibilità esistenti per casi specifici.

I casi specifici sono l'industria manifatturiera ad alta intensità di calore di Basilea, ad esempio l'industria chimica, e le FFS. La prima è stata scelta perché ha un grande potenziale di decarbonizzazione del calore utilizzando opzioni come le pompe di calore ad alta temperatura (HTHP). Gli shock influenzano anche la domanda e i prezzi dell'energia, nonché il costo del capitale dell'industria. Le misure di resilienza individuate si concentrano sull'approvvigionamento energetico e sugli aspetti operativi. Un'intervista con un produttore di HTHP ha evidenziato la rilevanza di una prima serie di misure di resilienza. Le FFS sono state selezionate perché mirano a raggiungere la neutralità delle emissioni di carbonio entro il 2030. I suoi sforzi per aumentare l'efficienza energetica possono promuovere in modo significativo la decarbonizzazione dell'intero settore energetico. Sebbene le FFS gestiscano un sistema elettrico esigente e volatile, caratterizzato da rapidi transitori, la loro resilienza è rafforzata dal pieno controllo di tutte le centrali e le apparecchiature, da collegamenti flessibili alla rete Swissgrid e da procedure di emergenza consolidate. Questo lavoro pone le basi per lo studio approfondito del caso tra il consorzio SURE, l'industria e le FFS. Nei prossimi documenti individueremo ulteriori misure e indicatori di resilienza agli shock e ai problemi di approvvigionamento energetico.

# 1 Introduction

Sustainability and resilience are two key concepts in current scientific and policy discourse. To meet national and international decarbonisation goals, current and future systems should be sustainable and maintain their sustainable aspects in the face of high stress or sudden events, so called shocks. Mitigation and adaptation efforts using energy resilience, in other words resilience against shock affecting the energy system, have gained considerable importance due to climate change (Yang et al., 2022). Effects of climate change will most likely raise the occurrence of such shocks, as, for example, heat and cold waves put the energy system and grid stability under high stress.

Events like shocks are relevant on the national and urban level (see D14.0). Yet, they are an immediate concern for private and public companies too. In energy-intensive process industries, threats related to the power grid or increased energy and capital costs could endanger a secure and economically efficient operation. For national public mobility carriers, energy grid resilience plays a very prominent role due to the high volatility of their network operation. For example, the timetable (“*Taktfahrplan”)* of the Swiss Federal Railways (SBB) leads to power peaks that (more than) double the power demand in only a few minutes (followed by an equally fast decrease). At the same time, companies in the industrial and public mobility sectors strongly contribute to the power demand in Switzerland. Hence, promoting sustainability in the sense of reducing their environmental impact is essential. For example, SBB helps to reduce the overall emissions of Switzerland, as it substitutes carbon intensive road transport, alongside its own sustainability initiatives.

However, as illustrated by recent global crises such as energy supply issues, the answers to deal with shocks have not always been “sustainable”, putting sustainability concepts at risk. Therefore, it is important to jointly consider sustainability and resilience. In this deliverable, we do this for sustainability and resilience in the industrial and public mobility sectors, both on conceptual levels and applied to specific cases. Our explicit focus lies on *energy* resilience in these sectors and the investigated cases.[1]

Existing definitions of sustainability and resilience build the foundation of this deliverable. First, we define 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). This boils down to four dimensions, which need to be considered: availability, accessibility, affordability, and acceptability (Sharifi & Yamagata, 2016). A resilient and sustainable system should be able to meet these dimensions, even under high stress or sudden shocks. For example, if energy prices spike or supply is unstable, the industrial production must have taken precautionary steps to still be available.[2] Furthermore, the industries products should be accessible and affordable to customers, and resource inputs and waste outputs be minimised to be acceptable. Second, there is no generally accepted definition of resilience in science, but several different and context-specific ones. However, in the context of this research, we interpret resilience as the ability of a system to survive a shock and return to an equilibrium, in other words, 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 system should be able to do this while perpetuating its sustainability goals.

The general relevance, definitions, and our scope cumulate in the general research question of D15.4: “*How can an energy system in the industry and public mobility sector be sustainable and resilient*?” To answer this question, we first adapt insights from the literature to develop a general concept which we then apply to specific cases. Our general concept is applicable to sectors in various geographical areas. For instance, insights about industry resilience and the necessary measures are also applicable to various subsectors of the manufacturing industries in Switzerland and abroad, and insights about the

[1] E.g., flood resilience, among other areas, is out of scope unless the energy grid is affected.

[2] The level to trigger such measures may differ between different industries.

resilience concepts for public mobility may as well be applicable to other national public transport carriers.

Second, we link the general resilience concept to previous work of the SWEET SURE project. For this, a selection of the national shocks is adapted from the project to this deliverable. While other shocks and threats are still relevant and partially covered in this deliverable, the SURE shocks are discussed in detail as they lay the foundation for various other tasks in the SURE project. Finally, the general concept and these shocks are applied to actual cases in Switzerland. For the industry part, this deliverable builds the fundament for a case study in the industry of Basel. For the public mobility part, resilience concepts are applied to the case of the Swiss Federal Railways (SBB). For these cases, our contribution is complemented by insights from relevant stakeholders.

The deliverable is structured as follows: this first 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 the Sections 4 and 5 the resilience concept is applied to specific case studies in the industry in Basel and the case of SBB. For the industry, we did this on a relatively general level, while for SBB, the current results are very specific to the company.

## 1.1 Case study selection and outlook on WP15

Our deliverable builds the foundation for the corresponding WP 15 which aims to apply the objectives, concepts and approaches of SURE to specific issues of industrial demand and public transport which are two sectors where the implementation of sustainability goals showed to be a particular challenge. The concrete cases are the industry in Basel (next Section) and SBB (Section 1.1.2).

