Industry4Redispatch (I4RD)

Deliverable 10.1

Key results and lessons learned

AUTHORS

Regina Hemm	regina.hemm@ait.ac.at	
Sophie Knöttner	sophie.knoettner@ait.ac.at	
Sawsan Henein	sawsan.henein@ait.ac.at	**AIT Austrian Institute of Technology GmbH**
Tara Esterl	tara.esterl@ait.ac.at	
Helfried Brunner	helfried.brunner@ait.ac.at	

Daniel-Leon Schultis[(1)], Matthias Traninger[(1)], Felix Hembach[(2)], Veronica-Sequeira Taxer[(2)], Michael Niederkofler[(3)], Gregor Taljan[(4)], Alexander Knöttner[(5)], Andreas Leitner[(6)], Magdalena Teufner-Kabas[(7)], Ralph Fuhlhage[(8)], Herbert Hummer[(9)], Erwin Zlabinger[(9)], Johannes Puschitz[(10)], Maximilian Urban[(11)], Andreas Abart[(12)], Leopold Fiedler[(12)], Sebastian Loziczky[(13)], Alexander Schirrer[(14)], Markus Fallmann[(14)], Lukas Stanger[(14)], Martin Fischer[(15)], Lena Lessig[(15)], Karl-Wilhelm Schenzel[(15)], René Hofmann[(15)], Michael Pusch[(16)], Parisa Mousavi[(16)], Reinhard Teufner[(17)]

[(1)]AIT Austrian Institute of Technology GmbH [(2)]APG Austrian Power Grid, [(3)]Energie Kompass GmbH, [(4)]Energienetze Steiermark GmbH, [(5)]EVN AG, [(6)]evon GmbH, [(7)]Kleinkraft OG, [(8)]Ankerbrot GmbH, [(9)]Mondi Neusiedler GmbH, [(10)]Netz Burgenland GmbH, [(11)]Netz Niederösterreich GmbH, [(12)]Netz Oberösterreich GmbH, [(13)]Siemens Aktiengesellschaft Österreich, [(14)]TU Wien Institut für Mechanik und Mechatronik, [(15)]TU Wien Institut für Energietechnik und Thermodynamik, [(16)]voestalpine Stahl GmbH, [(17)]Wiesbauer Holding AG

PROJECT MANAGEMENT : AIT – Tara Esterl, +43 664 8157 810, Tara.esterl@ait.ac.at

Document control information	
Title	D10.1
Dissemination Level	☐ **CO** Confidential, only for members of the consortium ☐ **RE** Restricted to a group specified by the consortium ☐ **PP** Restricted to other programme participants (NEFI) ☒ **PU** Public
Status	☐ Draft ☐ WP Manager accepted ☒ Co-ordinator accepted

TABLE OF CONTENTS

LIST OF FIGURES

GLOSSARY

CAPEX

Capital expenditures

CBA

Cost-benefit analysis

DA

Day-Ahead

DSO

Distribution System Operator

EPEX

European Power Exchange

FSP

Flexibility Service Provider

OPEX

Operational expenditures

RD

Redispatch

SME

Small and Medium Enterprise

TSO

Transmission System Operator

UC

Use Case

WP

Work Package

Executive summary

Austria has made significant strides in developing a **comprehensive redispatch framework** that enables the integration of decentralized assets, provides standardized processes, efficient data exchange, and a **TSO-DSO interaction**. Additionally, progress in **industrial control concepts** has further supported Austria's role in advancing redispatch innovation in Europe. A key achievement of the project was the successful **implementation and real-world demonstration** of a redispatch platform at the TSO and actual industrial redispatch activation. The whole project strengthened cooperation between **TSOs, DSOs, FSPs and industrial stakeholders**, fostering a shared understanding of redispatch integration of decentralized assets.

A redispatch platform was successfully implemented and tested to facilitate interaction between participants and the transmission system operator as well as distribution system operators. The demonstration proved successful; some further advancements are recommended though. These include an advanced proof of activation, a specification of the interaction and schedule exchange with balancing group responsible parties, to raise awareness among SMEs concerning flexibility and to optimize the TSO-DSO bid filter to account for nonlinearities and reactive power variations. A central regulatory challenge remains: the current cost-based incentive scheme provides limited motivation for industrial participation. Recommendations to enable a non-cost-based remuneration component were given to the regulator and could be included in the new Electricity Market Law, which is expected this year (2025). Some further regulatory adjustments are required to integrate redispatch from decentralized sources.

Industrial involvement was pivotal to the project's success, with automation algorithms implemented and tested on-site. While the primary goal was not to increase efficiency, automation led to improved efficiency in practice, demonstrating an additional benefit for the industrial plants and thus added value of such solutions beyond their original scope. In addition to technical challenges that are expected in adapting the model for broader rollout across various industrial processes and assets, non-technical issues arose, particularly concerning liability when working with research partners and external service providers, as well as the need for strong workforce engagement and clear direction from management. Surveys with industrial companies highlighted their concerns and readiness to participate in redispatch or provide other flexibility services. A study on Austria's industrial flexibility potential revealed +410 MW of positive and -190 MW of negative capacity, emphasizing the significant opportunities for flexibility utilization.

Overall, the project demonstrated that integrating distributed energy resources into the redispatch process is not only feasible but also holds significant potential when viewed as part of a broader strategy for using the flexibility across multiple purposes. However, broader implementation depends on regulatory adjustments, technological advancements, and increased industry engagement. Future efforts will focus on refining redispatch services, optimizing the TSO-DSO interaction, and improving the control and flexibility of industrial energy systems. With several follow-up projects already planned, Austria is well-positioned to build on these achievements and further strengthen its redispatch framework.

1. Introduction

The flagship project **Industry4Redispatch (I4RD)** is designed as a key project within the model region NEFI – New Energy for Industry. I4RD is the first NEFI project that develops innovative solutions enabling (i) the provision of flexibility from the demand and supply-side at distribution network level for redispatch and (ii) the demonstration of an online, predictive and site-holistic control concept for industrial energy supply systems, which optimizes a company's market participation while ensuring its energy supply. This approach enables participation of industry in redispatch and stipulated technological development within the NEFI community, especially by contributing to the central NEFI-innovation fields through *digitalization and flexibilization of the industry.*

In the years from 2013-2017, a growing need for redispatch in Austria and Germany, has been observed. This high need for redispatch remains ever since and is largely caused by the integration of renewable generation and continuing integration of the European electricity markets, which exacerbate existing grid congestions caused by a lag of critical transmission projects. This need is likely to increase more in the future. The costs for redispatch in Austria have been varying strongly within the last years between 86.5M€ and 147.8M€. Therefore, additional redispatch providers shall be incentivised to participate. For this, suitable **redispatch products** must be defined.

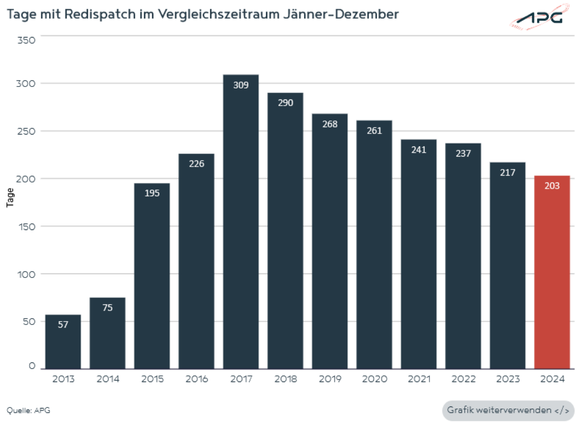

Figure 1 Days with Redispatch per Year (January-December)

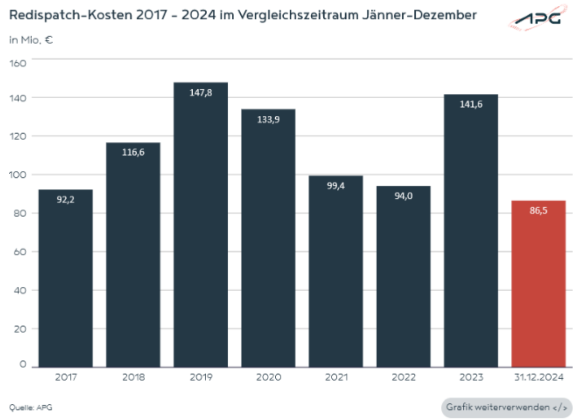

Figure 2 Redispatch Costs per year (January-December)

Redispatch, that is the shift of generation and demand of electrical energy to decrease the loading of a network element, is a necessary measure for congestion management to maintain n-1 secure operation. Currently, in most cases, flexibility from generation units is utilized for redispatch. If new types of units at the distribution level are introduced, adding new types of flexibility for redispatch on the distribution grid level necessitates increased coordination between TSO (Transmission System Operator) and DSO (Distribution System Operator) to ensure that these industrial redispatch measures do not cause critical operation conditions in the distribution grid. The increase in renewable generation and an increase of concurrency factors caused by smart devices is not limited to the transmission level and could also cause congestions on the distribution level. Consequently, it can be expected that in the future, congestions are going to be managed by redispatch even on distribution levels. However, the existing regulatory framework as well as given incentives are currently not attracting industrial customers to participate in redispatch. In addition, the available capability to shift power is small compared to current redispatch needs.

At the same time, the producing industry faces challenges such as achieving energy efficiency targets and adapting to the changing energy market. The current situation shows that a highly dynamic industrial plant operation is often not possible due to a lack of comprehensive process automation. Moreover, to enable flexible adaption of the industrial plants, the automation must be combined with algorithms combining industrial process optimization with automated participation algorithms in the congestion management (**industrial flexibility**). In addition, investments in plant flexibility are currently often unprofitable because of low incentives.

The primary goal of I4RD is enabling flexibility provision from both, demand and supply-side at distribution network level for redispatch. The project assessed all necessary technical, regulatory, economic and organisational requirements for this implementation, as well as the necessary coordination between TSO and DSOs. I4RD is the first project in Austria bringing all relevant stakeholders together to provide an integrated solution through automation and optimization of the industry, setting up a coordination process between the TSO and the DSOs, developing a novel redispatch module based on standardized requirements and demonstrating the value of the new approach by a proof-of-concept.

This report provides the key enabling factors **regarding the redispatch product and process, the TSO-DSO interaction and bid filter mechanism, as well as the industrial developments and perspectives involved**. The following provides significant findings and their impact and offers an in-depth analysis of the associated barriers and opportunities.

This report provides details on the following learnings:

- Key Result I: Standardization, specification and demonstration of redispatch product and process
- Key Result II: Industry-workable incentivising remuneration methods for Austria
- Key-Result III: Comparative analysis of the Austrian and European regulatory framework
- Key-Result IV: Industrial flexibility sources in Austria

Key Result V: Successful industrial demonstration of Energy Demand Control System

- Key-Result VI: Initial specification of the TSO/DSO interaction process
- Key-Result VII: Final TSO-DSO process specification definition and validation

We conclude with an overview about the impact and outlook across regulatory, scientific, and implementation aspects.

