

**HORIZON EUROPE PROGRAMME - HORIZON-CL5-2023-D3-01-01**

*Renewable Energy Valleys to increase energy security while accelerating the green transition in Europe - Innovation action (IA)*



**REFORMERS**  
RENEWABLE ENERGY VALLEYS

**REFORMERS**

Regional Ecosystems **FOR** Multiple-Energy Resilient Systems

Grant Agreement No. 101136211

Duration: 60 months | 1st November 2023 - 31st October 2028

## **D5.1: DIGITAL TWIN DESIGN REQUIREMENTS AND INITIAL ARCHITECTURE**

---



Funded by  
the European Union

## DOCUMENT INFO

---

**Deliverable number** D5.1

**Deliverable title** Digital twin design requirements and initial architecture

**Work Package** WP5

**Deliverable type** Report

**Dissemination level** Public

**Due date** M6 (April 2024)

**Pages** 18

**Document version** 2.0

**Lead author(s)** Selma Causevic (TNO), Milos Cvetkovic (TUD)

**Contributors** James Allan (EMPA), Syrine Ben Aziza (TNO), Hanmin Cai (EMPA), Philipp Heer (EMPA), Niek Hendriks (Alkmaar), Jawad Kazmi (AIT), Stefan Mark (AIT), Ander Martinez Alonso (VUB), Edrisi Munoz Mata (EMPA), Roberto Rocca (CIRCE), Edmund Widl (AIT)



**Funded by  
the European Union**

**Project funded by**



Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,  
Education and Research EAER  
**State Secretariat for Education,  
Research and Innovation SERI**

## DOCUMENT CHANGE HISTORY

Version	Date	Author	Description
<b>DRAFT</b>			
0.1	05.04.2024	M. Cvetkovic (TUD), S. Causevic (TNO)	Structure, initial contents
0.2	18.04.2024	M. Cvetkovic (TUD)	Consolidation of input from WP5 contributors
<b>COORDINATOR APPROVAL</b>			
1.0	30.4.2024	Stella Arapoglou (VUB)	Coordinator review
1.1	30.4.2024	Stella Arapoglou (VUB)	Consolidated version for coordinator approval
<b>FINAL VERSION</b>			
2.0	30.4.2024	Stella Arapoglou (VUB)	Format review, version ready for submission



## EXECUTIVE SUMMARY

This deliverable presents design requirements for the Digital Twin for Energy Valleys and proposes the initial software architecture solution for the Digital Twin. A Digital Twin of an energy valley is a digital replica of the energy system of this valley. The changes in the real-world are reflected in the digital twin by keeping the replica in sync using (real-time) measurements. The Digital Twin is used to provide mostly operational decision support, to analyse, evaluate and optimize the operation of the energy valley.

This deliverable, and this work package, look at the digital twin from two different points of view: generic and specific. The blueprint of the digital twin software architecture and the KPIs are provided as a generic solution that any energy valley in Europe could adapt to their needs. While D5.1 establishes the design requirements, D5.6 will give the final draft of the blueprint. One specific instance of the digital twin, compliant with the proposed blueprint, will be implemented within the City Information Platform (CIP) at the flagship valley, after validation in a field lab in T5.5. The real-time data for this digital twin will largely come from activities in T3.4. This deliverable looks forward to the intended developments at the flagship valley.

The first chapter sets the tone by explaining some possible use cases of the digital twin by its potential users. The second chapter continues by listing the design requirements. The design requirements are split across the scoping requirements, software requirements and finally result and interface requirements. The third chapter talks about the available and needed resources including data and supporting software components. The fourth chapter proposes a software architecture. And the fifth, and final chapter, defines the KPIs for assessing the performance of the digital twin.