### 1.1.1 Industry in Basel

The industry case study focuses on the industries in Basel, being in the energy supply area of Industrielle Werke Basel (IWB). Relevant companies from the manufacturing industries include those relying on high-temperature process heat, such as the pharma and chemical industries. In these cases, the cost-effectiveness and the potential to replace fossil heat production with smart and competitive low-carbon electricity-based technologies such as power-to-Heat (PtH), renewable or power-to-gas (PtG) fuels are explored. Empirical evidence about required payback periods, technical and operational pre-conditions, barriers and acceptance of industrial consumers are gathered. This includes the analysis of legal and regulatory aspects and the development of potential policy instruments to foster the adoption of decarbonizing approaches in the industry sector.

### 1.1.2 SBB case study

The second case study investigates the interdependencies of SBB and the Swiss energy system for several scenarios, with a particular focus on resilience and sustainability. SBB projections of future developments of electricity demand are integrated through the transmission grid model with the national energy system case study.

The SURE energy system model involves several aspects that go beyond the SBB case study, however, a bi-directional link will be established to include those relevant to the SBB system. These include in particular:

- Exchange and communication of the findings of the SURE energy system model to SBB in order to allow the inclusion in SBB’s own scenarios, as well as to receive feedback on the SURE findings. This process has already started and will continue within the SURE stakeholder workshops. In addition, bilateral exchanges and a dedicated stakeholder workshop will take place with the relevant people at SBB.

- Feedback of the SBB development paths to the SURE model will take place regarding the energy related scenarios. The energy reduction may free up generation capacity that can serve as flexible generation in the SURE model. In addition, assumptions regarding the future mobility demand will be harmonized with the SURE model.

The key part of the subsequent investigations of WP15 regarding SBB will consist of a deep-dive case study on SBB-resilience. In the discussions with SBB, two areas have been identified as potential topics.

<u>Dynamic operation and exchange with the Swissgrid network</u>

It is planned to couple a (possibly simplified) model of the SBB transmission grid with the Swissgrid network represented in the energy system model. This will allow to assess the benefit of exchanges between the networks during cases of contingencies in either network. The result may take the form of a flexibility assessment and deployment tool for the Swissgrid-SBB interface and may also be used to assess the impact on the SURE security indicators.

<u>Restoration after outages (e.g., cold shock).</u>

The controlled islanding and restoration procedures, outlined in section 5, meet the core of the SURE project, concerning the resilience assessment. It is planned to investigate the improvement of the system resilience from the envisioned fast black start capabilities. Potential questions include, how the "seeds" and islands of the black start should be selected to mitigate the severeness of a black out as much as possible.

Both topics are highly relevant to SBB and allow to apply the simulation and security assessment tools developed within the SURE energy system model. The energy grid simulation tool developed in WP6 (lead by ETHZ-FEN) is particularly relevant for the assessment. The benefit between the work packages is mutual: It is expected that the findings within the SBB case study will also provide insights to the overall energy system operation, for instance in the form of new security indicators.

# 2 Background

We present the current state of knowledge related to resilience in industry sectors and general resilience studies of the power system in Section 2.1. These studies tend to be fragmented, targeting specific aspects. Nevertheless, comprehensive resilience and sustainability frameworks that combine this knowledge exist and lay the foundation for our work. We present two relevant frameworks in Section 2.2

## 2.1 Resilience research areas

While urban, energy or disaster resilience has received considerable attention in literature (Bueno et al., 2021; Mola et al., 2018; Saboo et al., 1985; Sharifi & Yamagata, 2016), little work targets the industrial sector from a wholistic point of view. Nevertheless, a wide range of topics and aspects of interest to the resilience of the (manufacturing) industry were covered, albeit often in a fragmental fashion. This includes resilience aspects related to energy or internal heat distribution (Cimellaro et al., 2010; Hauser et al., 2017), diversity and supply security (Chalvatzis & Ioannidis, 2017; Stirling, 2010), use of process heat decarbonization options like heat pumps or solar power (Farjana et al., 2018; Gheysari et al., 2021; Schlosser et al., 2020).

Some studies focus on resilience and the application of HTHP in specific industries like the food manufacturing (Brooks et al., 2021) or German metal industry (Hoettecke et al., 2022). The latter finds that in the energy intensive metal industry, the future availability of groundwater could be an issue. Hence, heat pumps are seen as a technology to reduce groundwater use for cooling and use waste heat instead. A recent study has analysed the potential of HTHPs in food and beverage industry, and its ability to replace fossil fuels (Obrist et al., 2023). The authors find that HTHPs are able to decarbonise the heat production in these sectors cost-effectively and up to temperatures of 150 °C if appropriate support policies are in place.

Energy grid resilience, especially targeted at electricity, has been a strong focus of resilience studies (Dyson & Li, 2020; Hossain et al., 2021; Jasiūnas et al., 2021; Rusco, 2021). For instance, Hossain et al. suggest transforming centralized grids into microgrids and to make those as robust as possible to enhance the grids' reliability and resilience. Finally, overarching national concepts and roadmaps for resilience and decarbonisation have been proposed (David et al., 2017; Pilpola et al., 2019). We will not further investigate these studies but focus on general frameworks in the next section.

## 2.2 Sustainability and resilience frameworks

Sharifi & Yamagata (2016) propose a comprehensive conceptual framework for assessing energy resilience (Figure 1). While their framework has been developed with urban energy resilience in mind, they state that the general concepts and most of the proposed principles are applicable to other energy systems. We therefore adapt the framework for resilience and sustainability of the industry and public mobility sectors.

According to the Sharifi & Yamagata framework, an 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. From a vast body of fragmented literature, they haven then identified and collected a set of principles which underlie a resilient system. These principles must then assigned to criteria which are measurable and implementable to increase the resilience of a system.

