DigitalEnergyTwin

Report on the potentials and barriers for multiplication D2.4

DIGITAL ENERGY TWIN – OPTIMISED OPERATION AND DESIGN OF INDUSTRIAL ENERGY SYSTEMS

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1 Introduction

In order to optimise an industrial plant or an individual process, the creation of a digital twin is becoming increasingly important. This supports the identification of flexibilities and takes important process dependencies into account. However, the development of such a digital twin takes a lot of time. For this reason, the transferability to other industrial companies or processes is an important factor.

The primary objective of deliverable 2.4 is to evaluate the Digital Energy Twin for transferability to other industries and sectors and to identify the challenges that arise when transferring the Digital Energy Twin to another system. For this purpose, methods and approaches are to be identified that can be used for the comparison of industries, industrial plants and processes. Furthermore, specifications are to be defined that can be used for the comparison of sectors, industrial plants and processes. The transferability of the Digital Energy Twin should be evaluated for:

- other AT&S plants
- other semiconductor manufacturers
- industry with similar energy requirements
- general industry

2 Model description

Before discussing the potentials and barriers for multiplication, this chapter defines the different models of the Digital Energy Twin. This is because in order to be able to carry out an assessment of transferability, different application categories must be assigned to the models. Furthermore, the models used for the analysis are defined and described. A classification is made between process models, models of the energy supply aggregates, optimisation models and forecasting models.

2.1 Process models

With process models, either complete processes or only individual sub-steps of a process or a sequence can be modelled and simulated.

2.1.1 Entire process

The advantage of mapping a complete production process is that the transfer of this specific model within a company is relatively simple. As this production process is always structured in the same way. If we take AT&S AG as an example, we can say that the production of printed circuit boards at the plant in Leoben follows the same process steps as a similar plant at another location of the company. But transferability is also possible within the same industry. Since many companies use processes that do not differ or only slightly from each other. However, it is possible that the model has to be adapted to the standards of the company or to the specific processes.

2.1.2 Individual sub-steps

The modelling of a single step of a production process represents the second possibility of creating a process model. If a production process is divided into its individual sub-steps and models are created from them, this is much easier to handle. The partial models can be used again and again, almost like a kind of modular system. With this method, an overall process is broken down into sub-processes, which are mapped as individual process models. Each of these models is regarded as an independent unit. These can be nested as desired and then reunited to form an overall process. The decomposition into sub-processes simplifies the transferability of the models both within a company and within a sector, as well as in similar and general sectors.

2.2 Energy supply units

The models of energy supply units are elements of energy generation or delivery in a company. These include, for example, photovoltaic systems, heat pumps, chillers and recoolers. These energy supply units can be represented as black box models or physical models.

2.2.1 Black box models

In general, a black box is an object whose structure and functioning inside are not known. The focus is on the behaviour of the black box, which ensures a defined functionality via certain interfaces. This approach is often used to reduce the complexity of the system. This deliberate exclusion of information is exploited in this model to prevent complications in modelling. Only the relationship between input and output parameters is represented.

If you model an aggregate using a black box, you have few input parameters that need to be known to get a required output. This is nothing more than a mathematical model. The behaviour inside the black box is not considered in the modelling, only the reaction of the system is described in a mathematical formula.

In order to better describe this possibility of modelling, this is explained using an example of a heat pump, where this heat pump is to function as a black box. Only the flow and return temperature, volume flow and efficiency are known. Based on these parameters, the performance of the heat pump can be calculated, regardless of how it is constructed, which refrigerant is used or what the log(p)-h diagram looks like.

This method makes it much easier to transfer the data to other companies in the same or similar industry, as well as to other or general industries.

2.2.2 Physical models

Using this method, the energy supply unit is mapped completely and with all contents and details. For example, a heat pump is fed with all its input parameters and can simulate the complete energy conversion process using internal calculations. By simulating the processes of all system components, a physically exact model of the system is developed. This enables a better understanding of the cause and effect of certain actions as well as the complex interactions with the process. This method requires precise knowledge of all internal processes and parameters such as fluid properties and input parameters. The effort to create such models is very high and the parameters are sometimes very complex. The effort to transfer physical models within a company is simple, whereas transferability to general industries is difficult.

2.3 Optimisation models

Within optimisation, a distinction must be made between different procedures depending on the application.