**Funded by  
the European Union**

**Project funded by**



Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,  
Education and Research EAER  
State Secretariat for Education,  
Research and Innovation SERI

## TABLE OF CONTENTS

---

<b>1. USERS AND USE CASES .....</b>	<b>7</b>
1.1. Users .....	7
1.2. Use cases .....	7
<b>2. DESIGN REQUIREMENTS .....</b>	<b>8</b>
2.1. Requirements on user interaction .....	8
2.2. Real-world replication (model scoping) requirements .....	9
2.3. Digital tool (software) requirements .....	10
<b>3. AVAILABLE RESOURCES FROM THE FLAGSHIP VALLEY .....</b>	<b>11</b>
3.1. IT infrastructure to host the digital twin .....	11
3.2. Energy valley model .....	12
3.3. Historical data .....	12
3.4. Real-time data .....	13
<b>4. PROPOSED ARCHITECTURE .....</b>	<b>13</b>
<b>5. KPIS .....</b>	<b>15</b>
5.1. Real-world replication (model scoping) assessment .....	15
5.2. Specific DT objective ASSESSMENT .....	16
5.3. Digital tools assessment .....	16
<b>REFERENCES .....</b>	<b>17</b>



## LIST OF FIGURES

**NO TABLE OF FIGURES ENTRIES FOUND.**

---



**Funded by  
the European Union**

**Project funded by**



Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,  
Education and Research EAER  
**State Secretariat for Education,  
Research and Innovation SERI**

Acronyms	
<b>DT</b>	Digital Twin
<b>WP</b>	Work Package
<b>API</b>	Application Programming Interface
<b>REV</b>	Renewable Energy Valley
<b>GUI</b>	Graphical User Interface
<b>CIP</b>	City Information Platform



**Funded by  
the European Union**

**Project funded by**



Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Federal Department of Economic Affairs,  
Education and Research EAER  
**State Secretariat for Education,  
Research and Innovation SERI**

Swiss Confederation

## 1. USERS AND USE CASES

A Renewable Energy Valley (REV) in the context of the REFORMERS project is defined as a decentralised renewable energy system that promotes production of green energy, diversification of energy supply and energy self-sufficiency. One of the key technologies to enable these characteristics is a Digital Twin (DT). DTs are envisioned as operational decision support tools, observing the dynamics of energy supply in the valley, providing analytics and management advice to its users [Palensky2022].

### 1.1. Users

The potential direct users of a digital twin are:

- 1) Local municipality representatives
- 2) Businesses located in the valley
- 3) Energy companies operating in the valley

Each of these groups of users could use a twin in a distinct way. Local municipality representatives could be interested in an overview of the (renewable) energy production and consumption in the valley in order to form policies that further promote adoption of green energy. Businesses could be interested in advice on bill management given the local conditions in the valley that are accurately reflected in the twin. Energy companies could be interested in identifying business opportunities, ranging from installing new assets for generation and distribution of energy, to identifying the right types of contracts for their customers.

Within the REFORMERS project, all three groups of users are represented and all groups have expressed interest to a different degree in the digital twin.

### 1.2. Use cases

Some possible uses of the digital twin are listed next. These are given as examples and do not constitute a complete list. The purpose of this list is to provide the reader with a few specific examples so that the remaining part of the report can be read with having some potential applications in mind.

- **Increased observability into energy supply** – the DT contains the energy image of the valley which is regularly updated with the field measurements. Therefore, the twin is the go-to platform to observe the state of the energy supply in (near) real-time. The measurement data and any analytics performed by the twin are being stored and can be retrieved later for future use.
- **Forecasting of renewable energy production** – the DT could potentially be used to forecast solar and wind power generation for specific renewable energy sources in the valley. This can be done over the horizon of minutes and hours providing valuable information to all stakeholders who own or receive energy from these sources. With such information, the stakeholders could decide on, for example, how much energy they need



to import from outside of valley from one day to the next or even from one hour to the next.

- **Forecasting of energy consumption** – similarly to the previous, the DT can be used to forecast consumption, particularly for the larger commercial users and residential neighbourhoods, providing insight into the energy needs of the valley. Such information can be used in a similar way as described in the previous point. The emphasis remains on the ability to make decisions within hours, days and weeks.
- **Monitoring and analysing energy flows and network congestion** – in this use case, the twin is used to indicate how energy gets exchanged and if the energy flows in the valley are reaching the capacity limits of the network infrastructure. This is particularly interesting in the case of electricity grids which are quickly saturating due to rising numbers of electric vehicles, heat pumps and solar panels. Such information can be valuable to stakeholders who could act on it (near) real-time to help reduce the burden on the infrastructures.
- **Energy management** – since the DT has the complete picture of the energy situation in the valley, the DT can be used to provide advice on managing the energy generation and consumption by recommendations on how to utilize the available flexibilities. Due to such completeness, the advice would be more accurate and reliable than what each of the stakeholders could conjure independently. Additionally, it would arrive in a timely manner. The advice that DT gives could, but does not have to, be acted upon by stakeholders.
- **Scenario analysis** – what-if studies are of high value to all users and DT could be used to explore various pathways, including different weather scenarios, control options, usage patterns, etc. Although in this case the twin acts as a model, its richness in terms of modelling details and access to historic data could provide crucial benefits over the offline model-based studies.