2. Key Result I: Standardization, specification and demonstration of redispatch product and process

Currently, redispatch is carried out based on the technical characteristics of individual power plants. Parameters such as lead times or minimum production levels of power plants are known to the grid operator and considered when planning redispatch measures. The integration of smaller units leads to an increase in the number of participants required to achieve the same impact on the transmission grid as conventional power plants. This adds complexity, as all units and their technical capabilities must be considered in the process. To address this issue, we developed a standardized bidding process that eases this coordination problem, which grid operators and flexibility service providers (FSP) could follow (see Figure 3 and Deliverable 3.1 [1] for further description).

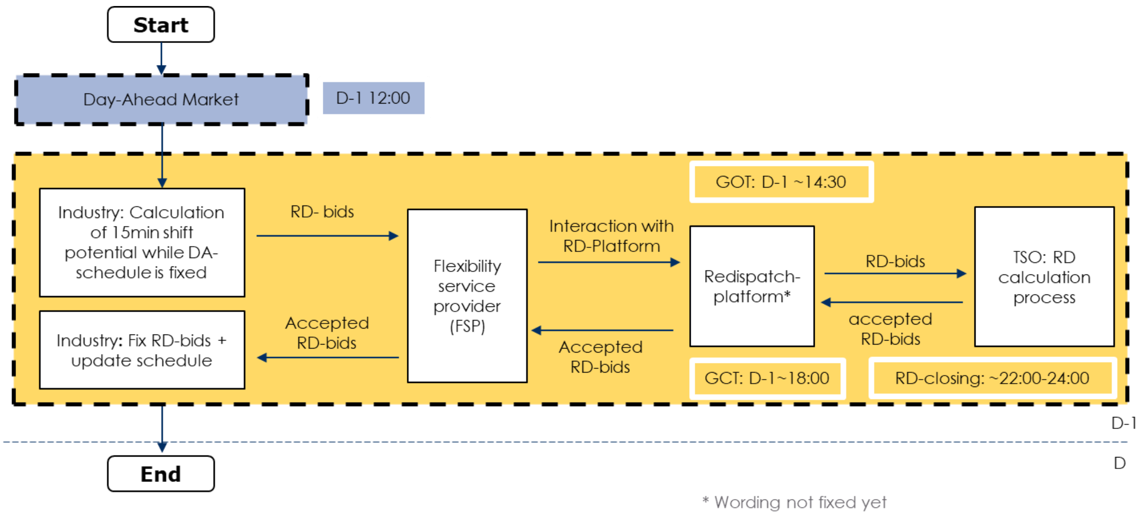

Figure 3 Exemplary redispatch bidding and activation process, see Deliverable D3.1 for further information

The **redispatch product** contains the technical and organisational criteria relevant for the redispatch bid (see Figure 4) and general timings related to the process were defined.

Parameter	Value	Background
Min. bid size	1 MW	Certain size is needed to effectively solve grid congestions, also limited by computational requirements of redispatch requesters.
Min. bid increment	0,5 MW	Redispatch is activated symmetrically, therefore bids should uniform to be easily balanced.
Max. bid size	400 MW	To prevent bids that exceed the needed redispatch amounts excessively.
Min. size of single assets in a pool	0,5 MW	For this asset size observability in grid levels 5 or 6 is usually ensured.
Max. size of single assets in a pool	50 MW	Such assets are usually capable of participating in redispatch on their own, thus undesirable inefficiencies are avoided.
Aggregation level	110 kV distribution grids	Trade-off between granularity of locational information and the ease of aggregation (to be further evaluated in the course of the project).

Figure 4 Excerpt from redispatch bid and participation requirements

In order to participate, flexibility providers must meet specified quality criteria. The key characteristics of redispatch delivery —observability, reliability, and shape of energy delivery—have been identified as critical factors for ensuring effective participation. Further organisational criteria encompass mainly the conditions of participation. To be able to participate on the redispatch platform the FSP and the corresponding assets must undergo prequalification. Both the interfaces and formats suggested in the project, as well as the process itself, shall enable a highly standardized and IT-supported bidding process that meets the needs of all involved stakeholders. Further it was considered reasonable to align with existing formats and interfaces from the balancing reserve processes in order to minimise implementation efforts for FSPs that want to offer both products.

2.1. Highlight: Operational demonstration of the redispatch platform at the TSO

A Redispatch platform to streamline the redispatch process for distributed flexibilities was developed and implemented at the transmission grid operator APG. It facilitates data exchange between flexibility service providers (FSPs) and grid operators, covering key processes such as registration, bid submission, and bid award information. The platform provides standardized interfaces for FSPs, simplifying their market access. By providing a code library for these interfaces in the future, the FSPs initial effort to contribute could be further minimized. Additionally, the backend provides an aggregated view of available redispatch potentials considering limitations by the DSO. Although direct connection of distribution system operators (DSOs) to the platform was not within the project's scope, it remains a viable future possibility.

2.2. Highlight: Successful demonstration of complete redispatch process

The whole redispatch process was tested during a demonstration with industry. It involved key industrial partners (Energie.Kompass, Wiesbauer Wien, Voest, and Mondi), FSPs (Siemens and EVN), DSOs (Netz Oberösterreich, Netz Niederösterreich, and Energienetze Steiermark), as well as the transmission system operator Austrian Power Grid (APG). Furthermore, parties not part of the project consortium were involved or at least informed including BRPs and a DSO.

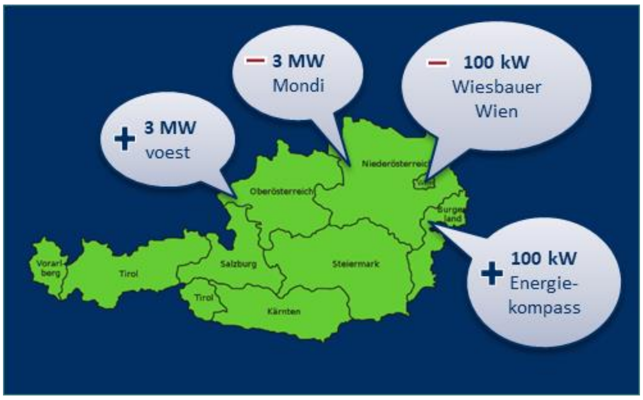

Figure 5 In demo participating industry sites

Each flexibility resource was directly linked to an FSP. The FSP collected flexibility potentials from the resources and submitted redispatch bids to the platform. In the backend of the platform the capacity management module processed the bids and the capacity information provided by DSOs to obtain possible bid combinations. When a bid was accepted, the activation signal was relayed via the platform to the FSP and finally to the respective asset. The specific communication technology and connection method between FSPs and flexibility resources were not defined within the project, leaving these decisions to the discretion of the FSPs and their associated resources.

Over two days, the following steps were executed:

1. Baseline Submission: By 14:30 each day, industrial facilities provided an initial day-ahead schedule to APG, serving as the baseline for delivery validation.
2. Bid Submission: FSPs submitted bids for three different hours of the following day via the redispatch platform.
3. Capacity Check: The bids were validated using the Capacity Management Module (CMM), based on capacity data provided by DSOs.
4. Award Process: Starting at 18:00, the APG control room operator awarded bids. FSPs received confirmation via the platform and executed the redispatch actions independently.
5. Schedule Adjustment: FSPs updated their schedules to reflect the awarded redispatch, ensuring the required adjustments to industrial production or consumption on the following day.

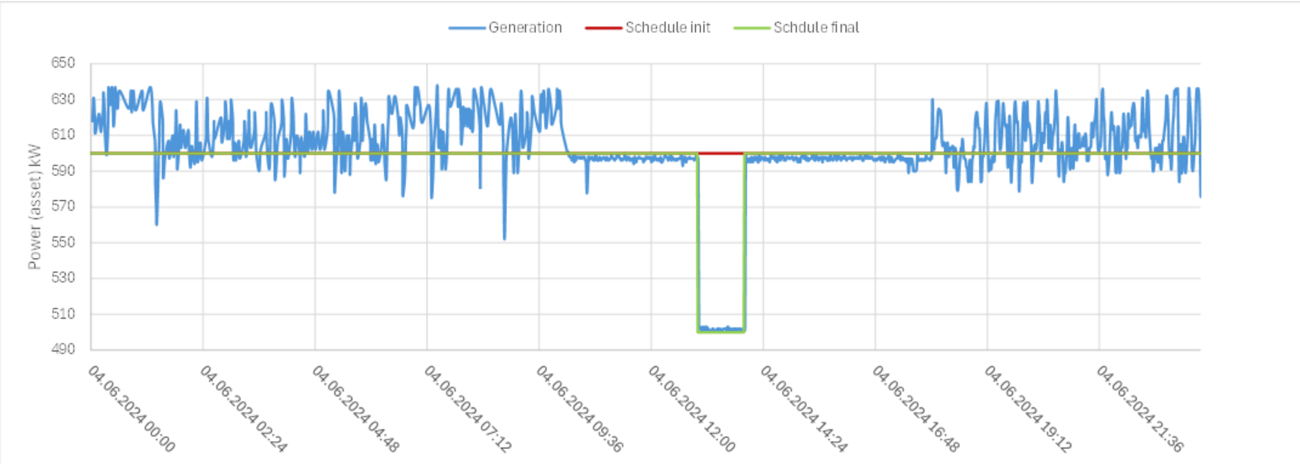

Figure 6 Initial schedule (red) and changed schedule (green) as well as actually consumed power (blue) at Wiesbauer Wien during demo day on asset level

Since the number of bids placed during the demonstration with industry partners was limited, a separate demonstration was organised to properly test the capacity management module with three DSOs individually. During each test session fictitious scenarios defined by the respective DSOs were tested with corresponding dummy bid sets. DSOs provided their grid capacities and sensitivities via an sFTP server. Based on that input the capacity management identified bid combinations that respect the constraints of the DSO. In all scenarios the DSO limitations were considered correctly, and no harmful combination of bids was available.

The demonstration confirmed the viability of the process and the feasibility of participation by smaller-scale units in congestion management. The capacity management proved to facilitate a procedure that ensures that no activation of redispatch bids could lead to new congestions in the DSO grid. Additionally, the practical implementation revealed necessary developments for taking the next steps toward integrating distributed units into congestion management.

2.3. Barriers

- The **process of schedule submission** and interaction with balancing responsible parties (BRPs) requires more detailed design to better accommodate the needs of suppliers, flexibility service providers and BRPs.
- If the **proof of delivery** is evaluated based on the schedule, a certain level of schedule quality is required, which cannot always be delivered by distributed resources. Even if the delivery of the resource is perfect, it is not always visible at the connection point and therefore does only have a limited effect on the grid. Therefore, the proof-of-delivery requirements **have to be further improved**.
- A significant challenge lies in **uncertainties regarding the load and generation profiles** of industrial processes. Smaller industrial enterprises, which currently have no balancing responsibility, often lack precise knowledge of their electricity consumption schedules, particularly for the following day. This represents a major shift for such enterprises. Industrial companies further place the highest priority on maintaining uninterrupted production processes. This necessitates a long-term balance between the transmission system operator’s critical need for schedule reliability and the non-disruption of production processes. The EDCS, an advanced energy management system, developed in the I4RD project, offers promising solutions in this area.
- **Aggregated participants in low-voltage virtual power plants** (LV-VPPs) face several hurdles, including the following:
    - Technical requirements currently necessitate a minimum nominal power per asset of 500 kW and above. Furthermore, redispatch offers must have a minimum bid size of 1MW. A LV VPP might not be able to participate in the redispatch market under these conditions.
    - Applying quality criteria at the level of individual assets or metering points would significantly increase the technical and organizational complexity of an LV-VPP. An LV-VPP would likely need to adopt a stochastic bidding approach—offering, for example, only 75 % of the theoretical flexibility across 100 assets while retaining a 25 % safety margin to cover any deviations during fulfilment. Consequently, both the baselining process and the proof of delivery would have to be adapted to accommodate this margin. Without such tailored solutions for redispatch provision and the aggregation of smaller assets, redispatch would cease to be a feasible business model for LV-VPPs.