2.3.1 Linear optimisation

Linear optimisation involves optimising an objective function that is constrained by linear equations. In business practice, linear optimisation is often used in production planning when the aim is to find the best possible capacity utilisation. But linear optimisation is also used to determine optimal investment programmes and sales quantities and to optimise waste in production and route plans. It can be solved either graphically or mathematically.

The goal of linear optimisation is to find one or more optimal solutions to problems. If no optimal solution exists and the problem cannot be solved using linear optimisation, the methods discussed in the next two sections can be applied.

2.3.2 Non-linear optimisation

Nonlinear optimisation is a subfield of mathematical optimisation. Non-linear programmes can be found in many ways in science and engineering. In economics, for example, the aim may be to reduce the costs of a process that is constrained by the availability of resources and capacities. The cost function may not be linear. Modern engineering applications often involve optimisation tasks in a complex way. It may be a matter of reducing the weight of a component, with certain minimum requirements that it has to meet. It can also be about adjusting the parameters of a model to measured values. This can also be used to make a process flow more efficient, while certain quality requirements must be met.

2.3.3 Heuristic optimisation

Heuristic methods are used wherever knowledge, time and money limit the development of algorithms. With the help of heuristics, approaches are available for determining solutions of optimisation models that are well acceptable and can be used to mathematically depict decision-making problems. In principle, optimisation methods find an optimal solution for an optimisation model and also prove the degree of optimality. Heuristic methods, on the other hand, are content with finding a solution that is considered to be sufficiently good. This has the advantage that solutions can be found also when conventional optimisation methods fail due to the high computational effort.

Heuristics thus have the strength of arriving at meaningful results or practical solutions with limited knowledge and incomplete information. These solutions can deviate from the optimal solution.

2.4 Forecast models

For the Digital Energie Twin, future load profiles are of particular importance, as they are necessary as input parameters for optimisation. The load profiles can be predicted in several ways.

2.4.1 Curve fitting

Curve Fitting is a method of equalisation calculation that is used to determine, or estimate, the unknown parameters of the model for a series of measured data. Curve fitting also provides the function to predict future values in a time series. Using a given function, a predictive model is constructed by fitting the selected function to the time series values at each position. This function is then used to predict the values of future time intervals. In many production facilities, workflows are regular and periodic. A pattern can often be seen in the load profile. Based on this pattern, it is possible to describe the progression using functions and to infer the future and forecast energy consumption.

2.4.2 Time-series forecasting

Time-series forecasting is another method of predicting the load curve. Many manufacturing companies have recurring and repetitive processes that usually run in the same way. These routines are often reflected in the load profile. With the help of time-series forecasting, conclusions can be drawn about the future load profile based on the historical load profile.

2.4.3 Neuronal networks

Artificial neural networks always consist of neurons that have different inputs, a function and an output. The input of one neuron is connected to the output of the other and through weighted coupling the results or outputs are prioritised differently. This concept can also be used to forecast load profiles.

2.4.4 Weather simulations

For the Digital Energy Twin weather forecasts are needed as input parameter for different models. As an example it is needed to calculate the provided electricity from the photovoltaic plant, to predict the future heating or cooling demand and also the efficiency of the heat pumps depends on the weather. Weather simulations and forecast are well developed and are online available. So it is not necessary to develop a knew model. But it has to be taken into account that the correct position is selected and the data is adjusted to it.

3 Potentials and barriers for multiplication

This chapter first describes the advantages and disadvantages of the Digital Energy Twin in the course of a detailed SWOT analysis. Subsequently, the models defined in the previous section are evaluated for their multiplication to other sectors or industrial systems.

3.1 SWOT analysis

In order to develop a strategy to test and evaluate the multiplication of a DET, a SWOT analysis was developed. This analysis addresses the advantages and disadvantages (strengths/weaknesses) that a DET entails. External opportunities and risks are also defined and analysed. External influences, such as the market or the environment, are taken into account.

3.1.1 Strength

With the help of the DET, it is able to use a uniform platform for applications for industrial energy systems. Instead of several different software programmes that are not compatible with each other, it is possible to create standardised interfaces due to the FMI exchange format. This allows the transfer of a model into different software tools. This uniform interface adaptation makes it possible to accelerate the development and dissemination of the DET. In addition, the DET offers a holistic energy management system. It is possible to carry out operational and design optimisations and to create predictive models. The DET can be connected to the system in near-real time so that, for example, simulation models are synchronised with the current state of the system in real time. Augumented and virtual reality (AR/VR) can be used to visualise these simulation models. Behind the DET project is a large team with a lot of knowledge and experience. A concept for data management and data protection and security was developed by the project team. This security concept includes security methods to protect the DET from cyberattacks.

