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Transparent AI Forecasts for Green Energy in Austria

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D5.1 Digital twin optimization result documentation

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Executive Summary

This deliverable presents the development and initial validation of digital twin models for selected proof-of-concept energy systems within the project. The work focuses on two main applications: a biogas plant digital twin and a multi-site mobility energy system digital twin. Both models aim to create reliable digital representations of real energy systems to support operational analysis, scheduling optimization, and future decision-making.

The biogas digital twin was developed using the AIT-internal TESCA simulation framework. It models the relationship between organic feed input, biogas production, gas storage dynamics, and combined heat and power unit operation. A data-driven methodology was established that requires only a limited set of operational data, including storage level evolution, CHP electric power output, and information on organic feed deposition. This approach enables quantitative estimation of biogas production characteristics and provides a flexible basis for modelling different biogas plant configurations.

The mobility digital twin was implemented using the IESopt optimization framework. It represents a bus operator's multi-site energy system, including photovoltaic generation, electric vehicle charging infrastructure, grid connections, and a large-scale battery energy storage system. The model incorporates technical asset specifications, measured operating data, forecast information, and owner preferences, including safety margins and coordinated energy scheduling across multiple sites.

Validation results for the mobility twin show that the model can reproduce the main operational dynamics of the battery storage system with good accuracy. Deviations between simulated and measured storage behaviour were mainly caused by forecast uncertainty, long lead times between schedule calculation and operation, and differences in the initial storage state. By integrating improved PV forecasts, updated demand forecasts, imbalance price estimates, and a more complete representation of operational behaviour, the model accuracy was substantially improved.

Overall, the results demonstrate that digital twins can provide valuable support for optimizing complex, sector-coupled energy systems under real-world operating conditions. The developed methods form a strong basis for further refinement, extended validation, and practical deployment of digital twin-based operational planning tools.

1. Introduction

This deliverable documents the application and results of digital twin models for first selected proof-of-concept sites within the project. The objective of the work is to establish digital representations of real energy systems that are sufficiently detailed to support operational analysis, optimization, and future decision-making. The documented activities focus on two main application areas: a biogas plant digital twin and a multi-site mobility energy system digital twin.

The digital twins combine measured operational data, site-specific technical information, operator knowledge, and data-driven modelling approaches. This enables the representation of both the physical behaviour of key assets and the operational constraints that influence their use in practice. For the biogas application, the work focuses on modelling the relationship between organic feed input, biogas production, gas storage dynamics, and combined heat and power unit operation. For the mobility application, the work addresses the coordinated operation of charging infrastructure, photovoltaic generation, grid connections, and battery energy storage across multiple sites.

The deliverable is structured into two main sections. The methodology section describes the modelling approaches, data requirements, parameter identification procedures, and optimization frameworks used for the development of the digital twins. It explains how the biogas twin was initialized using the TESCA simulation framework and how the mobility twin was implemented using the IESopt optimization framework. Particular attention is given to the integration of measured data, technical specifications, forecast information, and owner preferences.

The results and discussion section presents the outcomes of the digital twin application and validation. For the mobility twin, the comparison between simulated and measured battery storage behaviour demonstrates that the model can reproduce the main operational dynamics of the real system. The results also show the influence of forecast uncertainty, planning lead times, and initial-state deviations on model accuracy. Improvements in the scheduling workflow, including the use of updated forecasts and a more complete representation of operational behaviour, lead to a closer agreement between predicted and measured storage trajectories.

Overall, this provides the basis for assessing how digital twin models can support optimized operation of complex, sector-coupled energy systems. The documented work shows that combining data-driven calibration, detailed asset modelling, and operational optimization can improve understanding of system behaviour and support more robust scheduling decisions under real-world conditions.