2.4. Opportunities and Impact

A new product, which enables the participation of decentralized assets in redispatch, was designed, successfully validated within a demonstration. The final implementation is depending on the ElWG and would be executed not only by the TSO but in cooperation with DSOs. The whole process benefitted from strong stakeholder involvement and close collaboration with the Working Group “Systemführung 2.0” from Österreichs Energie. The project developments have unlocked new opportunities by enhancing the bidding, filtering, and activation process, paving the way for broader implementation and utilization. The standardization and automation of the process not only strengthens future grid stability but also sets the stage for further innovation. Valuable recommendations were submitted to the Austrian regulatory authority E-Control during the consultation phase of the new Elwg [2] (Elektrizitätswirtschaftsgesetz), which is currently pending.

2.5. Further information

Deliverable 3.1 Current and New Business Models of Industrial Customers as Grid Service Providers and Their Associated Incentives - Overview of Austrian Electricity Markets and description of project use cases:

Hemm, R., Esterl, T., Brunner, H., Henein, S., Monsberger, C., Wimmeder, S., Seitzhanova, G., Herndler, B., Knöttner, S., Glatt, A., Hembach, F., Sequeira-Taxer, V., & NEFI New Energy for Industry. (2025). Industry4Redispatch Deliverable 3.1 – Current and New Business Models of Industrial Customers as Grid Service Providers and Their Associated Incentives. NEFI. https://doi.org/10.5281/zenodo.14628519

Deliverable 3.3 Definition of Processes for the Provision of Redispatch [3] **- Description of for the project developed technical, organizational and data exchange related bid and product requirements:**

Hembach, F., Glatt, A., Sequeira-Taxer, V., Fuchs, E., Fanta, S., Hemm, R., Zobernig, V., & NEFI New Energy for Industry. (2025). Industry4Redispatch Deliverable 3.3 – Definition of Processes for the Provision of Redispatch. NEFI. https://doi.org/10.5281/zenodo.14628647

Deliverable 3.4 Estimated Industrial Redispatch Potential [4] **- Results and method for quantification of the technical Austrian flexibility potential based on preliminary studies, a comprehensive literature review and expert assessments:**

Traninger, M., Knöttner, S., Schützenhofer, C., Teufner-Kabas, M., Teufner, F., Hembach, F., Sequeira-Taxer, V., & NEFI New Energy for Industry. (2023). Industry4Redispatch Deliverable 3.4 – Estimated Industrial Redispatch Potential. NEFI. https://doi.org/10.5281/zenodo.14627931

Deliverable 9.1 – Link folgt

Explanatory short video of the project: https://www.youtube.com/watch?v=a6xKsizlhE0

3. Key Result II: Industry-workable incentivising remuneration methods for Austria

The investigation reveals a clear trend in Europe towards a **market-based remuneration** of Redispatch, as a possible result of Article 13 of the Regulation (EU) 2019/943 (Electricity Regulation). However, when comparing countries that use **cost-based procurement** with those that have implemented markets, it can be observed that in countries without markets, the RD demand that needs to be covered is much higher. There is a variety of other country specific characteristics that impact the establishment of market-based redispatch procurement and remuneration methods, like the ability to apply network topology reconfiguration measures in order to solve most of the congestions, the country origin of the redispatch demand, or liquidity of the overall electricity market. This demonstrates that several factors play a significant role in the feasibility of a remuneration model in each country. These factors have been analysed in detail for Austria (see 3.1. Highlight below). Several other remuneration methods, combination of methods as well as measures are applied in different European countries:

- In some countries, **hybrid procurement mechanisms** are applied. This means that these countries intend to procure market-based remunerated capacities for redispatch where possible, however, additional cost-based call schemes are implemented, indicating that there is the fear that purely market-based remuneration could increase socio-economic costs. A hybrid approach can be applied as a gaming mitigation measure, where market-based remuneration gets only considered where it efficiently reduces the overall costs.
- Besides market-based procurement, some countries additionally procure redispatch according to **negotiated bilateral contracts** (in addition to their market-based procurement) an approach taken to effectively limit the impact of parties with market power. In general, not only cost-based procurement must obligate participants to offer their capacities, also within market-based mechanisms it seems crucial to some countries to **oblige producers** to offer flexibilities for redispatch to ensure sufficient participation to a certain extent.
- Another measure that is considered as beneficial for cost as well as market-based approaches is the **participation of DSOs in procuring redispatch**. "The European Commission estimated that the EU could save up to 5 billion Euro per year in avoided investments by 2030, if DSOs were able to solve local congestions through flexibility markets" [5] . However, in a few countries the DSOs are only partially integrated, but the trend seems to be to further improve their participation.

3.1. Highlight: Liquidity and functional analysis of suitable remuneration mechanisms for Austrian Redispatch Provision

Gaming of participants is an evident risk in market-based models. The smaller the market the higher the risk usually. Therefore, especially in the case of Austria, it is important to gain a better understanding of the potential liquidity of such a potential redispatch market. For this the redispatch potentials that might be offered in Austria were analysed and compared with the historic redispatch demand.

The main research questions of this analysis can be summarised as follows:

- What are the minimum and maximum redispatch potentials available in Austria?
- What is the range of redispatch demand in Austria.
- Considering these circumstances, is a market-based redispatch technically possible?

In conclusion the analysis of redispatch potentials and comparison with the historical redispatch demand shows that a majority of redispatch potential is controlled by a few market participants which might therefore have significant market power and that the freely available redispatch resources without grid reserve are of a similar magnitude as the maximum historically requested redispatch and **may thus be insufficient for a fully market-based redispatch**. At last, the necessity of the existing grid reserve mechanism is also an indication that the legal obligation to participate in redispatch was not enough to secure sufficient redispatch potentials, but additional capacities had to be reserved. These limitations must be considered when configuring options for the integration of industrial plants into redispatch processes.

With a focus on Austria, there has been analysed the applicability of different remuneration mechanisms, as shown in Figure 7. The provision of redispatch may be compensated in a fully market-based model or via a more regulated cost-based model, with reimbursement of the incurred costs based on mandatory participation. Cost+, within the context of this project describes and remuneration model that is based on the cost incurred by the provider of redispatch but provides for an additional profit component to incentivize participation in redispatch. In all cases, CAPEX costs which are not directly connected to the provision of a single redispatch bid, e.g. to facilitate the participation in the redispatch platform, need to be covered as well. In case of a cost based or cost+ model this is subject to discussion with the regulatory authority, in case of a market the long-term plannability of revenues is crucial for investment decisions.

COST MODEL	COST BASED	COST+	MARKET-BASED
PRO	+ lower costs + higher efficiency if there are only few participants	+ slightly higher incentive to participate + Higher remuneration could cover additional costs of industry	+ higher incentive to participate + Higher remuneration potential could cover CAPEX/addition costs
CON	- Low incentive to participate - Mechanisms to secure capacity required - Effort for supplier to justify costs - Effort for TSO/NRA to verify costs - Information asymmetries between TSO/NRA and RD supplier - Solution to cover CAPEX needed	– Tendency to increase socio-economic costs – Effort for supplier to justify costs – Effort for TSO/NRA to verify costs – Information asymmetries between TSO/NRA and RD supplier – Solution to cover CAPEX needed	– Tendency for (inc-dec) gaming – Tendency to increase socio-economic costs – Validation by TSO/NRA of RD cost probably still necessary – FSP bidding strategy to cover CAPEX needed

Figure 7 Comparison of the remuneration mechanisms cost based, cost+ and market-based.

3.2. Highlight: Comprehensive survey of industry's interest in flexibility

The survey revealed insights into the industry's perspective on compensation models and incentives, highlighting the preference for a cost-plus or market-based approach along with the broader importance of fair remuneration.

A comprehensive survey with over 80 questions was developed, tested with industrial partners, and distributed through various industry channels. However, due to a lack of significant responses, direct interviews were conducted with three experts from the energy supply and pulp and paper sectors. As another corrective measure, a shorter 15-question survey focusing on incentives, remuneration, risks, and organization was later designed and distributed via the same channels.

Key Insights on Compensation Models from industry perspective:

- Compensation should follow either a cost-plus model or a fully market-based approach to create a meaningful incentive for participation.
- The remuneration model should ensure no disadvantage compared to other options, such as balancing energy.
- The implementation effort should remain proportionate to the expected benefits.
- While cost breakdowns are often viewed critically, they are not seen as a fundamental barrier.
- In addition to CAPEX and OPEX, key cost factors include risk compensation and personnel expenses.

3.3. Barriers

- **Liquidity and Remuneration:** A well-functioning redispatch market depends on sufficient liquidity and an adequate remuneration structure. Compensation must be designed to provide fair incentives without distorting competition or market efficiency. Power plant operators may also weigh whether offering their leveraged flexibility in the balancing market would be more profitable, potentially reducing available capacity for redispatch.
- **Gaming:** When looking at two sequential markets, on which practically the same products can be offered, there is always a risk of potential arbitrage trading. In the case of a redispatch market, which starts after the day-ahead market, it seems rational to take advantage of opportunities between those two markets. This might lead to strategical bidding behaviour of market participants in order to raise their profits. Such behaviour can result in an inefficient market outcome and welfare losses [6]. The most popular strategy in this context is the Inc-dec gaming, as described by [7] based on game theoretical analysis. This includes the strategic behaviour for two different types of providers, those that are in regions where regulation is predominantly downward and those which are predominantly regulated upward.
- **Market power:** Market-based procurement of redispatch bears the risk of relevant power plants being in a position to exercise local market power, in particular where a congestion is structural (i.e., frequent and predictable) [8] [9].
- **Plannability of revenues:** Predictable revenues are crucial for market participants to ensure long-term engagement. Transparent pricing mechanisms and stable regulatory frameworks contribute to confidence in the redispatch market. Additionally, redispatch is highly location-dependent, and its demand can change over the years due to grid expansion, changes in generation and consumption on national and international level and evolving network conditions. If revenue streams are too uncertain, participation may decline, reducing liquidity and increasing reliance on costly emergency measures.