3.1.2 Weaknesses

A system of such size and complexity as the Digital Energy Twin requires an infrastructure to obtain and process data. Establishing and operating a solid and reliable data infrastructure is one of the biggest challenges in implementing the DET. Furthermore, the data needed for processing must already be available in some form. In addition, there are issues related to system requirements, such as adequate software and databases, because these serve as the basis for a successful implementation and need to be clarified in advance. Furthermore, complex models can require increased computing effort. The DET project is backed by a large team with many partners. This project team consists of competent members who have acquired a lot of knowledge about the concept of the DET in the course of the development. This concentrated knowledge may not be available in every company where a DET is introduced.

3.1.3 Opportunities

The DET can make a significant contribution to the introduction, evaluation and maintenance of the energy management system in the company. In addition to reducing environmental impacts and increasing sustainability, an energy management system offers numerous advantages. A systematic energy consumption analysis and automated optimisation measures of energy consumption are possible. The planning, monitoring and continuous further development of the improvement measures are also part of its remit.

In addition, optimised procedures and processes lead to emission savings, lower costs and higher efficiency. Thus, high transparency increases customer satisfaction. In addition, the reduced environmental impact significantly improves the company's image and reputation. Furthermore, DET makes it possible to visualise and depict process sequences and relevant data, thus supporting efficient production and energy system monitoring. With the help of the DET methodology, it will also be possible to use Augmented and Virtual Reality (AR/VR), paving the way for improved and forward-looking staff training.

3.1.4 Risks

A critical point is data protection and data security. The data recording by various sensors must therefore be processed carefully. One risk would be the theft of secret or process-specific data as well as unauthorised access from outside the company. Furthermore, Digital Energy Twin systems are potential targets for cyberattacks and must therefore be actively secured.

Another risk is that the company does not have the appropriate interfaces and may have to create them subsequently. This is subsequently associated with costs that have not been taken into account and unforeseeable time expenditure.

The creation of suitable models is often time-consuming and requires corresponding competences. In the case of transfer, it can happen that models have to be subsequently adapted or, in the worst case, newly created. This requires additional time and costs for the adaptation or new creation. In addition, the required know-how must be provided, which may not be available in the company.

The DET can transfer the results directly to the control and regulation of machines. The autonomous control and regulation offers many advantages, but also carries the risk of errors. These errors are difficult to avoid with autonomous control and regulation and can strongly influence the production process.

3.1.5 SO Strategies

Due to a holistic energy management system and optimisation algorithms, the company can benefit from a reduction in the cost and risk of investment decisions, which would result in a significant increase in the implementation of energy-efficient process and supply technologies in industrial production. By simulating certain situations, it is possible to estimate the impact of rising energy costs on supply security. Using artificial intelligence, augmented and virtual reality applications, the DET can reduce the process-related energy demand, integrate renewable energies into the production process in the best possible way and reduce the ecological footprint. With the help of visualisations as well as AR/VR, an innovative form of staff training is possible. Through visual representation and direct interaction with the respective system, training is possibly more lucrative and better accepted by the staff. In addition, it is possible to use the DET for predictive maintenance.

3.1.6 ST-Strategies

Using the universal data exchange format FMI, the problem of using different tools and platforms with incompatible interfaces can be solved. The FMI standard can be used to ensure universal model exchange. The exchange of partial models of the DET without interface adaptations additionally enables accelerated development. Even though models allow increasingly complex and comprehensive programming, it is important to keep the models as general as possible. This is because with increasing complexity it becomes more difficult to transfer models to other systems. In order to close the knowledge gap that arises in another company when implementing the DET, the DET project team can be involved in the implementation and support with their knowledge. The consortium could significantly facilitate the transfer and help to avoid mistakes. Thus, a kind of service could be offered.