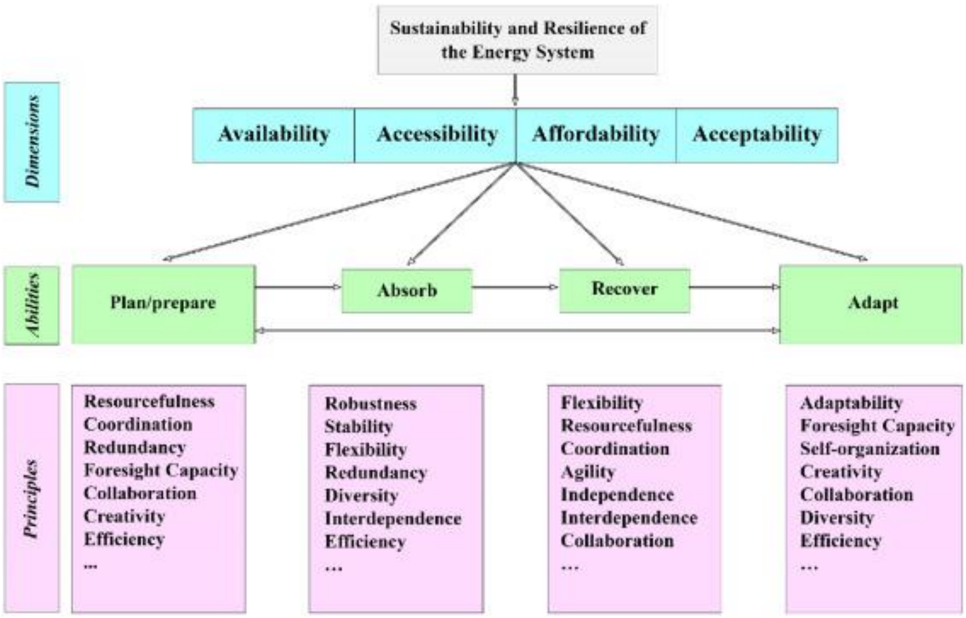


Figure 1: Sustainability and resilience framework of Sharifi & Yamagata (2016). Tailored to urban energy system but applicable to other energy systems, too.

A more specific framework about resilience in industry, specifically for disaster-resilience in the manufacturing industry, has been proposed (El-Halwagi et al., 2020). The El-Halwagi et al. framework is conceptually similar to the one by Sharifi and Yamagata, in the sense of proposing resilience principles and criteria. In it, 12 principles for designing disaster-resilient industries are presented, such as fail-safe by design, redundancy, and flexibility. We present principles of both frameworks in Section 3.2. and apply associated resilience measures to the cases of industry in 0 and more generally in Section 5 to the SBB case.

# 3 General sustainability and resilience concept

## 3.1 Stepwise procedure

We develop the sustainability and resilience concept based on a qualitative procedure inspired by literature (Table 1). 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 1: Proposal of the general concept to appraise the resilience and sustainability.

| Step and task | Descriptions |
|---|---|
| **1: Select** framework. | Facilitates the identification of principles and criteria. |
| **2: Assess** resilience dimensions. | The system needs to fulfil a set of principles that are measurable by specific criteria and can be implemented. |
| **3: Evaluate** shock robustness. | Evaluate relevant shocks for the specific system and potential measures to tackle them. |
| **4: Appraise** effects for sustainability. | Appraise the effect of resilience measures on the sustainability of the system |
| **5: Aggregate** indicators | Measurable criteria / indicators are combined to an index to evaluate overall resilience and sustainability. |

In this SURE case study, we have focused on steps 1-3, with and without stakeholder involvement. We present exemplary criteria and measures, as well as general sustainability concepts. In future work related to WP15, we will however assess more specific resilience measures and effects. Aggregate resilience index should be assessed in future research projects.

In the case applications, stakeholder inputs from the industry and the public mobility sector provide concrete examples of resilience concepts and measures and should be used to validate the result of every step. In the industry sector, we have interviewed a manufacturer (OEM) of HTHPs about the application of resilience measures in their customer base. Further talks with the manufacturing industry will contribute to more insights in a future amendment of the deliverable. In the mobility sector, we have conducted interviews with SBB to learn about their resilience concept which is already in use. Both cases show how a general resilience concept is applied in practice.

## 3.2 Resilience principles

Resilience principles serve as a general "compass" to assess the ability of system to be resilient. They are useful to categorise practical measures and obtain an overarching strategy. Table 2 lists relevant principles for the investigated sectors. These are based on the frameworks from the literature (Section 2.2). We particularly apply the one by El-Halwagi et al. but consider additional principles from the Sharifi & Yamagata framework, namely general applicable and prominent principles such as "efficiency", "diversity", "adaptability" and "redundancy". These principals are reflected in the measures used for the industrial and public mobility concepts in Switzerland (Sections 4 and 5).

Table 2: Principles of a resilient industrial system. Descriptions are all adapted from the corresponding literature review (El-Halwagi et al., 2020; Sharifi & Yamagata, 2016). Primary sources: see review articles.

| Principles | Description. The ability to… |
|---|---|
| **El-Halwagi et al., 2020** | |
| **Fail-safe by design** | Fail in a safe manner. |
| **Redundancy** | Maintaining the function of the system with different means. |
| **Reconfigurability** | Alter the process flow with existing components in alternative configurations. |
| **Modularity** | Use modules, which are produced off-site. |

| | |
|---|---|
| **Repurposability** | Use equipment in different arrangements for different purposes. |
| **Flexibility** | Operate in a variety of uncertain situations and to still deliver acceptable performances. |
| **Controllability** | Steer a system to a desired, final state. |
| **Reliability** | Function without failure, even under stress. |
| **Recoverability** | Return to a desirable state |
| **Rapidity** | Have a low response time |
| **Robustness** | Withstand stress without loss of function., |
| **Resourcefulness** | Use various resources like materials, energy or technologies |
| **Sharifi & Yamagata, 2016** | |
| **Redundancy** | (See above) |
| **Diversity** | Ensure supply security by having multiple options available. |
| **Adaptability** | Learn from shocks to be fail-safe and adapt to changing conditions. |
| **Efficiency** | Reduce energy intensity and input demands to absorb variation. |

### 3.3 Resilience criteria and measures

One aspect of our resilience concept is to identify measurable planning and design criteria, as well as corresponding measures which increase resilience in different resilience dimensions. For this, we gather resilience criteria and measures and categorise them according to the resilience principles. In the specific cases, we then assign these criteria and measures to different dimensions and shocks.

For the collection of the criteria listed in Table 3, we have relied on own considerations, stakeholder interviews, as well as principles and criteria proposed in open access literature, notably the frameworks by Sharifi & Yamagata and El-Halwagi et al. The current selection is not all-encompassing but includes relevant measures to increase resilience in the energy system. Future amendments may expand the current list.