3.4. Opportunities and Impact

Aligning the national law with EU regulations and opening the door to market-based redispatch would create new opportunities for decentralized assets and incentivize their participation. The ElWOG[10] in Austria only enables the implementation of a cost-based model. Therefore, any implementation of a remuneration model beyond a cost based one is subject to discussion with the National Regulatory

Authority. The work in the project I4RD gives a detailed base for discussion, by considering the industries perspective, the advantages and disadvantages of the possible cost models as well as the implementations in different European Countries. While a fully market-based redispatch is not yet foreseen in the mid-term due to potential liquidity issues, alternative approaches—such as the cost+ model or hybrid solutions—could help balance industry needs with socioeconomic costs for Austria. Expanding the remuneration model could thus foster innovation, improve grid stability, and increase overall system efficiency. These recommendations have been given to the Austrian regulator. Moreover, recommendations have been provided during the consulting phase of the new proposed law ELWG (implementation still pending).

3.5. Further information

Deliverable 3.2 Regulatory Analysis [11] **- Overview of the current regulatory framework as well as comparison of remuneration methods applied in different European countries and feasibility of models in Austria:**

Hembach, F., Sequeira-Taxer, V., Fanta, S., Zobernig, V., Poplavskaya, K., Gaal, T., Taljan, G., Zlabinger, E., Derler, L., & NEFI New Energy for Industry. (2025). Industry4Redispatch Deliverable 3.2 – Regulatory Analysis. NEFI. https://doi.org/10.5281/zenodo.14628594

4. Key-Result III: Comparative analysis of the Austrian and European regulatory framework

The regulatory analysis within the Industry4Redispatch project examines the legal framework regarding the roles and responsibilities regarding redispatch processes. We focus on enabling industrial facilities, including virtual power plants, to participate in the redispatch process. The analysis compares regulatory requirements with the technical needs identified in the project. We present our findings here as key legal and regulatory issues. The analysis includes a definition of redispatch, responsibilities of involved parties, data exchange requirements, and a financial compensation of redispatch services. We also give an overview on the different implementations of European countries and relevant regulations. Finally, we highlight regulatory gaps and provide potential solutions for aligning national laws with redispatch requirements for facilitating industrial participation.

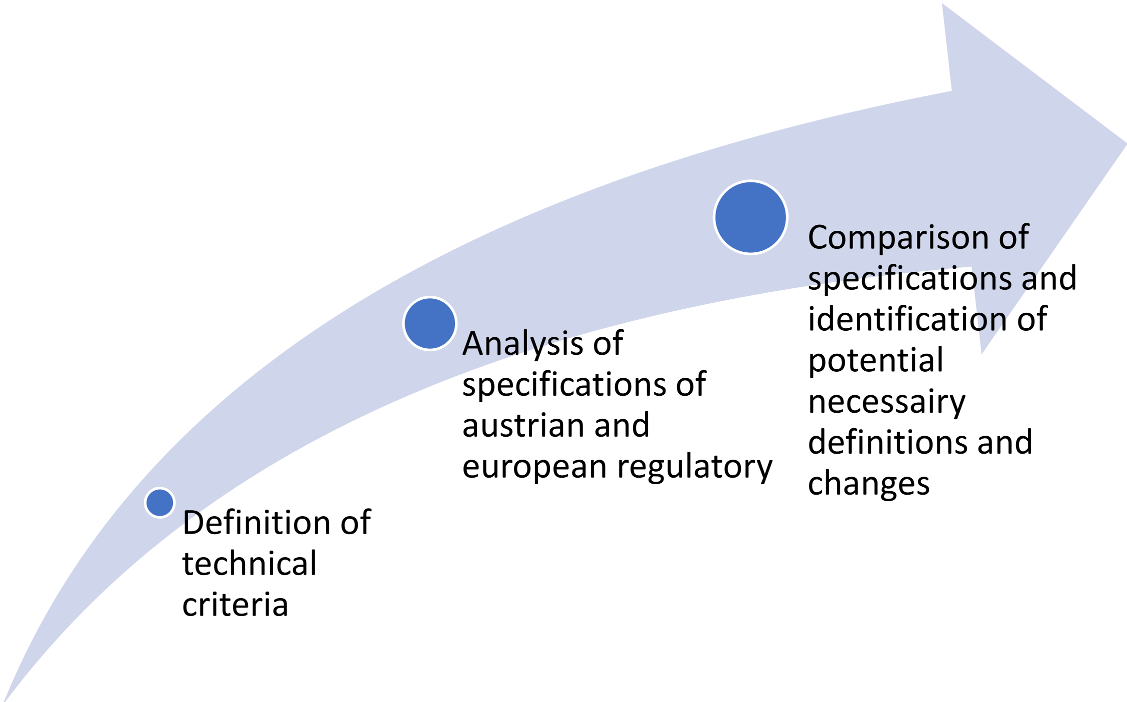

Figure 8 Schematic Overview of the Approach to the Regulatory Analysis

4.1. Highlight: Key hurdles in Austrian law have been identified

While the definition of TSO redispatch, the TSOs and the technical units' roles and responsibilities regarding redispatch as well as the grid connection requirements are regulated sufficiently, the following subjects require adaptation:

- The **roles and responsibilities regarding redispatch, attributed to the DSO need to be defined** within the national ElWOG[10] and while some federal ElWOGs allow for DSO redispatch the legislation is not harmonised within Austria. It is suggested to extend the national definition of congestion management to applications at distribution grid level and to harmonise the congestion management obligations and responsibilities by the DSO across the federal ElWOGs.
- The definition of **Significant Grid Users (**SGU) is crucial for determining the responsibilities of grid users, in particular regarding data exchanges relevant for the system operator's grid security analysis and

plays an important role in enabling the participation of industrial facilities in redispatch. While the **SGU definition** in the System Operation Guideline[12] (SO GL) was in line with the participation of industrial FSPs and virtual power plants, the definition in the SOGL Dataexchange-R came with more limitations at the time of analysis. It restricted the SGU definition to significant demand facilities providing demand response directly to the TSO with an installed capacity ≥ 25 MW. In general, all potential redispatch providers are significant grid users independent of their size. **This input has been provided to the regulator and the respective regulation has been adopted since then.**

- **An obligation to exchange schedules for demand facilities**, that are SGUs connected at the distribution level, was required as well at the time of analysis. Schedules are the basis of the system operators grid security analysis and function as a baseline for redispatch provision. The SOGL Dataexchange-R did not require demand facilities to provide schedules. The requirement to transmit schedules to the TSO needed to be added to the obligations of demand facilities with a similar wording to that of transmission connected demand facilities. **This input has been provided to the regulator and the respective regulation has been adopted since then.**
- **Financial compensation of redispatch is currently limited to economic disadvantages and incurred costs** by the national ElWOG. According to EU-Law, the default method for the procurement of redispatch is market-based procurement as stipulated in Art. 13 (2) Electricity Regulation [13]. Non-market-based redispatching may only be used, where one of the conditions listed in Article 13 (3) Electricity Regulation is met. Should the mechanism be changed to a market-based procurement, the current ElWOG [10] would not allow the TSO to compensate the participants above their economic disadvantages and costs. Therefore, any market model beyond a cost-based model is a subject to the decisions of the Austrian regulatory authority (E-Control), to ensure the costs of redispatch are acknowledged and considered within the system charges, i.e. the TSO is compensated for its expenses, if such a model should be deployed.

4.2. Barriers

Without precise regulations in place, there is a lack of clarity for both distribution system operators (DSOs) and industrial participants. For DSOs, this uncertainty complicates the implementation of a unified solution across Austria, leading to potential inefficiencies and fragmented approaches. For industry, the lack of clear guidelines creates a barrier to economic planning security, as businesses are unable to rely on stable conditions for investments in flexibility measures or participation in redispatch markets. This lack of regulatory clarity prevents industries from making informed long-term decisions, which is crucial for the successful integration of industrial flexibility in the energy system.

4.3. Opportunities and Impact:

A ministerial draft proposes a federal law to regulate the electricity industry (“Elektrizitätswirtschaftsgesetz” Electricity Act – ElWG)[2] and a federal law to define the term energy poverty for statistical purposes and to identify target groups for support measures (Energy Poverty Definition Act). The draft also includes amendments to the E-Control Act (ger.: E-Control Gesetz).

Public consultation on the draft was possible, but its progress has been delayed due to the ongoing formation of a new government. The I4RD consortium contributed feedback, and some of the identified gaps have already been incorporated into the draft:

- By harmonizing conditions and terminology for congestion management in the distribution network, there is an opportunity to create a unified framework for redispatch, enhancing efficiency and reducing complexity for grid operators. This has been included into the draft.
- Introducing clear framework conditions for the provision of schedules or baselines enables more accurate grid security analysis and an eased inclusion of smaller assets into the redispatch process. This has been also included in the draft.
- By adapting the regulatory framework to allow for adequate compensation models that are easily usable by DSOs and TSOs, there is an opportunity to create stronger financial incentives for participation. This could encourage more active involvement from a wider range of participants, improving overall efficiency. This feedback was provided on the draft.

4.4. Further information

Current (12.02.2025) draft of the pending Austrian Elwg (Elektrizitätswirtschaftsgesetz):

https://www.parlament.gv.at/dokument/XXVII/ME/310/fname_1604976.pdf

Deliverable 3.2 Regulatory Analysis - Overview of the current regulatory framework, as well as the resulting implications for the developed processes and project partners:

Hembach, F., Sequeira-Taxer, V., Fanta, S., Zobernig, V., Poplavskaya, K., Gaal, T., Taljan, G., Zlabinger, E., Derler, L., & NEFI New Energy for Industry. (2025). Industry4Redispatch Deliverable 3.2 – Regulatory Analysis. NEFI. https://doi.org/10.5281/zenodo.14628594

5. Key-Result IV: Industrial flexibility sources in Austria

We determined the installed electrical capacity for industrial processes in Austria and thus, the theoretical potential for flexibility provision in Austria to be around 6,290 MW. The assessed resources include e.g. industrial processes requiring high electrical load such as electric arc furnaces, mechanical grinders, air separation, chlorine electrolysis or electric smelting processes. Furthermore, also cross-sectoral technologies such as cooling, electricity supply or power-to-heat technologies, potentially also in combination with energy storages, can provide flexibility. Further flexibility potentials in industry are auto-electricity generation plants such as combined heat and power plants including gas turbines, steam turbines, engines, etc. Their capacity was estimated to be around 1,100 MW. The practical potential of these processes however turned out to be much lower at 190-410 MW (for negative and positive flexibility). Reasons for this large gap in comparison with other flexibility sources (e.g. hydropower plants) are explained together with further background information in the following sections.

The analysis of realistic bid costs for industrial redispatch bids was performed under the assumption that only cost-based bids are derived. In this chapter no further analysis of possible further remuneration schemes (e.g. establishment of a market or additional margins) to increase attractiveness for industry was done. For industrial processes hardly additional costs due to redispatch provision are expected to occur as long as the redispatch provision only includes process postponements or short-term shutdowns with no influence on the quality or quantity of the produced good. For industrial energy supply units positive or negative bid costs can occur (explanation see in Section 5.2). Comparably costs with conventional assets in redispatch provision were found for the combination of gas and steam turbines with heat-only-boilers as well as for the combination of power-to-heat boilers with heat-only-boilers.