3.1.7 WO-Strategies

The implementation of the DET in the existing IT infrastructure is associated with a significant amount of work. The documentation of the DET gives support in the implementation phase. In addition, it is possible that the consortium will offer assistance in implementing the DET in industrial companies (even after completion of the project). One aim of the DET is to keep the complexity of the model structure as simple as possible in order to keep the effort for adaptations as low as possible. Another important point is to stick to standards in model development and interface definition. The simplification and development of technical standard solutions (like FMI) and models for energy-relevant process and supply technologies will facilitate the multiplication to other industries.

3.1.8 WT-Strategies

To ensure data protection and data security and to prevent cyberattacks, a data security concept was developed in the DET project. In addition, standardised procedures for data security and data management between software and hardware components protect against wilful intervention in the system from the outside.

Modelling and its investigation in dynamic simulations requires extensive know-how about simulation technology. Furthermore, there is a high number of possible system variants, which can only be modelled, simulated and evaluated with a high expenditure of time. Within the framework of an engineering service from the consortium, the required know-how can be offered to assist in the implementation of the DET or adaptation of models. In addition, IT should always be involved in the planning and execution of the integration of a DET into the corporate environment. Since not all data is available to every company, it is important to clarify in advance which data is needed to implement the specific model. Missing data can either be generated by additional measuring points or sensors, or adjusted by adapting the model.

Autonomous control by the DET is associated with the risk that the production process can be disrupted in the event of incorrect calculations. For this reason, the DET is not designed to control and regulate the processes automatically, but to provide the personnel with recommendations for action.

Table 1: SWOT-analysis

	Strength Availability of standards Uniform platform Holistic energy management system	**Weaknesses** System requirements (software, database, IT infrastructure) Computing power Data availability Expert knowledge necessary
Opportunities Better energy management system Visualisation by VR, AR Monitoring Improved staff training	Cost and emission savings Efficiency increase	Offer know-how and services from the consortium Provision of information
Risks Data safety and security Missing interfaces Adapting or renewing the models Autonomous control	Keep models as general as possible Uniform modelling by using FMI Involve IT from the beginning	Data security concept Provide service to adapt models Data screening before project start

3.2 Multiplication of the models

For the multiplication, the models described in chapter 2 are analysed for the following characteristics:

- **Effort for the development**
  The development of suitable models is very often time-consuming and requires appropriate skills. The effort for modelling and simulation is one of the biggest challenges for implementation. Therefore, it is important to evaluate the effort required to create the individual models.

- **Complexity of the input parameters**
  Whether a model can be transferred to another system with little effort depends strongly on the properties of its input parameters. The simpler the input parameters, the easier it is to disseminate the model. On the other hand, a transfer of complex input parameters requires more effort, as the model may have to be adapted. Furthermore, complex models may require more computational effort. If the complexity increases, corresponding expert knowledge is also required to be able to handle the system. For this reason, a fundamental goal is to keep the models as simple as possible.

- **Multiplication**
  The effort of a transfer of a reference system into a target system depends on the conditions of the target system. For this reason, four target systems were defined:
  1. The extent to which a dissemination of models is possible internally, i.e. within AT&S AG, is evaluated.
  2. Furthermore, it is determined how well models can be transferred to similar sectors, i.e. other companies in the semiconductor industry.
  3. In addition, the transferability to similar energy industries is evaluated. Similar energy sectors in this case are companies with similar load profiles or similar energy sources.
  4. And as last point the multiplication to general energy industries.

3.2.1 Process models

The modelling of a complete production process can be quite complex. As the length of the process increases, the complexity of the entire model and the number of input parameters can also increase. If you want to transfer an entire production process, it is easiest to do so in the own company. In other companies of the same sector, sub-processes may already run differently and there is no way around a costly and time-consuming adaptation of the model. Transferring a complete production process to companies that use completely different procedures and processes would involve a great deal of effort, as the model would have to be completely revised or re-modelled. However, the general concept for creating the models could be applied.

Breaking down an entire production process into sub-processes makes modelling easier. There is an independent model for each sub-process, which can be used as often as desired. The model has lost complexity and the number of input parameters is lowered. A transfer of a single model is easily possible within the company and the models can also be used for other PCB manufacturers. However, other companies from the same energy sector or general sector still use different processes, which is why the multiplication of these models tends to be lower than in the same sector.