With the application to the case studies (Sections 4 and 5), we contribute to the literature: while the framework provide a fundamental basis to build upon, their authors also state the necessity to apply them to actual cases.

Table 3: Measures to increase resilience to shocks and threats to the energy system, categorised in a selection of principles. Adapted from own considerations and the literature sources (Src.), either (1) (Sharifi & Yamagata, 2016) or (2) (El-Halwagi et al., 2020) or own considerations and interviews. Measures can apply to multiple principles. Primary sources: see review articles.

| Principles | Src. | Criteria and Measures |
|---|---|---|
| **Fail-safe by design** | 2,1 | - Consider effects of failed components, e.g., cooling pumps.<br>- Resilient containments.<br>- Combined heat and power.<br>- Ability in chemical industry: to use alternative reactants. |
| **Redundancy** | 2 | - Duplicate units available, i.e., N-1 is considered.<br>- Dedicated power generation system available.<br>- Energy storage available.<br>- Backup generation available. |
| **Reconfigurability** | 2 | - Process flow can be changed and adapted. |
| **Modularity** | 2 | - Deployable heating or cooling system can be integrated. |
| **Flexibility** | 2,3 | - Ability to use different fuels like biofuels or hydrogen.<br>- Ability to store heat.<br>- Ability to store power. |
| **Reliability** | 2,3 | - UPS available to make power supply system reliable.<br>- Backup generation available.<br>- High quality and minimal maintenance. |
| **Diversity** | 1 | - Energy systems function in different configurations.<br>- Energy systems use different heat sources. |
| **Efficiency** | 1 | - Energy inputs are reduced without reducing outputs. |

### 3.4 Shocks and the link to SURE

Shock are sudden events that threaten systems. Hence, they need to be considered for the national public mobility carriers and the manufacturing industry, as well. 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 functioning resilience concept, a system is enabled to either bounce back to its original state or to a new one.

Shocks and vulnerabilities which are relevant in Switzerland and similar western countries include[3] extreme weather events and temperatures, peak oil, volatility of global energy markets, old infrastructure, technical failures and lock-ins, geopolitical conflicts, long-distance energy systems, cyber-attacks and sabotage, (sudden) population increase and privatisation (Sharifi & Yamagata, 2016).

The shock concept is an essential component of the SWEET SURE project, in which five shocks were selected for deeper investigation. Several of the threats shown above are represented by the five shocks defined in SURE D2.1 (Panos et al., 2022). The *SURE shocks* are based on stakeholder inputs and will be modelled in other work packages as part of the SURE scenario concept (Table 4). They relate to sudden global and regional events that potentially affect the current and future decarbonisation pathways or costs of Switzerland.

Table 4: Five Shure shocks and descriptions from D2.1 (Panos et al., 2022). Related threats are adopted from literature (Sharifi & Yamagata, 2016).

| SURE Shock | Description | Related threat | Effects |
|---|---|---|---|
| **Financial shock** | A deterioration of exchange rates between Asia and Switzerland. This affects import prices as Switzerland will most likely be dependent on imports up to 2050. | - Volatile global (energy) markets. | - Affects technology costs and energy prices. |
| **Heat wave** | High temperatures and low precipitation | - Extreme weather events<br>- High temperatures<br>- Drought | - Extreme weather puts the energy system under stress.<br>- Security of hydropower supply under stress.<br>- Higher electricity demand due to air-conditioning and transportation |
| **Cold spell** | Sudden cold wave and dry fall | - Low Temperatures<br>- Peak oil<br>- Volatility of global energy markets | - Extreme weather puts the energy system under stress.<br>- Security of hydropower supply under stress.<br>- Higher electricity demand due to heating.<br>- Imports of gas, oil and electricity to Switzerland are low. |
| **Societal change** | Sudden population growth in Switzerland due to refugee crisis | - Geopolitical conflicts<br>- Population increases | - Uncoordinated response may lead to disputes, nationally and internationally.<br>- Increase of demand for food, goods and building materials.<br>- Temporarily uneven access to energy services, e.g., mobility (more public transport), heating (renting apartments in inefficient buildings). |

[3] excluding electricity theft, energy poverty and lifestyle change to Western standards as risks mainly in developing countries.

| | | | |
|---|---|---|---|
| **Nuclear power re-introduction** | A political decision around 2030 to keep running and introduce new nuclear power plants to the Swiss power mix. | - Old infrastructure<br>- Technical lock-in | - Potentially stranded assets such as renewables or fossil-fuel power plants providing baseload.<br>- Support provision of heat by nuclear sources.<br>- More centralised energy supply. |

### 3.5 Sustainability concept

Sustainability has been defined as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (WCED, 1987). The United Nations have proposed the 17 Sustainable Development Goals (SDG), which is one of the most prominent sustainability frameworks.[4] Although not all of the goals are equally important for the industry and public mobility context in Switzerland, there are untapped potential regarding various goals (**Error! Reference source not found.**), for instance, affordable and clean energy (7), industry, innovation and infrastructure (9), or responsible consumption an production (12). These sectors 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 4).


Figure 2: 17 SDGs of the United Nations

Companies can be guided by these goals, but may already have developed their own sustainability concepts, e.g. SBB (see Section 5.3). For the industrial sector, we propose to pay special attention to heating demand and its decarbonisation. To achieve some of the targets, industries will therefore need to introduce low-carbon heating options (see Section 4.3).

[4] See **https://sdgs.un.org/goals**

# 4 Application of sustainability and resilience in the manufacturing industry

This section describes the resilience concept for the manufacturing industry and the associated energy supply system. Overall, the manufacturing industry plays a key role in the decarbonization of Switzerland. Process heat, with a share of ~12%, is the third largest contributor to total final energy consumption in Switzerland, and process heat contributes to more than 50% of the total energy demand in the Swiss industries (BFE, 2022a, see also Section 4.3). Current results are applicable to various contexts, subsectors, and regions, and thus, do not only apply to the selected case study of WP15. Further outcomes from interview with the industry in Basel, as part of upcoming work tasks, may be added in future amendments. These will focus more explicitly on the manufacturing industry in Basel, for instance chemical industries.