5.1. Highlight: Positive and negative technical flexibility potential of Austrian industry is +410 MW and -190 MW

This analysis revealed an installed electrical capacity of approximately 6,290 MW in industrial processes and cross-sectional technologies, plus about 1,100 MW in electricity auto-production plants. Three provinces - Upper Austria, Styria, and Lower Austria - account for 67.7% of the total installed capacity, reflecting the concentration of energy-intensive industries in these regions. Regarding technical flexibility potential, in the project approximately 410 MW of positive and 190 MW of negative flexibility potential for one-hour call times, including auto-production plants, were identified. The largest positive potential is found in energy-intensive sectors such as chemical/petrochemical industry, non-metallic minerals, and paper/pulp production. Negative potential was primarily concentrated in the paper sector. Auto-production plants contribute about 55 MW of positive and 110 MW of negative flexibility potential for 15-minute and 1-hour durations. However, their actual contribution highly depends on the actual economic situation including energy prices, order situation, etc. In comparison to the flexibility potential of other technologies (other sectors such as e.g. power plants, households, etc.), the industrial flexibility potential determined in this work is currently still very low. For example, the potential of pumped-storage and storage power plants in 2020 was 8,844 MW (positive) and 4,200 MW (negative), respectively [14].

Site based assessment but also several current developments impact the values for actual and future industrial flexibility. With an increasing need for decarbonized concepts in industrial energy supply higher shares of electrified heat supply seem possible. Nevertheless, this development could be accompanied by a reduction in industrial on-site electricity supply, especially from fossil fuels such as natural gas.

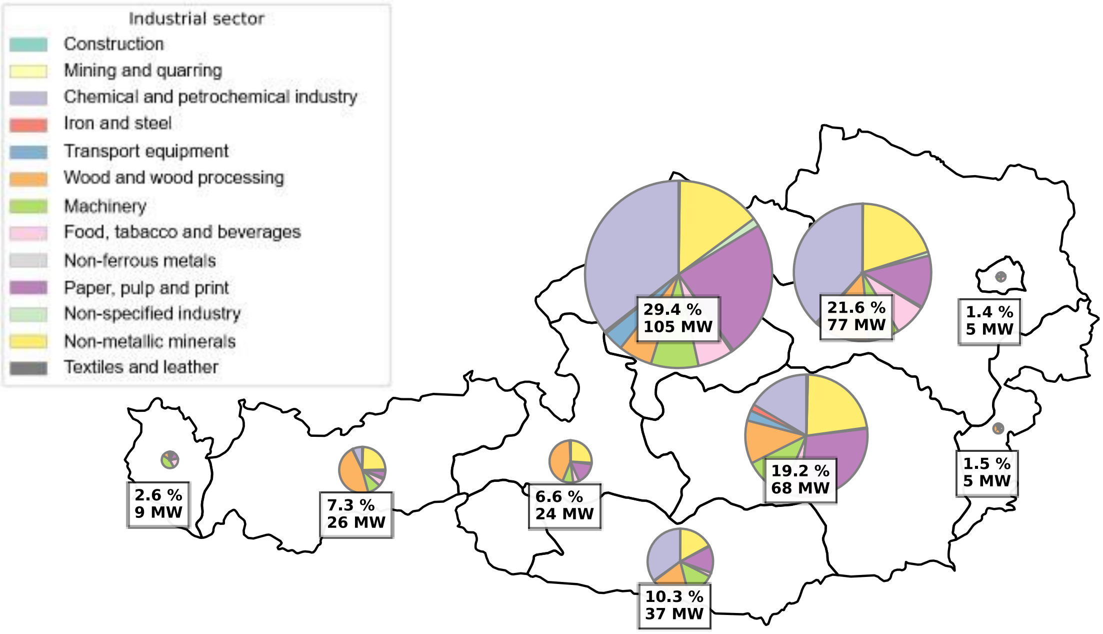

Figure 9 Distribution of the positive technical flexibility potential (excluding electricity auto-production plants) with a request time of 1h among the provinces and industrial sectors. Positive technical potential in MW and relative shares of the total available

In the following a short description is given how the quantification of the industrial flexibility potential was performed. In general, we applied a combined top-down-bottom-up method to identify positive and negative flexibility potential in the industry.

Thus, first a method for estimating installed electrical plant capacities in the Austrian industrial sector was setup consisting of three main steps. First, it determines sector-specific full-load equivalents using both regression analysis of German industrial load profiles and expert assessments. For sectors where load profile data was unavailable, the project team relied on domain knowledge from various sources including previous projects, and industry associations. Second, the installed plant capacities are calculated by dividing the annual electrical energy consumption per sector (from Statistics Austria's data) by the determined full-load equivalents. This calculation allows for both sectoral and geographical distribution of power capacities across different plant types and federal provinces. Finally, the method includes bottom-up analyses to validate assumptions and increase granularity. The study also evaluates technical flexibility potential by assessing which proportion of the total installed capacity can provide flexibility (positive or negative) for various activation durations (15 min, 1h, 4h). These technical flexibility potentials are further categorized by temporal availability (diurnal, daily, and seasonal patterns), though regulatory barriers and the realizability on-site are not considered in this assessment.

5.2. Highlight: Costs of flexibility provision from different technologies

The cost analysis revealed the following key findings.

1. **Negative bid cost possible:** Industrial flexibility bids for redispatch can have negative costs. Positive costs indicate that the (transmission) network operator is liable to pay compensation, while negative costs indicate that the industrial site would pay up to those costs. A typical example is, that a fossil fuel fired steam boiler is replaced by an electric power-to-heat boiler. Assuming, that the remuneration for redispatch is cost-based, the (negative) bid costs for this case would be derived from the avoided cost for natural gas and the efficiencies of the respective technologies.
2. **Cost Range and Symmetry**: Redispatch bid costs for the considered technologies and energy price assumptions vary significantly across technologies, ranging from 26.3 €/MWh to 188.0 €/MWh for positive redispatch, and from -87.7 €/MWh to -26.3 €/MWh for negative redispatch. Some technologies, notably conventional sources such as pumped hydro storage or combined cycle plants, demonstrate relatively symmetric costs for positive and negative redispatch.
3. **Technology Comparison**: Conventional technologies generally show more balanced bidding costs compared to industrial alternatives.
4. **Industrial Applications**: Among industrial technologies, back pressure steam turbine (BPST) systems show the highest positive redispatch costs at 188.0 €/MWh, while the technology combination of heat pump and thermal storage systems demonstrate more moderate costs (-85.0 €/MWh negative, 86.7 €/MWh positive) for the given prices assumptions.

The analysis demonstrates that while conventional technologies offer relatively balanced redispatch options, industrial technologies present a wider range of costs, reflecting their diverse operational constraints and primary industrial purposes.

From a methodological point of view the cost analysis includes the following: average industrial energy price levels incl. fees in Austria from 2024 and typical efficiencies of considered technologies. From an industrial perspective, the costs associated with a flexibility bid encompass the difference between conventional energy consumption expenses in a base scenario and those incurred in a scenario that accommodates the specific flexibility bid.

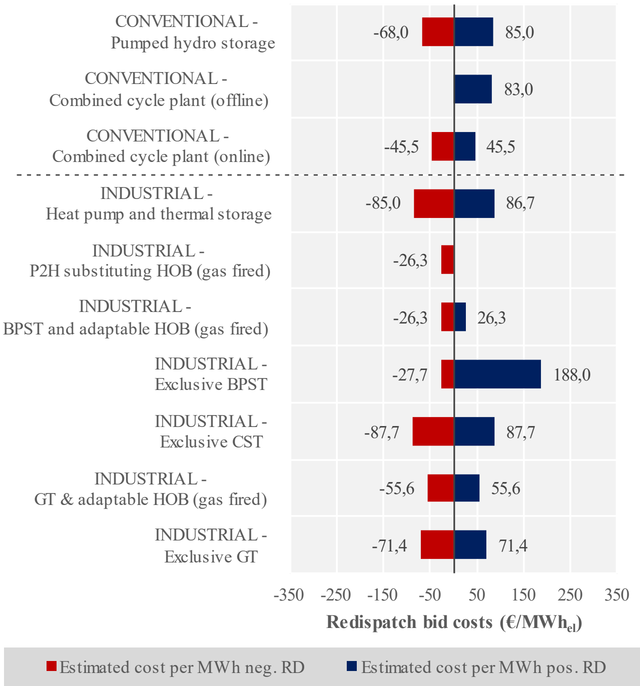

Figure 10 Overview of industrial and conventional technologies for RD supply and estimated negative and positive flexibility costs excluding changed fees for power-related grid charges. (HOB-heat only boiler, BPST-back pressure steam turbine, CST-condensing steam turbine, GT-gas turbine)

5.3. Barriers

In this section we summarize the exiting barriers to use industrial flexibility especially for redispatch. Industrial facilities face multiple challenges when providing flexibility services, particularly for redispatch operations. These barriers can be categorized into four main areas: technical, organizational, regulatory, and economic constraints.

- Technical barriers primarily stem from infrastructure limitations. Many facilities lack adequate measurement systems, data processing capabilities, and control mechanisms, making it difficult to identify and utilize flexibility potential, especially for smaller sites with considerably smaller energy consumption and loads. Additionally, the coupled operation of energy supply plants, such as combined heat and power systems, can restrict operational flexibility.
- Organizational challenges are equally significant. High-capacity utilization often means that load reduction or shifting directly impacts production output. Quality concerns and production risks associated with flexible operations create reluctance among operators. Furthermore, the unavailability of qualified personnel across all shifts might limit (all-day) flexibility options. At some sites additional staff could even be required to take over the additional tasks redispatch provision brings along.
- Regulatory restrictions pose another layer of complexity. Plants must maintain compliance with noise emission limits and efficiency targets, which can prevent shifting operations to nighttime hours or utilizing alternative energy supply technologies. At the same time they need to fulfil pre-qualification requirements which might pose another burden.
- Economic barriers are particularly crucial for redispatch services. Industrial flexibility sources often struggle to compete with conventional systems, and more attractive opportunities exist in short-

term and balancing energy markets. The additional organizational burden of providing redispatch services, combined with the requirement for accurate baseline load forecasting, further complicates participation. Even energy-intensive companies with established load forecasting practices face challenges with production process fluctuations, affecting forecast accuracy.

These multifaceted barriers significantly impact the practical exploitation of theoretical flexibility potential in industrial settings.

5.4. Opportunities and Impact

The overall potential is estimated to be 190 MW of negative, and 410 MW of positive flexibility. This is currently considerably lower compared with conventional technologies for redispatch provision. Nevertheless, industrial flexibility for redispatch poses several opportunities in the overall energy system due to its distinct characteristics compared to traditional flexibility sources on the one hand but also compared to traditional trading schemes (balancing energy and spot markets) on the other. Two key differences to conventional redispatch sources and thus opportunities – especially for grid operators - of industrial redispatch are:

1. Economics: Redispatch requires bids that specify both power quantity and associated costs for compensation. This differs from spot market trading, which primarily focuses on price prediction and cost minimization. Furthermore, industrial bids typically have smaller sizes compared to large power plants currently used for redispatch. This could even lead to reduced costs, in particular if industrial flexibility would avoid starting up big power plants.
2. Geography: Unlike balancing energy or spot markets, redispatch effectiveness depends on the facility's grid location relative to congestion points within the control area. Thus, for system operators it might be a more effective option – regarding energy and costs – to overcome congestions.