Table 2: Overview of the mutliplication

○ ... very low
◔ ... low
◑ ... medium
◕ ... high
● ... very high

		Effort for development	Complexity of the input parameters	Multiplication			
				In-house	Same sector	Similar energy sector	General energy sector
Process models	Entire process	●	◕	◑	◑	○	○
	Individual substeps	◑	◔	●	◕	◔	◔
Energy supply units	Black box models	◑	◔	●	◕	◕	◑
	Physical models	●	●	◕	◑	◑	◔
Optimisation models	Linear optimisation	◑	◑	◑	◑	◔	◔
	Non-linear optimisation	◑	◑	◑	◑	◔	◔
	Heuristic optimisation	◔	◔	◕	◕	◑	◑
Forecast models	Curve fitting	◑	◔	●	◕	◕	◕
	Time-series forecasting	◑	◔	●	◕	◕	◕
	Neuronal networks	◕	◔	◕	◑	◑	◑
	Weather simulations	○	◔	◕	◕	◕	◕

3.2.2 Energy supply units

Models of energy supply units, such as a heat pump, chiller, photovoltaic system, wind turbine or air compressor can be modelled as a black box. Since this model has a simple structure and consists of only a few simple input parameters, the effort required to create it is less than for creating process models. This model can be transferred within the own company without any restrictions. Other companies in the same sector or with the same load profile mostly have the same energy sources and the same temperature levels, which means that only minor changes to the model are necessary. In general industries, the type of energy sources and temperature levels differ greatly. This also requires more adjustments to the model, which can make dissemination more difficult.

Energy supply aggregates, which are modelled physically correctly, are the second variant. This variant contains more input parameters and its calculations and dependencies are very complex. This makes modelling extremely demanding. In the own company, there are usually similar equipment, which makes it possible to transfer a model within the own company with a few adjustments. In the same sectors and in companies with the same load profile, it can be assumed that similar types of equipment are used and that energy of a similar amount is required. The energy sources used also barely differ and the temperature levels are very similar. A transfer is possible in this case, but major adjustments are to be expected. If absolutely different orders of scale are required, restrictions are clearly to be expected and transferability is not possible without major editing of the entire model. This is especially relevant for the general sector.

Due to the limited number of input parameters, black box models only allow a limited scope for adjustments and may not be able to be adjusted to the new circumstances. Physically correct models, however, can always be adjusted because their behaviour is precisely described. This is not the case with black box models.

3.2.3 Optimisation models

It is assumed that the models for processes and energy supply units are already available and the effort has already been discussed in the section above. For this reason, only the optimisation concept is examined in the optimisation models.

The effort required to create an optimisation model for a specific application is average. Depending on the application, the model can become quite complex. However, once an optimisation model has been created, it can be duplicated and transferred as often as desired for the specific application. Since in the own company and other PCB manufacturers handle similar processes, transferring an optimisation model that was created for a specific process or power supply model is very easy.

With linear optimisation, the models have to be linearized accordingly, which results in additional effort. However, the optimisation concept is very simple. For non-linear models, no prior linearization is necessary, but setting up the optimisation concept is more complex. As a result, the effort required to disseminate linear and non-linear models is about the same.

Heuristic optimisation models are used when required knowledge is limited. They achieve meaningful results with incomplete information, but do not find a global optimum. Heuristic optimisation models can be used for optimisation without much effort. However, heuristic models require more computing power. The greatest effort lies in the parameterisation. Nevertheless, a transfer is easier than with linear and non-linear optimisation models.

3.2.4 Forecast models

Although curve fitting models involve complex mathematical calculations, these methods are already widely used. Tools such as those in Python or Excel simplify their application. There are also tools for time series forecasting. Therefore, these methods are easy to transfer to other companies or sectors and even easier to apply in your own company. Assuming that the data and correlations are available in the appropriate quality and can be trained well.

Artificial neural networks use variables such as production parameters, weather data, days of the week, load values of the previous day or hour. These parameters are model-dependent and usually already available. The great advantage of artificial neural networks is that they can handle a large number of input parameters well. The effort to create such a model is estimated to be relatively high without corresponding knowledge or templates. If this model is to be transferred within the company and to other companies, the input parameters such as weather data must be adapted to the respective situation. It is less important whether the model is to be transferred within the company, within the same industry, to similar energy industries, or to other industries.

Several models are already available on the internet for weather simulation. The data can be downloaded free of charge or for a fee. This means that the creation of such models requires very little effort. Only the right location has to be selected and the data can be retrieved. For the multiplication, only the location needs to be adjusted and therefore little effort is required for all target systems.