The representatives of the city of Alkmaar have identified increased observability and congestion analytics as two use cases with a high priority for the flagship valley.

## 2. DESIGN REQUIREMENTS

The design requirements are split into three groups, each of which relates to a specific part of the DT. The same groups of requirements will be followed up upon in the KPI section from the context of evaluation and validation.

### 2.1. Requirements on user interaction

By analysing example use cases in Section 1.2, it is possible to distinguish several requirements related to user interaction with the digital twin. These are blueprint requirements. Each energy valley could choose to reduce this set per their need.

- **Analytics** – the twin should provide the means of displaying and analysing the current situation in the energy valley in terms of energy levels, power exchanges, CO2 emissions, etc. In other words, the twin should be able to present the current



image of the valley to the users in near real-time. In addition, it should also provide the means to users to save the image and reload it later for offline analysis.

- **Forecasting** – the twin should provide the means of forecasting the energy levels, power exchanges, CO2 emissions, etc. Similar to before, the user should be able to store the forecasts and check them later against the realizations adding to the analytic potential.
- **Management** – the twin should proactively provide advice to the user on energy management, power management, bill management, etc. This advice can be provided through a GUI or an API. Similar to before, the user should be able to store the advice together with the image of the valley for later analysis.
- **Scenarios** – the twin should provide the means to test what-if scenarios. Within the what-if scenarios, the user might want to change an external condition, such as weather profile, or an internal behaviour of some assets, such would be the change of control logic. Similar as before, the outcome of the study should be stored for later use.

For all listed requirements, meta data should be included when storing the results.

In the case of the digital twin of the Alkmaar flagship valley, all requirements are of interest although the analytics requirement takes priority over the others.

## 2.2. Real-world replication (model scoping) requirements

The main purpose of the digital twin is to act as a digital replica of the energy valley near real-time. To achieve this goal, the DT must replicate truthfully the energy ecosystem of the valley. To this end, we can define the following dimensions to be represented in the DT:

- **Spatial scope** – the spatial size of an energy valley can vary. Although the DT is focused on the city of Alkmaar, the DT will broaden the modeling scope per need and per availability of measurements to include other relevant energy aspects. The key modeling challenge is the representation of what is beyond the spatial scope but still has influence on the local energy system. This could be, for example, the high-voltage transmission system representation, or the electricity wholesale market representation or the representation of weather in the broader region.
- **Temporal scale** – the DT is primarily an operational decision support tool. Hence, the model should run with temporal scales with time resolution of seconds, minutes, and hours. The real-time data from the valley must comply to this requirement. The time horizon that is being used for forecasting and scenario/management advice is in terms of days and months ahead.
- **Stakeholders and decentralized operation** – Another distinct characteristic of an energy valley is its decentralized operation in an ecosystem with multiple stakeholders. The typical actions of these stakeholders should be captured in the twin. For example, an energy consumer has a battery and a controller that makes sure that the company stays below its contracted capacity for electricity connection. The key modelling challenge is to capture the overlaying forms of the stakeholder operation principles including their risk preferences and options.



- **The energy carriers (vectors)** of interest are electricity, heat and gas. Their couplings are also important to consider. All three of these carriers are present in the city of Alkmaar, electricity and gas under the governance of Alliander and district heating network under the governance of HVC. Even though there is yet no hydrogen infrastructure in the city of Alkmaar, hydrogen is generally seen as the upcoming energy carrier, and therefore, it is of interest for the modelling in the DT. The main variables to capture are power and energy. The topological information of the networks, together with their capacities, are also of interest. In the case of the electricity grid, the MV and LV levels are of interest. In the case of the gas grid, lower pressure gas distribution is of interest.
- **Energy assets (generation, storage, consumption)** – any renewable and non-renewable energy sources, storage options such as batteries, and large consumers should be modelled within the DT to obtain a representative image of the energy system. The diversity and heterogeneity of options are the key challenges for implementation while the models can range from single asset models to lumped technology representations.
- **Uncertainty** – in the case of energy valleys with many stakeholders and energy assets, it is almost certainly the case that some parts of the system will be best described using stochastic principles. Most naturally, the uncertainty is an integral part of weather and energy demand. Furthermore, it is present in the stakeholder behaviour and to some extent in the behaviour of the flexible demand assets. It is important to consider the three forms of uncertainty and to identify their role in different segments of the digital twin. These three forms of uncertainty and corresponding mitigations are: 1) short term uncertainty that is predictable and best captured with forecasting models, 2) medium term uncertainty that is not predictable but whose probability density function is known, and 3) long term uncertainty that is best captured by devising edge case scenarios.