A relevant opportunity for industry is presented in the following:

3. Timing: Redispatch notifications typically come the evening before or hours ahead of activation, allowing for planned operations in the industrial setting. In contrast, balancing energy activations occur with minimal notice (<1s to minutes), while spot market trading ranges from day-ahead to minutes before delivery. This allows also to include further flexibility potentials compared to spot and balancing markets. Examples can be processes such as felt change in paper machines or exhaustive cleaning activities.

Furthermore, the analysis of flexibility potentials in industry often unlocks unused efficiency potentials leading to improved energy and cost performance of industrial systems – see also Chapter 6.

5.5. Further information

IEWT Conference Paper[1] Industrielles Flexibilitätspotenzial zur Bereitstellung von Redispatch – Description of the method for industrial flexibility assessment and the analysis of backlaying processes:

Traninger, M., & Knöttner, S. B. (2023). Industrielles Flexibilitätspotenzial zur Bereitstellung von Redispatch. in *13. Internationale Energiewirtschaftstagung an der TU Wien: Die Zukunft der Energiemärkte in Europa vor dem Hintergrund neuer geopolitischer Ungleichgewichte.* Online available: https://iewt2023.eeg.tuwien.ac.at/download/contribution/fullpaper/30/30_fullpaper_20230221_125829.pdf

Deliverable 3.4 Estimated Industrial Redispatch Potential – Description of the method for industrial flexibility assessment and the analysis of backlaying processes. Furthermore the survey performed in the project is presented and the results are discussed:

Traninger, M., Knöttner, S., Schützenhofer, C., Teufner-Kabas, M., Teufner, F., Hembach, F., Sequeira-Taxer, V., & NEFI New Energy for Industry. (2023). Industry4Redispatch Deliverable 3.4 – Estimated Industrial Redispatch Potential. NEFI. Online available: https://doi.org/10.5281/zenodo.14627931

EEM Conference Paper A Cost Analysis of Integrating Industrial Assets in the Redispatch Process in Austria – Description of the cost assessment method for industrial flexibility:

Knöttner, S., Traninger, M., Hemm, R., Fanta, S., Strömer, S., & Esterl, T. (2024). A Cost Analysis of Integrating Industrial Assets in the Redispatch Process in Austria. *2024 20th International Conference on the European Energy Market (EEM)*, 1-6. Online available: https://www.semanticscholar.org/paper/A-Cost-Analysis-of-Integrating-Industrial-Assets-in-Kn%C3%B6ttner-Traninger/5795f2f4813d5828d8c89ca016284a5a7f5f5b4f

[1] honored with Young Author Award

6. Key Result V: Successful industrial demonstration of Energy Demand Control System

Energy management systems can form a significant contribution for leveraging industrial (electrical) flexibility. In this project the applied energy management system included a modular approach allowing for (1) optimal energy planning and (2) optimal realization of this planning as control system, e.g. by means of model predictive controllers. They enable real-time monitoring, analysis, and optimization of energy consumption patterns. Such systems allow industrial facilities to adjust their energy supply based on e.g. on-site renewable generation or energy prices while maintaining production requirements and transform processes from consumers into flexible assets that can participate in grid services and energy markets. In I4RD the Technology Readiness Level of such an “energy demand and control system” (EDCS) was significantly increased. Starting from Technology Readiness Level 4, which was realized in the project EDCSproof (2018-2021), in I4RD an increase up to Technology Readiness Level 7 was realized. This demonstration was shown at two sites. At one of those sites, it was operated over weeks and showed significant performance increase – energy consumption could be reduced for about 8% and the number of start cycles could be reduced by 36%. At the second site, the EDCS was applied to control the energy system of an industrial plant for 72 hours and for 2 redispatch calls as part of the industrial redispatch demonstration.

6.1. Highlight: EDCS was demonstrated in industrial environment

In the course of I4RD, we achieved an advancement in the Technology Readiness Level from 4 to 7 by progressing from demonstration in a laboratory setting (EDCSproof) to successful testing and demonstration in an industrial environment. The EDCS was successfully demonstrated and integrated into the automation systems of two industrial sites, establishing both reading of actual state and measurement data, which was the input data for any EDCS calculation, and partial also writing of new setpoints for the included units (e.g. storages, heat supply, etc.). At one of these locations, an extended operational phase lasting several weeks could be conducted, which provided valuable insights into the EDCS performance under real-world industrial conditions. The application of the EDCS led not only to savings in overall energy consumptions and thus reduced energy costs. Also reduced starts and stops of the equipment could be realized providing additional monetary benefits on the long-term – energy consumption could be reduced for about 8% and the number of start cycles could be reduced by 36%. One the other side, the robustness of the running capability could be improved. Thus, also a suitable and applicable human-machine-interface was elaborated to allow efficient operation and handling on-site. The successful operation of the EDCS is not possible without appropriate operation by the employees on site.

This progression from controlled laboratory testing to actual industrial deployment represents a crucial step in validating the EDCS’s practical applicability and effectiveness in real operational settings.

6.2. Highlight: EDCS contributed to successful redispatch demonstration

The EDCS demonstrated its advanced capabilities in supporting the demonstration of industrial redispatch services, (one main goal of the project) at one of the three included industrial sites participating in redispatch provision during the demo phase. The EDCS was applied to control the energy system of an industrial plant for 72 hours and for 2 redispatch calls as part of the industrial redispatch demonstration.

Multiple functionalities of the EDCS were necessary to realize this redispatch provision. Beyond its core function of generating optimal schedules and trajectories for energy supply units, the EDCS was enhanced during the project to handle flexibility bid generation and execution.

Through targeted code extensions, it gained the ability to calculate and submit flexibility bids to e.g. a flexibility service provider (as interface to any further market or platform), and upon successful clearing by external systems, it could implement the accepted bids by adjusting the operational (control) parameters of the energy supply units accordingly.

6.3. Barriers

Wide application of such a tool as the EDCS faces several significant implementation barriers in industrial environments.

A primary challenge lies in the heterogeneous nature of industrial energy supply systems, where each site presents unique configurations and requirements, making standardized solutions difficult to implement. This heterogeneity still takes extensive manual effort to develop and validate site-specific models. A resource-intensive process that currently hinders broader and especially faster market penetration.

Integration with existing automation systems presents another hurdle, as many facilities operate with systems that have evolved over decades, making seamless data exchange and control implementation complex.

Liability concerns also pose significant challenges, particularly when the EDCS actively adjusts system setpoints, as especially manufacturers are often hesitant to delegate control of critical processes.

In addition, often the prerequisites for the EDCS are currently not given at industrial sites including digital production plans. In those cases the implementation of an energy demand control system might make organizational adaptions of workflows and tasks necessary. Typically, such processes require excellent communication of the benefits and needs and are thus challenging in the transition process.

In general, to achieve wider industrial implementation, the effort required for site-specific modeling and integration must be substantially reduced, e.g. through standardization and automated model generation approaches, while simultaneously addressing security and liability concerns in a comprehensive manner.

6.4. Opportunities and Impact

As indicated above not only energy cost savings could be derived – an optimal operation of energy supply systems showed also additional benefits, such as reduced starting procedures of the included technologies leading to less system wear, longer service life and therefore lower costs in the long term.

The EDCS's usefulness is demonstrated through its ability to address a wide range of objectives, delivering both immediate and long-term benefits. While direct financial advantages can be achieved through reduced energy consumption, lower energy costs, and increased utilization of on-site renewable generation, the system also yields significant indirect benefits that may not be immediately quantifiable in monetary terms. These include e.g. extended equipment lifetimes and reduced maintenance costs through optimized operation patterns, particularly by minimizing unnecessary starts and stops of machinery.

The tool is primarily relevant for small to medium-sized industrial sites where energy consumption is important but has not been a top priority in operational decisions in the past. The potential impact of the EDCS extends even further through its expandable architecture, as demonstrated in the project through the successful implementation (on simulation level – not demonstrated at industrial scale) of process scheduling capabilities. This enhancement opens additional application scenarios, showing how its core optimization framework can be adapted to address broader operational challenges and create new value streams for industrial facilities that previously may have overlooked energy optimization opportunities.

6.5. Further information

Journal Paper Experimental Validation of Mixed-Integer Model Predictive Control for Energy Management in an Industrial Food Processing Plant - Description of EDCS test in real industrial application:

Fallmann, M., Stanger, L., Fischer, M., Kureck, M., Schirrer, A., Hofmann, R., Jakubek, S., Kozek, M. Experimental Validation of Mixed-Integer Model Predictive Control for Energy Management in an Industrial Food Processing Plant. (in progress).

Journal Paper Model-predictive energy management system for thermal batch production processes using online load prediction – Description overall energy management systems architecture and simulation results:

Fuhrmann, F., Schirrer, A., Kozek, M. (2022). Model-predictive energy management system for thermal batch production processes using online load prediction. Computers & Chemical Engineering. Volume 163. 107830. Online available: https://doi.org/10.1016/j.compchemeng.2022.107830

Journal Paper Energy management for thermal batch processes with temporarily available energy sources – Summary and report of experimental laboratory tests:

Fuhrmann, F., Windholz, B., Schirrer, A., Knöttner, S. B., Schenzel, K., & Kozek, M. (2022). Energy management for thermal batch processes with temporarily available energy sources– Laboratory experiments. in *Case Studies in Thermal Engineering* (Band 39). Elsevier. Online available: https://doi.org/10.1016/j.csite.2022.102473

Journal Paper MPC for Process Heat Supply Systems: Considering Load Prediction Uncertainty Caused by Human Operators. Computer Aided Chemical Engineering – Simulation results for uncertainty in load prediction:

Fuhrmann, F., Schirrer, A., Kozek, M. (2020). MPC for Process Heat Supply Systems: Considering Load Prediction Uncertainty Caused by Human Operators. Computer Aided Chemical Engineering. Elsevier. Volume 48. Pages 1219-1224. Online available: https://doi.org/10.1016/B978-0-12-823377-1.50204-4

Conference Paper Prediction of pulsed heat loads in manufacturing plants – Heat load prediction approach for thermal batch processes:

Fuhrmann, F., Schirrer, A., Kozek, M., Jakubek, S. (2020). Prediction of pulsed heat loads in manufacturing plants. IFAC-PapersOnLine. Volume 53. Issue 2. Online available: https://doi.org/10.1016/j.ifacol.2020.12.2787

7. Key-Result VI: Initial specification of the TSO/DSO interaction process

The initial specification of the planned TSO/DSO interaction process has been defined based on the stakeholder requirements and lessons learned from other projects. It defines the functionalities and their distribution between the involved stakeholders as well as the necessary interfaces. Focus is given on the specification of the data required to communicate the constraints within distribution networks and the efficacy of redispatch bids at the TSO/DSO intersection. The process flows are designed by addressing a set of defined requirements and the learnings from various European research projects and initiatives.