2. Methodology

This section describes the methodological approach used to develop and validate digital twins for the selected proof-of-concept sites. The work builds on the AIT-internal simulation framework TESCA for detailed modelling of biogas systems and the IESopt optimization framework for the mobility energy system. Across the test sites, the methodology combines access to measured operational data, site-specific technical information, operator knowledge, and data-driven parameter identification to represent both physical asset behaviour and operational decision-making. The approach was first applied to a biogas plant, where recorded storage levels, CHP electric power output, and organic feed information were used to derive relationships between feeding, biogas production, storage dynamics, and CHP operation. In parallel, a multi-site mobility twin was developed to model charging infrastructure, photovoltaic generation, grid connections, and battery storage under forecast uncertainty while also incorporating owner preferences and operational constraints.

2.1. Biogas twin

The initial steps for the development of detailed digital twins of the proof-of-concept sites using the AIT-internal simulation framework TESCA have been taken. For the experimental tests, data access was ensured to four test sites through NDAs. Moreover, partner PBEG provides access to a fifth test site at their office location. These sites comprise assets such as biogas plants, battery energy storage systems, PV plants, and electric vehicle charging infrastructure, among others.

The digital twin development was initialized for a biogas plant test site operated by Bioenergie Bleier with an inspection of the plant including a discussion of relevant modelling aspects with the operator.

Biogas plants consist of several components, most importantly the combined heat and power (CHP) unit that produces electricity and heat, the organic feed receiving area, the digester, and the gas storage. Through literature review, it was identified that there is a lack of approaches providing a sufficient level of detail and correlation between feeding, biogas production rate, storage level, and CHP output. To bridge this gap, Task 5.2 focuses on the development of an approach that uses deep system understanding combined with processing of big amounts of data and statistical methods. So far, a data-driven method was established to:

- Map the storage level to the electric CHP output
- Establish the effects of requested CHP electric output power on the storage level evolution, considering the set-point dependent efficiency of the power unit
- Quantify the biogas production out of the deposited organic feed. It is important to highlight that through carefully designed parameter identification, not only a qualitative, but quantitative evaluation of the produced biogas is possible. This includes:
    - Mapping the mean time that a certain type of organic matter needs at the specific site in the respective season until the gas development begin,
    - Energy (methane) content of the gas, being also site, organic matter and season specific,
    - Expected amount of biogas per unit of organic matter of certain type.

Within the task, a flexible pipeline was developed that is suitable to develop the first, most important step towards the digital twin of an in principle arbitrary biogas power plant: it fully implemented the methodology to develop the digital model of such a plant based on data which is minimal in terms of requirement. This means, it is sufficient to feed the parametrization procedure with information on the:

- Recorded storage level evolution
- CHP electric power output
- Organic feed deposition time instances and organic matter type.

A coupling both in forward and backward direction can be established between all the biogas site components and a connection interface to other assets (such as grid connection points, batteries or heat sinks) can be established.

A publication on the developed methodology for the conference “IEEE SMC 2025” in Vienna has been submitted, presented and published. This methodology is also the essence of P. Reisz’s master thesis.

For the aforementioned biogas test site (Bioenergie Bleier), experimental validation tests have been carried out based on the recorded data of the:

- combined heat and power unit’s (CHP) electric output power,
- biogas storage level,
- available information on the feeding (amount and type of organic waste deposited in the digester).

All of the aforementioned data can be obtained from the data-interface (API) created in WP2.

2.2. Mobility twin

For this digital twin, the test setup represents a bus operator located in Lower Austria, covering both scheduled (public transport) line services and travel operations. The main asset site is modelled with a 1 MW grid connection, a controllable 1650 kWp PV system, and a battery storage system with 1.2 MW power and 5.7 MWh capacity, serving two charging locations with a total of 900 kW charging power. In addition, the location is linked to two further sites connected at separate grid access points: one with 600 kW charging power and another with 1800 kW charging power, the latter occasionally reaching simultaneous charging loads above 1300 kW. Together, these assets form a multi-site mobility energy system that is modelled using the IESopt optimization framework to assess operational strategies under forecast uncertainty.