### 2.3. Digital tool (software) requirements

The digital twin is a software solution, and as such, must adhere to the software/digital specifications. The digital tool specifications should of course be derived from the use cases that the twin is supposed to handle, and hence, it is not possible to define them precisely for a generic blueprint of the digital twin. However, we can define the following groups of requirements for the blueprint.

- **Data quality** – it is essential that the data collected from the valley by the DT is as complete as necessary, that it is accurate and timely and that it is consistent. In case data quality is poor, replacement with default values and/or estimation of missing/inaccurate values should be performed.
- **Performance** – it is necessary that the computational performance of the DT is within the temporal needs of the use cases that the DT covers and that the result is numerically accurate to the desired level. In case computational effort is too high leading to poor performance, the complexity and/or resolution of the models should



be reduced or stronger computational environments (such as HPC clusters) should be used.

- **Result archiving** – it is important that the results of DT computations are stored for offline analysis and later use. In case the local storage options are not sufficient, a cloud based options could be explored.
- **Interoperability** – it is important to comply with common model ontologies and common data exchange standards to ensure interoperability between elements of the digital twin and between the twin and the rest of the world. The interoperability should be in service of functionality and not a goal in itself.
- **Scalability** – it is essential that the twin is modular and scalable allowing re-scoping of the models and services that it offers in order to evolve together with the valley.
- **User experience** – it is important that the twin is available to users when needed, that its methods and algorithms are transparent and understandable to users and that its processing steps are logged and stored to ensure tractability.
- **Versioning** – it is necessary to properly version, test and maintain different digital elements of the DT.
- **Security** – it is important that a user account system is in place and that the GDPR are followed when/where necessary.
- **Privacy** – necessary privacy rules must be applied and compliance with GDPR ensured.

Each energy valley would have to define each of these requirements more precisely and per need. Before this can be done, the valley should shortlist all use cases of interest. Since we are covering many use cases for the Alkmaar digital twin, and since this effort is largely a research and innovation action, we do not try to create a unified set of specific digital tool requirements beforehand. Instead, we will reflect on these aspects during the evaluation of the digital twin.

### 3. AVAILABLE RESOURCES FROM THE FLAGSHIP VALLEY

In the case of the REFORMER's flagship energy valley, following are resources that stand on the digital twin disposal. They are separated in four segments out of which three relate to data. It is worth noting that different energy valleys might have different resources available. However, every energy valley will have some of these on their disposal.

#### 3.1. IT infrastructure to host the digital twin

The city of Alkmaar already runs a City Information Platform (CIP) that was developed as a part of a Horizon2020 project called Pocityf (H2020-SCC-01-2019, GA: 864400). This platform already contains some of the essential IT components for running the DT. These include a database with plenty of data about the city, a visualization GIS-based platform, user account management system, etc. Although the IT systems are in place, the information about the energy system of the valley is rather scarce and not available in real-time. Yet, the CIP will provide the foundation for the implementation of the REFORMER's digital twin.



## 3.2. Energy valley model

Following is the list of all available information at this time that can be used to construct the model of the Alkmaar energy valley. The data is provided by the project partners as a part of T3.2. The data will be used in accordance with the data management plan of the project which can be found in D1.6.

- Generation:
  - Wind turbine locations and capacities
  - Solar panel locations and capacities including residential & commercial installations
  - District heating plants location and capacities
- Consumption:
  - Energy labels of buildings and households
  - Locations of large consumers and contracted network connection capacities
- Networks:
  - Electricity network outline at the MV and LV level including cable and substation capacities
  - Natural gas pipeline outline including the capacities and pressure levels
  - Heat network outline including the capacities and temperature levels

## 3.3. Historical data

Following is the list of the historical data that is available as of the time of writing this report. The data is provided by project partners within T3.2 or available open source. The data will be used in accordance with the data management plan of the project which can be found in D1.6.