Based on extensive discussions between the Austrian network operators, the project consortium decided that a central and sensitivity-based bid set filtering approach – similar to the one used within DA/RE – is the most suitable to meet the Austrian stakeholder requirements. The functionalities and data exchanges relevant for the planned TSO/DSO interaction process are shown in Figure 11.

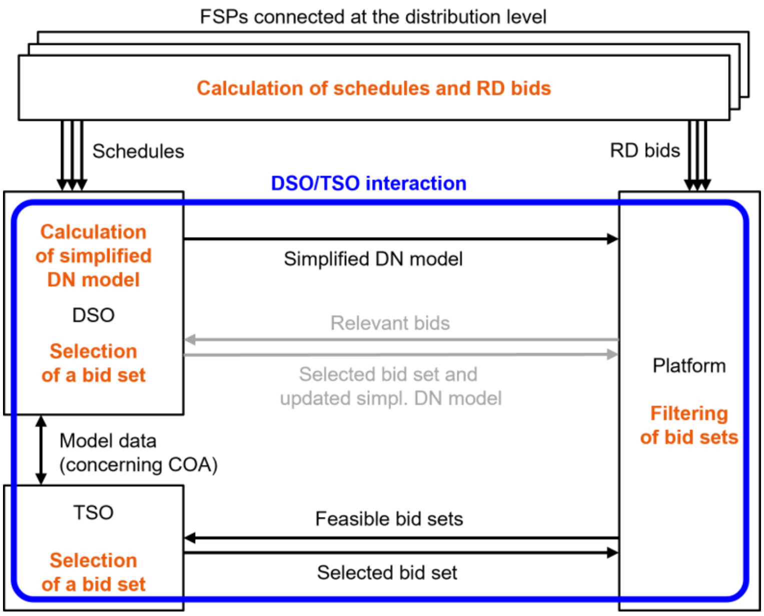

Figure 11: Functionalities and data exchanges relevant for the planned TSO/DSO interaction process.

The major process functionalities are divided into three blocks: the *calculation of the simplified distribution system (DS) model*, the *filtering of bid sets*, and the *selection of a bid set*, whereby the calculation of the simplified DS model and the bid set filtering to constitute the core functionalities of the TSO/DSO interaction process.

7.1. Highlight I: Stakeholder requirements have been defined first

Within the I4RD project, different European projects and initiatives are reviewed to assess the existing TSO/DSO coordination mechanisms based on market-based and non-market-based schemes. From these projects, synergies to the I4RD project, lessons learned, and key success factors are identified. This creates the basis for the definition of the TSO/DSO interaction process for the Austrian Redispatch market. Bid optimization process, bid filtering, and bid selection are also presented with the main findings.

Expert interviews were also conducted within the project to gain an overview of the Austrian network operators' requirements on the TSO/DSO interaction process.

The identified basic requirements are divided into four categories, i.e., fairness, practicability, accuracy, as well as scalability & replicability.

Fairness comprises transparency, freedom from discrimination, and self-determination, which means that outsiders can understand and reproduce the coordinator's decisions, all flexibility providers have an equal prospect to contribute to system operation, and each network operator maintains the operational responsibility for its own network. **Practicability** implies the use of simple, robust, and quick procedures that involve low data exchanges and avoid the exchange of sensitive and confidential data. **Accuracy** promotes optimal resource utilization and **scalability and replicability** allow for the seamless process integration of additional participants and system portions without deteriorating fairness, practicability, and accuracy. Fairness, practicability, and accuracy are conflicting requirements that must be traded-off against each other. Especially, resource utilization, transparency, and privacy span a trilemma in which only two requirements can be maximized at the expense of the remaining one.

7.2. Highlight II: Major process functionalities have been defined

The major process functionalities are divided into three blocks: the *calculation of the simplified DS model*, the *filtering of bid sets*, and the *selection of a bid set*, whereby the calculation of the simplified DS model and the bid set filtering to constitute the core functionalities of the TSO/DSO interaction process. The DSO uses load flow simulations and local sensitivity analysis to calculate the simplified model of its distribution network based on the flexibility providers' schedules and other data and sends it to the platform.

The platform uses this simplified DS model to filter the bid sets for redispatch at the transmission level, i.e., it identifies feasible bid sets. Finally, the TSO selects the most suitable bid set for redispatch at the transmission level and reports the selection back to the platform as shown in Figure **11**.

7.3. Barriers

The trilemma of power system coordination

The conflicts between resource utilization, transparency, and privacy are fundamental for the design of coordination schemes in general and deserve dedicated analysis. Resource utilization relies on high simulation accuracy and thus detailed system models as the basis for power system coordination. Transparency requires full disclosure of the optimization problem behind the coordination and privacy avoids the exchange and disclosure of sensitive or confidential data such as detailed system models. Only two out of the three requirements can be maximized at the expense of the remaining one, regardless of whether centralized or decentralized coordination is used and whether coordination is implemented at the control center or platform level. This trilemma is illustrated in Figure 12.

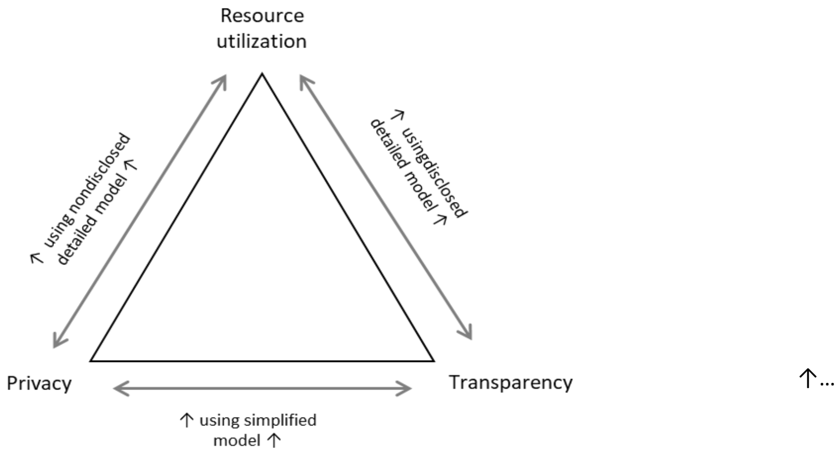

Figure 12: Trilemma of power system coordination.

The following examples correspond to the triangle's edges and shall clarify this trilemma:

a) Resource utilization and privacy are maximized by using a nondisclosed detailed system model for coordination.
b) Resource utilization and transparency are maximized by using a disclosed detailed system model for coordination.
c) Privacy and transparency are maximized by using a disclosed simplified system model (or just capacity information) for coordination.

System non-linearity

The proposed sensitivity-based distribution system model allows calculating the states of network elements for a specific bid combination, while reducing calculation times (compared to load flow simulations) and supporting confidentiality of DSOs and transparency to an acceptable degree. Its accuracy depends on the linearity of the distribution system and the bidden power. Distribution systems contain several sources of non-linearity, including network- and control-related ones which are not fully modelled yet. Network-related non-linearities arise from branch resistances and spatial voltage magnitude and angle variations, thus increasing from the high to the low voltage level.

Control-related non-linearities are relevant when distributed energy resources are controlled to adapt their (active/reactive) power contributions depending on the distribution network state. They have a non-negligible effect and must be therefor considered in some form, to obtain reliable results. SOs often use such controls to increase the hosting capacity of their grid and because of that such effects must be considered in the TSO-DSO coordination mechanism.

The sensitivity-based model supports the precise detection of limit violating bid combinations in the analysed synthetic distribution system when accurate forecasts are available, and bids have unity power factors, indicating almost linear relations between the network state (node voltages / branch loadings) and active power changes of flexibility providers is almost linear in the regarded system. However, the linearity of any real distribution system should be analysed prior to implementation and re-evaluated after network reinforcements/expansions and adjustments of the applied controls.

The estimation on the impact on local voltage limits and related voltage managements cannot be simplified and requires very detailed models of the distribution system. Therefore, validation is necessary for each grid to assess the impact of these factors and determine whether they can be reasonably neglected.

7.4. Further information

Deliverable 5.1 Summary of the Stakeholder Requirements and Initial Process Specification

Henein, S., Schultis, D.-L., Herndler, B., Brunner, H., & NEFI New Energy for Industry. (2025). Industry4Redispatch Deliverable 5.1 – Summary of the Stakeholder Requirements and Initial Process Specification. NEFI. https://doi.org/10.5281/zenodo.14628018

Deliverable 5.2 Specification of the TSO-DSO Interaction Process

Schultis, D.-L., Henein, S., Hembach, F., Fabian, T., Knöttner, S., & NEFI New Energy for Industry. (2025). Industry4Redispatch Deliverable 5.2 – Specification of the TSO-DSO Interaction Process. NEFI. https://doi.org/10.5281/zenodo.14628097

8. Key-Result VII: Final TSO-DSO process specification definition and validation

The final specification of the planned TSO/DSO interaction process, which ensures that the activation of industrial flexibilities on request of the TSO does not lead to violations of the operational distribution network limits at the HV and MV levels, is conducted and validated through running a number of simulations. A simulation environment is developed for the conceptual implementation and pre-validation of the process, for this purpose. A detailed process description which provides insights into the performance of the process for specific test cases were conducted and results are analysed.

8.1. Highlight I: Development of bid filtering method and TSO/DSO interaction process

The final TSO/DSO interaction process is defined and all information relevant for process implementation is analyzed and formalized. Figure 13 depicts the functionalities (orange fonts) and data exchanges (arrows) of the planned TSO/DSO interaction process (blue box).

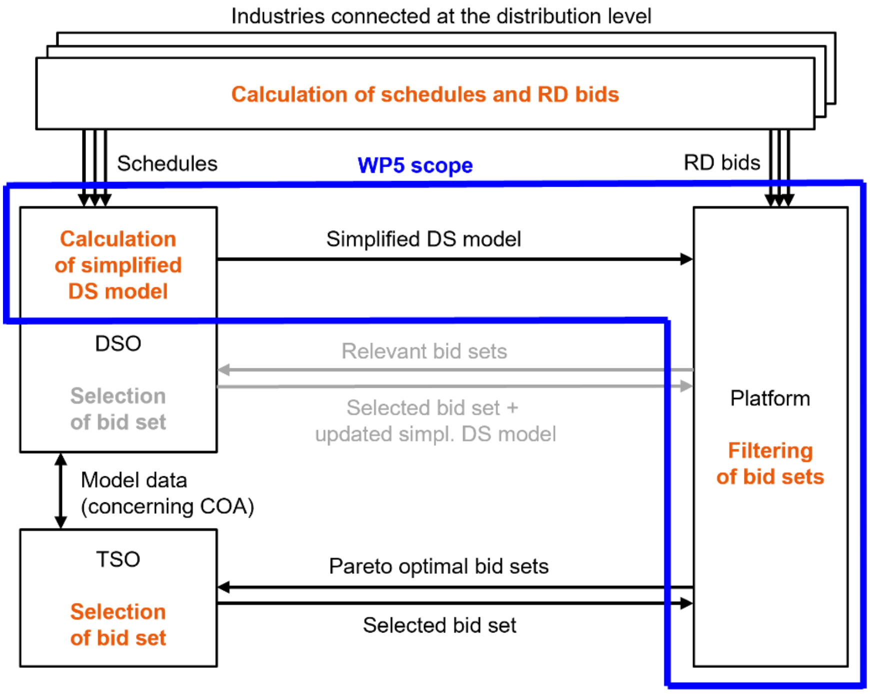

Figure 13: Functionalities and data exchanges of the planned DSO/TSO interaction process.