2.2.1. Battery energy storage system

Special care was taken in the representation of the battery energy storage system. The model was parameterized using technical specifications provided by the supplier and further calibrated through manual tuning against actual measured operating data. This ensured that the simulated battery behaviour reflects the technical capabilities and operational characteristics of the real asset as closely as possible. This results in a roundtrip efficiency of close to 90% and a passive loss of 0.06% of energy content each hour (around 3 kWh per hour at full charge).

2.2.2. Human preferences

In addition to the technical asset representation, particular attention was given to modelling the owner’s preferences in order to capture the human and operational decision-making element of the mobility twin. This includes applying increased safety margins for both the battery’s power and energy limits, allowing deviations caused by forecast errors to be balanced more frequently during real operation. Furthermore, the owner prefers a coordinated scheduling approach across the three sites. Where reasonably possible, the sites are therefore scheduled to use energy “internally” across the portfolio, even if this exchange physically relies on sections of the public grid. In practice, this means that expected surplus generation at the main site is scheduled to be fed into the grid during periods when the other locations are expected to consume electricity. This rule of thumb is only overridden when expected cost differences between alternative market time periods are sufficiently high to justify a different scheduling decision.

3. Results and Discussion

The results and discussion section presents the outcomes of the digital twin development and validation activities for the selected proof-of-concept applications. It summarizes how well the developed models reproduce observed system behaviour, highlights the main sources of deviation between simulated and measured operation, and discusses the relevance of these findings for optimized scheduling and practical deployment. Special attention is given to the mobility twin, where comparisons of predicted and measured battery storage states demonstrate the impact of forecast quality, planning lead times, and operational updates on model performance.

3.1. Biogas twin

Detailed information is given in *“Development of biogas power plant models based on statistical methods”* by Reisz, P. (2026).

3.2. Mobility twin

The first comparison, see Figure 1, between the simulated and measured battery energy content shows a close agreement between the digital twin prediction and the actual operation of the storage system. The predicted storage state, shown as a dotted line, follows the measured storage state, shown as a dashed line, with only limited deviations over the assessed period. Where deviations occur, they are mainly visible as an earlier increase in the measured storage state compared to the model prediction. This behaviour can be linked to deviations between forecasted and actual PV generation, in particular to an earlier-than-expected rise in PV production. Overall, the result confirms that the digital twin is able to reproduce the operational behaviour of the battery storage system with good accuracy under the observed conditions.

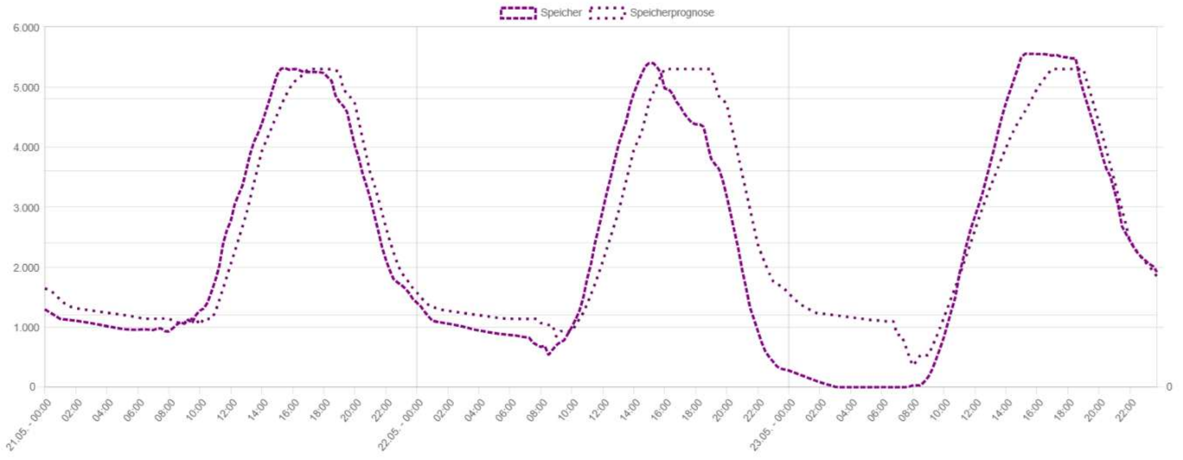

Figure 1: Comparison of storage state between digital twin (dotted) and actual operation (dashed).