We first list the total energy values over one year period.

- Generation:
  - Large solar and wind energy production
  - Aggregated generation capacity of residential customers per zip code
- Consumption:
  - Aggregated consumption of residential customers per zip code
  - Energy consumption of largest energy consumers

Next, we list the energy/power profiles of various assets. The time horizon is one year unless stated otherwise.

- Generation:
  - District heating plants generation profile with an hourly resolution
- Consumption:
  - Synthetic load profiles for various businesses
- Networks:



- Electricity power profile over several substations in the network with hourly resolution
- Natural gas profile at particular locations in the network with daily resolution

Finally, historical weather data is available as open source through Copernicus Climate Data Store.

### 3.4. Real-time data

Following is the list of the real-time data that should be made available as a part of T3.4. The data is sampled with the resolution higher than 1 Hz unless stated otherwise. The data will be used in accordance with the data management plan of the project which can be found in D1.6.

- Generation:
  - 50 largest energy producers
- Consumption:
  - 20 largest consumers which are non-controllable
  - 50 residential customers
  - Consumption forecast at the regional level (bigger than the valley) with 15 minute resolution

In addition, online weather services can be used to obtain the real-time weather data.

## 4. PROPOSED ARCHITECTURE

In this section, we conceptualize an architecture of the digital twin. This is the first proposal, while the final description of the architecture will be delivered as a part of the digital twin blueprint in D5.6.

First, we recognize that the variety of use cases that the digital twin handles can best be encapsulated with a service-oriented architecture. In this context, looking at the use cases from Section 1.2, we can say that the digital twin should provide, for example, an energy flow analysis service or a wind forecasting service.

Reference [Aheleroff2021] presents a possible reference architecture model centered around Digital Twin as a Service principle. Although defined for manufacturing industry, this reference model provides a neat categorization of digital twins, digital models and digital shadows that gradually show the spectrum of integration of the digital system with the physical one.

Similarly, the ISO/IEC/IEEE 15288 [ISO15288] standard on systems and software engineering provides a neat way to differentiate between enabling systems (such as data storage, user account management, etc.) and services and functions that our system of interest provides (for example already mentioned wind forecasting service). This reference architecture can be used to differentiate between the supporting elements and the elements ensuring the main functionality of the digital twin for energy valleys.



The following architecture sketch in Figure 1 is proposed for the implementation of the energy valley digital twin. The purpose of this sketch is to establish the main elements that we foresee will constitute the digital twin for energy valleys. Its purpose is not in any way to show a final or complete architecture.