The goal of investigating this case is to identify potential industry resilience and sustainability aspects that can serve as a more detailed case study in the subsequent part of the project. To this end, the following steps have been carried out:

1. An initial literature review about high-temperature heat pumps (HTHP) has provided insights into potential measures to decarbonise the sector and provided valuable background for the resilience assessment.

2. The sampling of interview partners has focused on the supply side, i.e., HTHP manufacturers. Several national and international companies were contacted.

3. One contact has been established with a major HTHP manufacturer. To explore this company's perspective on the resilience of those industries to which they supply their products, we conducted two semi-structured interviews. Further information about the procedure, see D15.1.

4. The insights from these interviews complete the findings from the literature review. Topics for a more detailed analysis and further interviews with the demand side, i.e., the manufacturing industry in Basel (in the subsequent tasks of WP15) have been identified. The upcoming actor analysis and the involvement of relevant stakeholders will be conducted and coordinated with the SURE project partner IWB.

The results are presented in the remainder of this section. In Section 0, these are structured along the different aspects: energy price and supply, and operation. Section 4.2 summarizes the anticipated impact of the shocks on the industry, and the final subsection proposes a sustainability concept for the industry and the relevance of decarbonising the sector.

A key finding should already be mentioned here: our contribution to the sustainability concept in industry mainly focuses on the decarbonisation of the sector, due to its large potential. Other sustainability goals, which are part of the SDGs, may still be important but differ in different subsectors, for instance the sustainability of material use. Resilience dimensions in industry

Resilience and sustainability in the industry is relevant in at least two dimensions. In this section, we provide a brief overview of resilience measures in these dimensions. A future amendment to the deliverable and upcoming results in WP15 will provide further insights into resilience measures and the companies' willingness to install and adopt the proposed measures.

### 4.1.1 Energy price and supply resilience

Using alternative technologies like HTHP, power-to-heat technologies or low-carbon fuels reduces the dependency on natural gas or other fossil fuels for process heating and cooling applications. Substituting fossil fuels by low-carbon alternatives is not only an advantage regarding decarbonisation (see sustainability concept Section 4.3), but also reduces the risk of natural gas (NG) supply and price spikes, strengthening diversity and flexibility principles. We further analyse the economic and technical potential of such options in deliverable D15.1.

To improve the resilience of the industry sector against electricity supply shocks, the individual companies may consider measures against electrical power supply shocks. Although the Swiss power gird has been stable, companies may scrutinize mid- and long-term reliability due to the power supply discourse from 2022[5]. Industrial companies may want to integrate electricity backup generation or UPS systems or use other carriers such as thermally driven HP (which are however not very common in the market). Barriers could be the associated costs of such measures, as pointed out by the OEM of HTHP.

#### 4.1.2 Operational resilience

The OEM of HTHP has provided insights into the use of hot water storage tanks to buffer demand spikes and fluctuations. Large storage tanks in combination with HTHPs are already in use, for instance in the district heating system of Nordic countries. Furthermore, implementing modularity measures such as modular units to vary heat and cold supply may be another option to balance demand fluctuations.

In the upcoming survey with industrial companies in Basel, we will assess whether storage tanks, or modular units are a viable option in Swiss industries. This may be scrutinised as manufacturers with a relatively consistent throughput might not require measures to tackle a fluctuating heat demand. In general, the application will have to be tailored to the specific use case, and the economic feasibility need to be considered.

Regarding redundancy and reliability principles, the OEM of HTHP has pointed out the general robustness of HTHPs units, and the low cost of maintenance, at least regarding their proprietary products. However, a less biased insights from the industry will be needed to assess the reliability principle. Furthermore, the implementation of redundance with large scale HTHP is likely not viable, but still needs to be assessed.

### 4.2 Shock robustness of development paths in industry

Based on own considerations, we have assessed the relevance and effect of the proposed shocks for the industry sector. Given the overarching focus of WP15, the focus lies on risks related to the energy supply and the operation of heat supply units. In an additional step, we will evaluate the concept and relevance in a co-creational process together with stakeholders from industry. Table 5 provides an overview of consequences and our estimation of the relevance, followed by an in-depth discussion below.

Table 5: Overview of relevance of SURE shocks for industry. Own considerations. Sources: (Panos et al., 2022)

| Shock | Consequences for industry | Relevance |
| --- | --- | --- |
| **Financial shock** | - Higher capital costs for firms<br>- Renewable energy production could become more expensive | High |
| **Heat wave** | - Higher electricity prices could severely affect high load industries unless hedged against.<br>- Potential power outages | High |
| **Cold spell** | - Higher electricity prices could severely affect high load industries unless hedged against.<br>- Energy prices affect industries.<br>- Risk of local power outages if infrastructure is affected by frost. | High |
| **Societal change** | - Tensions could affect energy resources and technologies.<br>- Increased demand for products. | Mid |
| **Nuclear power re-introduction** | - Long-term effect on energy supply.<br>- Potential effects on renewable energy assets. | Low / Mid |

[5] Energy supply issues due to the Ukraine war have brought potential power supply problem to general attention in 2022.

### 4.2.1 Resilience against financial shocks (shock 1)

A financial shock caused by higher exchange rates in Asia may lead to higher capital costs for the companies due to higher import costs for technologies, resources and components. This may also affect investments in new renewable energy capacity, and thus indirectly energy prices. Both effects depend on the supply chain, and thus, one resilience measure is to diversify the supply chain. On the one hand, companies could buy their goods from more local suppliers; increased prices may be considered as risk premiums. On the other hand, the resourcefulness principle promotes the ability of a process to use various resources, which also mitigates the effects if local resources are available and affordable.

### 4.2.2 Resilience against heat waves and cold spells (shock 2 & 3)

The effects of these shocks are similar in the sense that they affect the electricity demand and the supply of energy. Both shocks affect electricity prices and the stability of the power grid due to the increased cooling and heating demand. Hence, criteria related to power grid stability should be considered. Also, redundancy is an essential principle, which translates to having backup power generation available. Depending on the energy sources of heating and cooling units, these shocks also affect international energy prices, e.g. of NG. Hence, diversity of energy and fuels contribute to hedging against energy price shocks or supply issues.