A second evaluation, see Figure 2, over three consecutive days shows that the digital twin captures the structural behaviour of the storage system well, even when the absolute energy content differs from the measured state. At the beginning of the first day shown, the modelled storage state is approximately 2000 kWh below the measured value, and this initial deviation is not recovered during the displayed period. Nevertheless, the overall shape of the predicted and measured storage trajectories remains similar, indicating that the model represents the charging and discharging logic consistently. Further analysis showed that deviations of this type are mainly caused by the long lead time between schedule calculation and actual operation. Since the schedule is calculated between 5 and 6 a.m., there is a lead time of at least 18 hours until the first 15-minute interval of operation, and more than 40 hours at the end of the day of operation. This increases the impact of forecast errors and initial-state deviations on the subsequent storage trajectory.

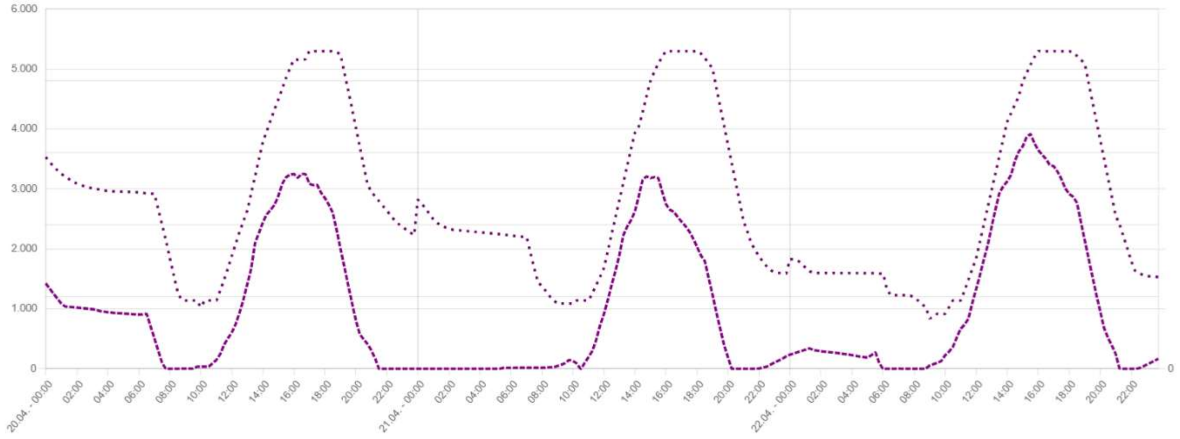

Figure 2: Comparison of storage state between digital twin (dotted) and actual operation (dashed).

A third comparison, see Figure 3, over another three-day period highlights the sensitivity of the storage prediction to planning updates and initial-state mismatches. In this case, the modelled storage state starts with an energy content approximately 500 kWh above the measured value at the beginning of the first day. During the first day, the prediction improves, and the modelled storage state aligns comparatively well with the measured value toward the end of the day. However, the updated schedule for the second day, which had again been calculated in the morning of the previous day, worsens the agreement between model and measurement. This indicates that even when the digital twin achieves a good match within one operating day, subsequent planning updates based on forecasts and long lead times can reintroduce deviations. The result underlines the importance of frequent state updates and robust handling of forecast uncertainty in the operational use of the mobility twin.