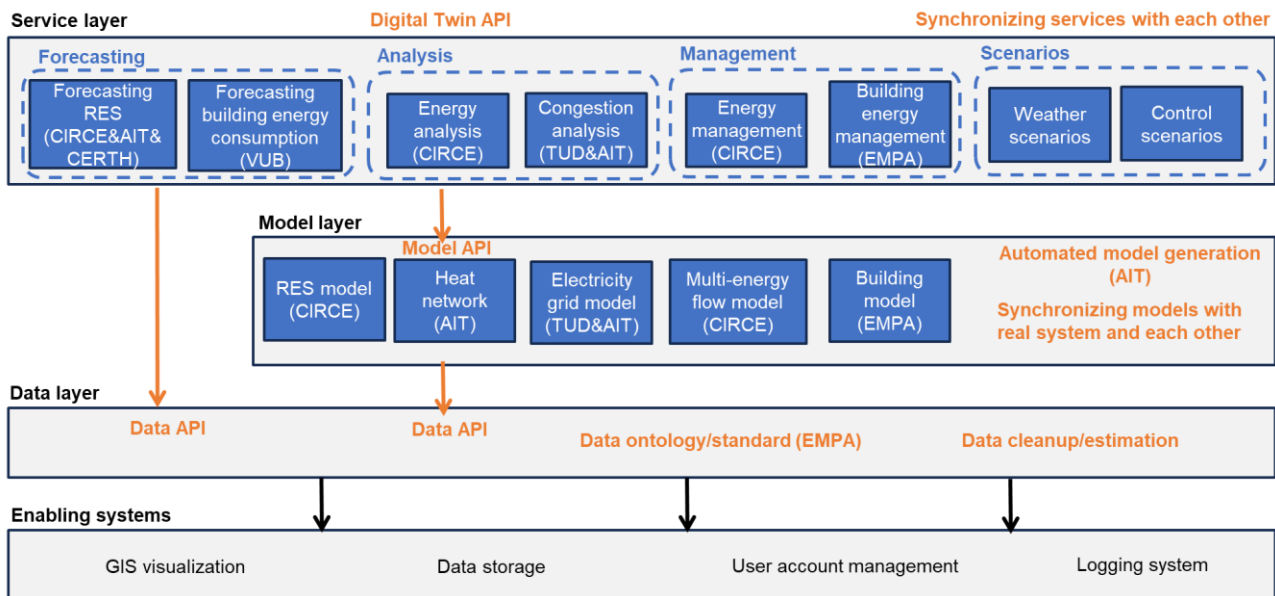


Figure 1 Architecture sketch of the digital twin including references to partners

The top three layers in the image represent the three layers of the digital twin focusing on data, models and services. Each of these layers is covered in one task of this WP. The deliverables of those tasks (D5.2, D5.3 and D5.4) will give more details on each of the layers, while the main ideas will be presented in this deliverable. The enabling systems are the IT systems which are in the case of the Flagship Valley provided as a part of CIP.

The role of the data layer is to manage the necessary data to ensure the functionality the digital twin. This includes communication between the physical asset and the integrated services and models. Where possible, data will be standardized to common data models and schemas to support interoperability and scalability.

The model layer is in charge of keeping and regularly updating the image of the energy valley. The image is contained within a model. Since it is almost impossible to have a single comprehensive model of a complex system like an energy valley, this layer should provide for the existence of multiple models. The models contained within this layer can be of different resolution and scope. However, they all must be in sync with the energy system of the valley in terms of system configuration. In other words, every single model within this layer is a digital representation of the same physical energy system. To ensure such alignment, automated model generation techniques are used together with the timely model synchronization.

The service layer is in charge of accepting the requests from the users and on addressing those requests by using the models and the data. Within the service layer, we recognize four categories of services as described in Section 2.1. Each individual service will likely be linked to a specific model and/or to a subset of data. Since services might need to provide additional (and sometimes extensive) calculations on top of data and model outputs, it is paramount to harmonize advice between services or at least provide warnings in cases when conflicting advice could occur. For example, it should not happen (without a warning) that a bill management service advises to perform action that creates congestion while the congestion management service advises an action in the opposite direction.

Finally, this figure also shows the names of the partners which will develop each of the elements of the digital twin.

## 5. KPIS

This section discusses the Key Performance Indicators (KPIs) that will be used to assess the DT developed and implemented for the energy valley. Assessing a DT requires a multi-fold approach, as a DT is a digital replica of a real-world that should serve a defined purpose and accommodate defined requirements. To this end, the DT developed in REFORMERS will be assessed on different levels: (1) on a real-world replication level, (2) stakeholder objective (DT purpose) level, and (3) on the digital tools (technical) level. The assessment criteria will follow requirements defined in Chapter 2. However, not all the requirements will be assessed, as each energy valley has to scope their DT for their specific purpose.

### 5.1. Real-world replication (model scoping) assessment

The first assessment looks at how well a DT replicates a real-world system for which it is built. It is important to note that depending on the purpose of a DT, different level of details is required in the digital replica. This assessment does not generate a quantifiable KPI, but offers a general framework that can be used to gain an insight into what a developed DT offers to the involved stakeholders, with respect to their objective. The framework will generate a form of a lookup matrix to show the features of the real world a DT replicates. The dimensions of this assessment are multi-fold, and some of them include:

- **Spatial scope** – This dimension assesses whether the DT models the entire (required and relevant) spatial scope of the real-world. Depending on the purpose, different aggregation levels can be required for different aspects of an energy system. This will also depend on privacy concerns of involved stakeholders. The spatial dimension also involves the challenge of representing what is beyond the spatial scope of the valley itself, but still has influence on the local energy system. This could be, for example, the high-voltage transmission system representation, or the electricity wholesale market representation or the representation of weather in the broader region.
- **Temporal scale** – This dimension assesses how often the DT collects necessary data for operational, prediction, and modelling purposes. For example, if it is real-



time, per second, hourly, daily etc. As is the case with spatial scope, the temporal scope requirements depend on the DT purpose.