### 4.2.3 Resilience against a societal change and nuclear power re-introduction (Shock 4 & 5)

We assume that these shocks have less effect on the industry than the previous three. Major societal changes might affect the demand for products, and the availability of new workforce in the industry, which are potentially positive outcomes. Effects from a nuclear power re-introduction depends on the electricity supply contracts of individual companies, and on the final electricity prices which these firms need to pay. Stranded renewable assets might be issues if a strong re-introduction of cheap and financially supported nuclear power occurs.

## 4.3 Sustainability in industry

One of the major potentials to improve sustainability in Swiss industries lie in decarbonising their heat demand. Process heat contributes to more than 50% of the total energy demand in the Swiss industries (BFE, 2022). However, only a small share of the sector has adopted power-to-heat technologies or low-carbon fuels such as HTHP, biofuels, synthetic fuels, hydrogen, or district heating systems. This is surprising given the fact that a considerable share of the process heat generation in Europe could be provided by HTHP or other technologies (Figure 3). This discrepancy can be explained by integration and knowledge barriers (see D15.4).This means that the manufacturing industry could considerably contribute to the decarbonisation of the sector and the associated integration of renewables in the power system (Bloess et al., 2018). It would save a significant amount of domestic GHG emissions (GHGE) and should be considered as part of the industry sustainability and resilience concepts.

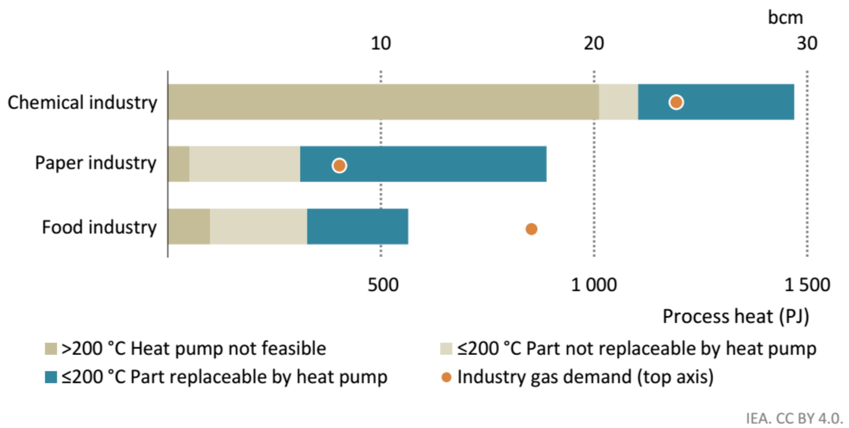


Figure 3: The dissemination potential of HTHP in Europe and different industries. The potential is dependent on the industry, it's typically useable temperature, and the availability of waste heat (IEA, 2022).

In WP15, we dive deeper into the economic feasibility of process heat decarbonisation options (see D15.1), which complements our current focus on resilience. As a final thought, it is worth mentioning that HTHP rely on a reliable electricity system. Resilience measures targeting the power system and electricity prices are thus essential in the context of industrial decarbonisation.

# 5 Application of resilience at SBB

This section describes the application of our resilience concept for SBB and related to the company's energy supply system. As the national rail transportation carrier, SBB plays a key role in the decarbonization of the transport sector, operates part of the critical infrastructure and provides essential services to Switzerland. SBB operates its own power grid with transmission lines, a fleet of power plants and time-varying loads. While many operational challenges are similar to other transmission grids, there are several differences to be considered:

- The SBB power grids experience high load transients, typically peaking every 30 minutes due to their timetable ("Taktfahrplan"). The power demand can more than double within a few minutes.

- The technical characteristics are different than Swissgrid's 50-Hertz grid[6].

- The SBB grid has several asynchronous connections through motor-generators ("Umformer") or frequency converters ("Umrichter") to Swissgrid, being treated as a customer at Swissgrid's high voltage level. Furthermore, the SBB grid is synchronously connected to the grids of DB (Germany's train operator) and ÖBB (Austria's train operator).

- SBB has full ownership and control of the power plant fleet. These plants are primarily used to meet the highly volatile electricity demand for transportation. In addition, SBB's is acting in the bulk electricity market to purchase and sell electricity. While the overall power transients are much more volatile than in other electricity supply grids, the full ownership of the power plant fleet allows for increased flexibility of the SBB power grid.

The goal of investigating this case is to identify potential parts of SBB's resilience and sustainability aspects that can serve as a more detailed case study in the subsequent part of the project. To this end, the following steps have been carried out:

1. An initial discussion with the SURE-contact person at SBB (working on energy strategy and research activities) gave an initial set of relevant SBB documents (on sustainability, development goals and operational aspects) that have been reviewed and are integrated in this chapter.

2. Additionally, a contact has been established with 3 people from the areas of grid operation, development scenarios, as well as sustainability. To review the resilience concept, interviews have been conducted with each one.

3. Based on the findings from the interviews, key concerns have been identified and topics for a more detailed analysis in the subsequent tasks of WP15 have been prioritized and developed.

4. The proposed topics have than been reviewed again with SBB for more detailed feedback and were integrated in this deliverable (see section 1.1.2).

The results are presented in the remainder of this section, which is structured along the different operational levels of the energy supply system: daily operation, seasonal operation, and emergency

[6] frequency 16.7 Hz instead of 50 Hz, 2 phases instead of 3 phases, voltage level 132 kV instead of 220kV or 380 kV

operation. Section 5.2 summarizes the anticipated impact of the shocks on SBB's energy supply system, and the final subsection presents the sustainability concept of SBB.

A key finding should already be mentioned here: SBB has prioritized sustainability and full carbon neutral operation much faster than the full Swiss energy system. The targets are the year 2025 (for transportation) and 2030 (for all of SBB, including building operation). Therefore, the subsequent case study of WP15 will focus on the resilience aspects of SBB's energy system. However, the effect of shocks on the development paths of SBB, including the carbon neutrality, will still be reviewed.