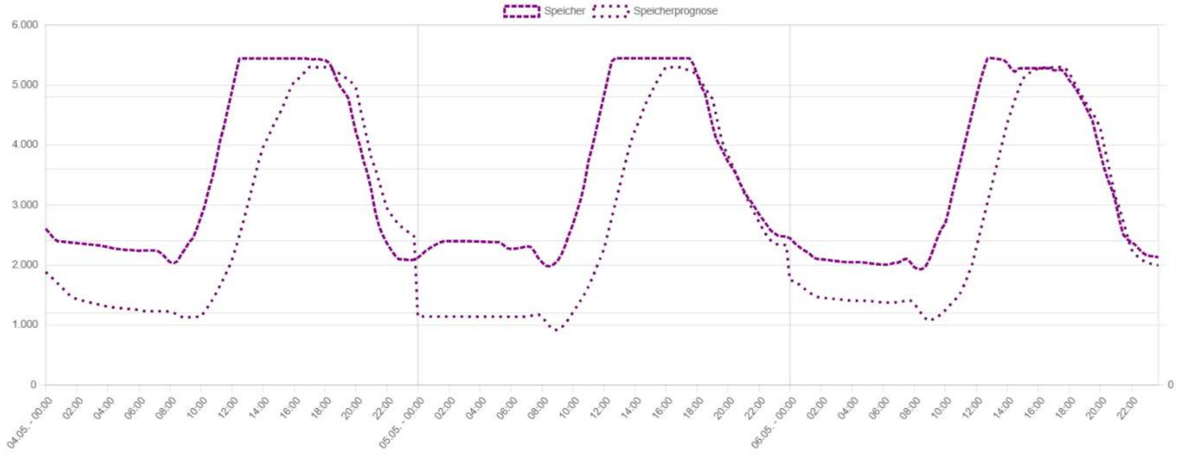

Figure 3: Comparison of storage state between digital twin (dotted) and actual operation (dashed).

A key improvement was achieved by explicitly addressing the causes of these deviations in the scheduling workflow. Forecast quality was continuously reviewed, and the best available PV generation forecasts, developed in a separate task, were integrated into the planning process. In addition, the full operational behaviour was incorporated into the scheduling model. This includes estimating imbalance prices in addition to the supplied day-ahead electricity price forecasts and combining these with the most recent generation and demand forecasts. As a result, the model can estimate when and to what extent deviations from the previously submitted schedule will affect the current operating day. Since the current-day schedule has already been submitted and is fixed while the schedule for the following day is being prepared, the model accounts for the operational objective of following the fixed schedule as closely as possible, while also representing unavoidable deviations and their impact on the battery storage system used to balance them. As shown in Figure 1, this leads to a substantially improved fit between predicted and measured storage state. The model no longer shows visible jumps at day boundaries, and after deviations caused by forecast errors occur, the predicted storage state returns much faster toward the measured trajectory. This result is particularly encouraging given that the measured state of charge provided by the battery energy management system itself has an uncertainty of slightly below 10%, with higher accuracy mainly occurring close to calibration events. For commercial battery systems of this type and size, this level of measurement accuracy is already considered good, which further supports the robustness of the achieved modelling performance.

4. Conclusion

This deliverable demonstrates the successful development and initial validation of digital twin models for selected proof-of-concept energy systems, covering both a biogas plant and a multi-site mobility energy system. The work shows that combining measured operational data, site-specific technical information, operator knowledge, and data-driven modelling approaches enables the creation of digital representations that capture key physical and operational system behaviour.

For the biogas application, a flexible methodology was established to model the relationship between organic feed input, biogas production, storage dynamics, and CHP operation using only a limited set of required operational data. For the mobility application, the digital twin developed in IESopt successfully represented the coordinated operation of PV generation, charging infrastructure, grid connections, and battery energy storage across multiple sites.

The validation results for the mobility twin show that the model can reproduce the main dynamics of the real battery storage system with good accuracy. Remaining deviations are mainly linked to forecast uncertainty, long scheduling lead times, and differences in the initial storage state. By integrating improved forecasts and a more complete representation of operational behaviour, the agreement between predicted and measured storage trajectories was significantly improved.

Overall, the results confirm that digital twin models can provide valuable support for operational analysis, scheduling optimization, and decision-making in complex sector-coupled energy systems. The developed approaches form a strong basis for further refinement, extended validation, and future deployment in real-world operational environments.

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