- **Energy carriers (vectors)** – This dimension assesses if all relevant energy carriers (vectors) present in the valley are replicated by the DT.
- **Energy assets** – This dimension assesses if all relevant energy assets present in the valley are replicated by the DT.

These dimensions follow a number of requirements defined in Chapter 2.2 and can be assessed as Low/Medium/High, depending on how detailed they are. The dimensions are given as an illustrative example, and should further be worked out with the DT owners, as they will also depend on the objectives and specific use cases.

### 5.2. Specific DT objective ASSESSMENT

A DT should be developed with an aim to serve a certain purpose, reflected in one or more objectives. These objectives should be defined by relevant stakeholders (DT “owners”), and their evaluation should show a benefit of having a DT. The objectives stem from different use cases, as defined in Chapter 1.2. Based on KPI outcomes, an evaluation of the use cases can be made to show the impact a DT on the objectives. To demonstrate how the effect of a DT installation and development can be assessed given a specific objective, a comparison between a baseline scenario (where no energy interventions are installed, and no DT is in place), a scenario with energy interventions, and a scenario with interventions and a DT will be performed. For example, if (increase in) self-sufficiency (SS) is the main objective, the following SS values can be calculated and compared:

- Baseline  $SS_B$  [%/year] - SS before the project started, no new interventions installed, no DT
- Interventions  $SS_{INT}$  [%/year] - SS after the interventions are installed, but no advice/optimization from the DT
- Interventions + DT advice  $SS_{INT+DT}$  [%/year] - SS after the interventions are installed, and with the advice/optimization from the DT

$$SS = 100 * \sum_{v=1}^V \sum_{t=1}^T \frac{E(t)^v_{consumption} - E(t)^v_{net imports}}{E(t)^v_{consumption}} [kWh]$$

Depending on the objective, the evaluation of the DT replication assessment framework can have different requirements on the level of details. For example, if the objective is focused on improving a very specific subset of the network, the assessment that the DT is not a full replication might be less relevant. So, the focus should be on replication of the target subsystem, and the rest of the system could be replicated on a more aggregate value. The objectives also depend on specific use cases. Therefore, the KPIs in this section should be specified based on use cases, as defined in Section 1.2.

### 5.3. Digital tools assessment



This assessment is focused on technical aspects of DT such as data quality, performance, and security. For now, the focus is on:

- **Data completeness** [%/year] - (In)Completeness of collected data with respect to the model requirements and DT objective/purpose. To assess this KPI, data types, granularities etc. required by the model should be specified, and the assessment for time t with respect to DT objectives should be analyzed. Finally, a conclusion on the total percentage of the missing data points for time t is calculated.
- **DT modularity** [unit and formula TBD] - This assessment focuses on how well DT is able to adapt to changes in terms of adding, removing, and changing model elements.
  - Adding X new assets
  - Adding Yk existing assets
  - Adding Zk diverse assets

## REFERENCES

---

[Palensky2022] Palensky P, Cvetkovic M, Gusain D and Joseph A. Digital twins and their use in future power systems [version 2; peer review: 2 approved]. Digital Twin 2022, 1:4 (<https://doi.org/10.12688/digitaltwin.17435.2>).

[Aheleroff2021] Shohin Aheleroff, Xun Xu, Ray Y. Zhong, Yuqian Lu, Digital Twin as a Service (DTaaS) in Industry 4.0: An Architecture Reference Model, Advanced Engineering Informatics, Volume 47, 2021, 101225, ISSN 1474-0346, doi: 10.1016/j.aei.2020.101225.

[ISO15288] ISO/IEC/IEEE International Standard - Systems and software engineering-- System life cycle processes," in ISO/IEC/IEEE 15288:2023(E) , vol., no., pp.1-128, 16 May 2023, doi: 10.1109/IEEESTD.2023.10123367.



Funded by  
the European Union

Project funded by



Schweizerische Eidgenossenschaft  
Confédération suisse  
Confederazione Svizzera  
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,  
Education and Research EAER  
State Secretariat for Education,  
Research and Innovation SERI