## 5.1 Resilience dimensions at SBB

### 5.1.1 Operational resilience concept

On the operational level, the power balance between supply and demand of electricity has to be met on a second-to-second basis at every node of SBB's electricity grid, while respecting the line limits at every connection of the network. To this end, the following measures are implemented:

- To accommodate the large power transients, an adequate power reserve is always maintained for short-term deployment. This involves SBB's own power plants for fast ramping up and down of the production, as well as imports from the connections to Swissgrid, DB and ÖBB. Automatic frequency reserve ensure that unforeseen power deviations are accommodated.

- To respect the current and voltage limits of every line and node of the network, continuous network simulations are carried out. Constraints from individual lines are translated to transfer capacity limits of the network, imposing bounds on the operation of power plants or trading activities. To accommodate the system needs, flexibility is used in the form of the allocation of SBB's power plants, the connections to Swissgrid, or changes in the network topology.

- The system is designed to accommodate unplanned outages of network elements, called N-1 security. In the case of one line outage, other lines have to take over the power flows. To prevent cascades of overloading and outages, N-1 scenarios are also considered in the network simulations.

- The system is in a particular vulnerable state during maintenance of transmission lines. To mitigate the risks, these maintenance operations are planned as far ahead as possible (up to 5 years). During the maintenance, the connected network parts are carefully monitored and operated in a secure state. If general N-1 security is no longer possible, the system may also be prepared for a controlled islanding (split of the system into multiple synchronous parts).

In summary, these measures are similar to the operation of the European ENTSO-E transmission grid, but on a smaller level and in much more dynamic circumstances. The SBB grid operation may provide inspiration and insights for the future operation of 50-Hertz transmission grids.

### 5.1.2 Seasonal resilience concept

Besides the second-to-second power balance, the SBB grid also has to provide sufficient generation adequacy throughout the entire year. The power plants do not have infinite production capacity but are hydro power plants with a finite water inflow. Since the lowest hydro levels occur usually in Winter, SBB faces a winter gap, where the missing production capacity has to be met through imports.

While there is usually sufficient import capacity and network capacity in SBB's grids, there may be operational constraints in the Swissgrid network also affecting SBB. For instance, future scenarios with high electricity transit flow through the Swissgrid network can result in congestions, that limit how much power can be imported by SBB. Furthermore, European trading restriction towards Switzerland may limit the overall import or make it very expensive. Consequently, SBB faces a winter gap, where a fully independent operation of the SBB network is not possible.

To mitigate the risks, the following measures are taken:

- Long-term planning of the available production capacity. It is possible to operate hydro power plants with a security margin on the storage level (also known as “Winterreserve”). While this reduces the risk of power imbalances due to more flexible capacity in the Winter months, this measure is also quite expensive, since the reserve is usually used in the spring, when prices tend to be very low. In contrast, when requiring more imports in the winter, prices tend to be relatively high. Nonetheless, careful management of the production assets is an integral part of the seasonal resilience concept.

- Long-term agreements for power imports. These measures include power trades in the forward markets and other contract agreements, to ensure adequate energy availability throughout the year.

- Development of the SBB production capacity for the coming decades to include more flexible generation, expand the production from renewables and diversify to other flexible resources. While a power- or energy-driven adjustment of the train timetable is not foreseen, more (and fast) flexibility will help to mitigate power peaks and increase the overall system efficiency.

In summary, SBB faces similar challenges as Switzerland as a whole, to ensure the energy supply throughout the whole year, in particular during winter. However, due to the high volatility of the power demand, a substantial part of SBB’s power plants needs to be kept “on hold” instead of producing a base load. This causes a need for more flexible production over the year, compared to other Swiss utilities, in order to cover the peak demand occurring every 30 minutes,

### 5.1.3 Emergency resilience concept

Compared to other utilities, SBB’s electricity grid is smaller and more volatile, increasing its fragility. On the other hand, the direct control of the production units allows a much more agile operation of the energy system, in order to react to disturbances or threats. This is true for the daily operation, but also in the cases of emergencies and shocks.

A particular focus in SBB’s energy grid resilience is the preparation and fast reaction to severe disturbances and network outages (black/brownouts). This topic encompasses the core of the resilience definition as outlined in sections 1-3. It contains several aspects covering preparation, reaction and monitoring of events, that form dedicated procedures in the SBB grid operation:

Independent operation

In principle, the SBB network can operate independently from Swissgrid network, although it is usually coupled through the “Umformer” and Converters. This independence works both ways: Swissgrid can operate during and SBB outage (as has happened for instance in 2005) and SBB can in principle also operate without the Swissgrid network, using its own flexible power plant fleet.
The two networks (Swissgrid and SBB) could therefore provide mutual assistance during black-out situations.

Preparation for controlled islanding

SBB’s network usually operates N-1 secure, meaning that the unexpected outage of one transmission line can be tolerated. If this security is not possible, for instance during maintenance, a cascade of further outages could lead to a system split into multiple areas. If the production-demand balance in each area deviates too much, a partial or full black-out can occur. To mitigate this risk, SBB will ensure that the balance in each potential area is approximately met, so that a system split will not further escalate to other outages.

Fast black start capability:

If a black-out of the SBB network occurs, the consequences for Switzerland are severe, since the entire rail-based transport comes to a stop. However, if the network operation can resume quickly, the consequences can be bounded. A central goal of SBB's grid operation is therefore to reduce this black start time as much as possible.

Traditional black start approaches use a top-down approach, connecting a power plant with loads (substations) and "growing this seed" in step-by-step manner. This process requires a dedicated procedure which requires multiple hours, even when efficiently executed.

An alternative approach is, to grow multiple "seeds" simultaneously in order to speed up the availability in different areas of the network. This could significantly reduce the black start time and limit the overall impact of a black out. The "multi-seed" approach also complements the preparation for controlled islanding, that also requires a careful balancing of different network regions.

Mutual black start support with Swissgrid:

Connecting two networks in a reliably controllable manner always improves the resilience, since it increases the flexibility of both networks. In principle, this mutual support is available in critical situations for both the SBB and Swissgrid network. However, the coordination is currently not taking place in a systematic manner, but a direct communication between the control rooms of Swissgrid and SBB is possible.

## 5.2 Shock robustness of development paths

Besides the overall resilience concept, we have reviewed how shocks (Section 3.4) may affect SBB, in particular its energy system operation. The findings include both the analysis of the shock descriptions from the SBB perspective, as well as direct discussions during the interviews with partners from SBB.

### 5.2.1 Impact of financial shocks (Shock 1)

The SURE Shock 1, the financial shock, will have direct impacts on the energy price, affecting SBB's energy system operation. Energy is bought and sold on the market and will increase the costs, since SBB is import-dependent during winter. Since there is virtually no flexibility on the demand side management (reducing the SBB schedule servicing certain areas), there is not much room to mitigate the increase in energy costs.

In addition, SBB owns significant assets (the railway system, electricity system, power plants, buildings) that have to be continuously maintained. The financial shock will directly impact the purchase of materials that become more expensive.

### 5.2.2 Impact of heat wave (Shock 2)

A heat wave has impact on the energy demand since the air conditioning of the trains increases. However, trains will cool down to a fixed temperature difference which limits the impact on the energy demand.

In addition, a long-term heat wave may have an impact on the energy production, if the storage inflow of the hydro power plants becomes exceptionally low. As a secondary effect, the change of the overall European energy system (high demand for air conditioning, less production from run-of-river power plants) will increase the price of SBB's energy purchases on the market.

### 5.2.3 Impact of cold spell (Shock 3)

A cold spell has a direct impact on the energy demand since trains need to be heated. The additional consumption is on the order of 10 MW/°C, on top of the usual operational costs. In addition, frozen electricity lines servicing the trains may lead to problems in the system operation of trains.

### 5.2.4 Impact of societal change (Shock 4)

SBB experienced a major shock affecting the transportation demand during the COVID years 2020 and 2021. The trains had to keep operating but were mostly empty. This leads to a decrease of the environmental efficiency of SBB, for instance increasing the emissions of GHG per person-kilometre travelled from about 14g to about 22g[7].

In the context of the SURE societal shock, a drastic increase in population might increase the demand for public transport. SBB will need to increase service intervals and potentially require more electricity imports. In particular during winter, covering the import requirements with all green energy sources may be challenging and expensive.

A relevant aspect of SBB is, that the transport capacity cannot be simply increased or decreased in a linear manner. Instead, transport capacity operates in steps, e.g., by doubling the service intervals or cutting them in half on certain locations. This has also been observed during the COVID shock (for a decrease of services) and holds accordingly for a potential increase in transportation demand from a societal shock.

### 5.2.5 Impact of Nuclear power re-introduction (Shock 5)

SBB currently holds long-term purchase rights of nuclear power plants in France and Switzerland (Leibstadt) through the company AKEB, making up about 10% of the electricity demand. It is foreseen to switch to renewable energy sources, but selling the shares of AKEB currently not feasible due to lack of buyers. In the meantime, SBB plans to purchase certificates of origin from renewable sources to reach its 100% renewable energy objective by 2025.

A scenario like in the SURE nuclear shock is seen as highly unlikely from SBB side. Even if it takes place, it is not foreseen that SBB would increase its shares or long-term contracts with nuclear power plants. There could be an indirect effect through an increased Swiss production capacity, reducing the demand for imports during winter for all Swiss consumers, including SBB.

## 5.3 Sustainability concept of SBB

Sustainability is a core activity at SBB, with the goal to provide a carbon neutral operation by 2030. It includes both the transportation and building operation, where the latter represents the main portion of the decarbonisation activities. A suite of measures has been identified, to achieve these goals even given the overall increase of transport requirements until 2050[8].

Since the energy sources of the SBB electricity grid are mostly carbon neutral already (based on hydro and other renewables), most carbon reductions come from other measures, such as changes to the heating system of buildings with fossil heat sources. Therefore, the subsequent case study will focus on the resilience aspects of SBB's energy system. However, this case study will also investigate, how the shocks affect the development paths of SBB, including the carbon neutrality.

Regardless of the emissions, SBB also pursues the optimization of the overall energy demand. Compared to the total annual energy demand 2019 (about 3070 GWh), SBB expects a nominal increase of 700 GWh (due to increased mobility demand) until 2050 but aims to counter this increase with a

[7] SBB Nachhaltigkeit. Zahlen und Fakten. https://reporting.SBB.ch/nachhaltigkeit?=&years=0,1,4,5,6,7&scroll=0

[8] SBB: Perspektive BAHN 2050, Abschlussbericht, 13.8.2021

reduction of more than 1000 GWh (about 2700 GWh in 2050). Note that only about 75% of the energy demand is used for the railway operation[9]. While the increase in energy efficiency has little impact on SBB's own emissions, the reduction will have positive secondary impacts on the Swiss energy supply system, since more carbon neutral energy sources are available for export to the Swissgrid network (or, in turn, reduction of the import need to the SBB network).

# 6 Conclusion and Outlook

In this deliverable, we have proposed a general sustainability and resilience concept for industry and public mobility. The general concept as well as the applications to the specific cases answer our research question about how to design a resilience concept for these sectors. Integrating the principles, criteria and resilience measures into the sectors will help to maintaining system operation and sustainability in different operational dimensions.

One essential contribution of this deliverable is the evaluation of different shocks. With our energy system focus, shocks from the SURE project have been related to energy supply and demand issues. This was done both in stakeholder interviews and based on own considerations. Resilience and sustainability concepts for SBB are already advanced, providing a basis for upcoming work in WP15. Concepts for industry have been proposed, and their relevance will be scrutinized with various stakeholders from industry. We will do this in an amendment to this deliverable.

More work needs to be done to broaden the scope of the resilience concepts, which currently strongly focus on the electricity system. Particularly in industry, there may be need for such a consideration.

[9] SBB Nachhaltigkeit. Zahlen und Fakten. https://reporting.SBB.ch/nachhaltigkeit

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