The major process functionalities are divided into three blocks: the *calculation of the simplified DS model*, the *filtering of bid sets*, and the *selection of a bid set*, whereby the calculation of the simplified DS model and the bid set filtering constitute the core functionalities of the planned TSO/DSO interaction process. However, before executing these functionalities, the network operators exchange relevant network model data concerning their common observability area (COA), i.e., a part of the network that is included in the models of both, the DSO and TSO. The DSO uses load flow simulations and local sensitivity analysis to calculate the parameters of the simplified model of its distribution system based on the schedules of the industrial customers and other data and sends them to the platform. The model parameters are calculated for all relevant time points and contingency cases necessary to ensure (n-1) security. The platform uses the simplified DS model to filter the bid sets for redispatch at the transmission level, i.e., it identifies the pareto optimal bid sets (optimality in costs and impact). The platform uses the simplified DS model to filter the bid sets, i.e., to calculate the pareto optimal bid sets, which do not violate any distribution network constraints (voltage and loading limits). Finally, the TSO selects the most suitable bid set for redispatch at the transmission level and reports the selection back to the platform.

8.2. Barriers

As mentioned before, the process should be **fair, practicable, accurate, scalable, and replicable**, there are some other barriers which can affect the total implementation process which are illustrated down below.

- From a physical perspective, validating the feasibility of bid combinations requires an adequate degree of bid aggregation:
    - Several assets behind a single delivery point of the distribution network may be aggregated.
    - Bids related to different delivery points cannot be aggregated.

- Low-quality forecasts and non-unity bid power factors significantly degrade calculation accuracy, leading to misjudgements concerning the feasibility of bid combinations and possibly to increased redispatch costs.
- The synthetic distribution system exhibits significant non-linear relations between reactive power adjustments of flexibility providers and the network state, indicating accuracy-related challenges in the sensitivity-based consideration of non-unity bid power factors in network calculations.
- The linearized DS model enables a slim problem formulation that preserves the privacy of DSOs and promotes transparent bid set filtering while degrading calculation accuracy. Simulation results underline its ability to accurately estimate the effects of bid set activations on the loading of critical branches and the active power exchanges between the DSO and TSO. However, they also reveal severe inaccuracies in voltage estimations, which are necessary to consider the upper and lower voltage limits of distribution networks in bid set filtering.
- The process pre-validation results show that the optimization problem formulation does not guarantee the rejection of all infeasible bid sets if the actual voltage limits of the distribution network are used. Using tightened limits removes all false approvals but increases the number of false rejections, leading to a high false rejection rate of 82.92 % of all bids. These false rejections reduce the power available for redispatch at the transmission level and increases the redispatch costs. The NSGA2 algorithm identifies the correct pareto front when no margins are applied to the investigated example, but when margins are applied and only a few bid sets remain that satisfy the optimization constraints, it does not find any solution.
- As the false decision rate is very sensitive to the underlying scenario, a comprehensive scalability analysis is necessary to evaluate the applicability of the planned interaction process under various conditions. This analysis, which is conducted in WP8 of this project, should systematically investigate scenarios that are critical for the upper and lower voltage limits and the loading limits at both the high and medium voltage levels.
- The proposed sensitivity-based DS model allows calculating the states of network elements for a specific bid combination, while reducing calculation times (compared to load flow simulations) and supporting confidentiality of DSOs and transparency to an acceptable degree. Its accuracy depends on the linearity of the distribution system and the bidden power.
- Distribution systems contain several sources of non-linearity, including network- and control-related ones. Network-related non-linearities arise from branch resistances and spatial voltage magnitude and angle variations, thus increasing from the high to the low voltage level. Control-related non-linearities are relevant when distributed energy resources are controlled to adapt their (active/reactive) power contributions depending on the distribution network state. Their accurate consideration is crucial to obtain meaningful results because such controls are often employed to increase the network's hosting capacity.
- The sensitivity-based DS model supports the precise detection of limit violating bid combinations in the analysed synthetic distribution system when accurate forecasts are available, and bids have unity power factors, indicating almost linear relations between the network state (node voltages / branch loadings) and active power changes of flexibility providers is almost linear in the regarded system.

However, the linearity of any real distribution system should be analysed prior to implementation and re-evaluated after network reinforcements/expansions and adjustments of the applied controls.

- Non-unity bid power factors generally tend to provoke higher redispatch costs due to their high impact on the distribution network voltages.
- Network state calculations for bid combinations that contain XOR-conflicts should be avoided during the optimization process when using heuristic algorithms to improve the performance of the solver.
- The proposed solution approach, which is based on a modified NSGA2 algorithm and limited to a runtime of 15 min, does not support the consideration of voltage limits in large networks with many redispatch bids due to calculation speed issues. However, it successfully identifies cost-effective bid combinations in the analysed scenario when voltage limits are neglected, of which approximately 95 % respect the loading limits of the synthetic distribution network. Most of these bid combinations have negative costs irrespective of whether the redispatch power at a certain time interval is positive or negative.
- Network expansion or reinforcement cannot be fully replaced, and the process becomes complex when the distribution is overloaded.

8.3. Opportunities and Impact:

A significant milestone in the development of the TSO/DSO interaction process has been achieved. It sets the floor for further process enhancement in the future. The performance of the process can be enhanced by a set of actions that can be considered as future work such as: Improving the load and generation forecast quality. Further analysis of Bid power factors and the effect of their sensitivity-based consideration on the filter performance. The solution approach should be improved to enable the consideration of distribution network voltage limits within short runtimes. This can be achieved, by increasing the speed of constraint calculation (e.g., through carefully selecting a low number of critical elements and nodes of influence) and by reducing the number of generations that must be calculated to find a proper solution (e.g., by using another heuristic algorithm for two-objective optimization).

8.4. Further information

Deliverable 5.1 Summary of the Stakeholder Requirements and Initial Process Specification

Henein, S., Schultis, D.-L., Herndler, B., Brunner, H., & NEFI New Energy for Industry. (2025). Industry4Redispatch Deliverable 5.1 – Summary of the Stakeholder Requirements and Initial Process Specification. NEFI. https://doi.org/10.5281/zenodo.14628018

Deliverable 5.2 Specification of the TSO-DSO Interaction Process

Schultis, D.-L., Henein, S., Hembach, F., Fabian, T., Knöttner, S., & NEFI New Energy for Industry. (2025). Industry4Redispatch Deliverable 5.2 – Specification of the TSO-DSO Interaction Process. NEFI. https://doi.org/10.5281/zenodo.14628097

9. Conclusion and Outlook

Austria has made significant progress in developing the specifications for a redispatch product and process that allows industrial participation as well as a TSO-DSO interaction algorithm, positioning itself at the forefront of European innovation in this field. Some project results are already being implemented by the transmission system operator. The product definition for the redispatch product has been established. It incorporates input from all relevant stakeholders. This project did foster a deeper mutual understanding between the TSO, FSPs, DSOs, industrial partners and research institutes.

Distribution System Operators (DSOs) benefit from the TSO-DSO processes Distribution System Operators (DSOs) benefit from the TSO-DSO processes because their limitations are inherently considered in the way that no bids can be awarded, that would result in a congestion in their grid. The more the grids are stressed, the more important this process will be. Currently in Austria the imminent need is only just emerging. Many DSOs are interested if the Transmission System Operator (TSO) integrates the proposed process. A general level of acceptance of the proposed processes and incentives has been achieved in the project. Looking ahead, DSOs are supposed to actively utilize flexibility where it proves more cost-effective than traditional grid enhancements. Further improvements to the TSO-DSO platform could support and facilitate this transition.

It has been found that realizable, cost-effective industrial flexibility potential is rather limited, especially compared to both installed capacity and other flexibility sources. Still, it could be shown that automation is crucial in reducing energy consumption, demonstrating that while optimized systems may limit available flexibility under normal conditions, automation can enhance both efficiency and overall flexibility. Current framework conditions hardly attract participation and flexibility valorisation for redispatch provision. If the contribution of industrial flexibility for redispatch is to be increased, stronger incentives must be implemented for both existing and new flexibility sources in industry.

Several follow-up projects are being planned, each focusing on specific aspects:

- Further development of redispatch services as an integrated product
- Enhancing TSO-DSO interaction by refining the bid filter mechanism
- Facilitating a more robust and efficient implementation of the EDCS control system

The following table summarizes the key project achievements and remaining needs for action for the three main stakeholders on different levels (implementation, scientific, regulatory):

Project Achievements	Need for action	Category of Achievement and Need for Action • Implementation • Scientific • Regulatory
Successful implementation and demonstration of redispatch platform including product definition and process specification for interaction	• Schedule exchange processes with balancing group responsible parties, especially with from the supplier independent flexibility service providers	Implementation

between participants and the transmission grid operator.	• Improve method for Proof of activation • Consideration of aggregated bids in the network filter	
Successful operation of Energy Demand Control System (EDCS) in industry, additional effects such as efficient operation of assets could be shown.	• Robustness and features of EDCS need to be further elaborated (for several asset types/industries). • Awareness initiatives for SMEs helping businesses recognize their flexibility potential • FSPs supporting in connecting assets to the redispatch platform and other flexibility markets • Further incentives for participation required • Establishing Clear Liability Frameworks: Develop standardized agreements and legal frameworks to clarify liability responsibilities among industry stakeholders, research partners, and external automation service providers • Employee awareness and clear directives from management, along with a driving force within the company and training initiatives • Incentives for design adjustments (overcapacity, FHG through storage, etc.) and input for funding programs	Implementation
TSO-DSO bid filtering process has been developed and implemented	• Non-linearities of the distribution grid (e.g. from grid control mechanisms) need to be fully incorporated • Information from industrial enterprises on their ability to adjust reactive power could be included in the method of the bid filtering process	Implementation and Scientific
Identification of trilemma between transparency, accuracy, and confidentiality, with different stakeholders having varying interests, ultimately resulting in the grid filter developed in I4RD.	• Uniform guidelines could help to standardize the identification of critical network elements.	Regulatory
Regulatory analysis has been carried out and adjustments were identified	• New ElWG (Elektrizitätswirtschaftsgesetz – Electricity Market Law) is currently pending and needs to be approved by the relevant authorities	Regulatory
Evaluation of suitability of different remuneration models for Austria	• Regulatory changes concerning non-cost-based remuneration component in Austrian law is required	Regulatory

References

[1] R. Hemm, T. Esterl, H. Brunner. S. Henein, C. Monsberger, S. Wimmeder, G. Seithanova, B. Herndler, S. Knöttner, A. Glatt, F. Hembach, V. Sequeira-Taxer, „Industry4Redispatch Deliverable 3.1 – Current and New Business Models of Industrial Customers as Grid Service Providers and Their Associated Incentives“, 10. Januar 2025, *NEFI*. Zugegriffen: 12. Februar 2025. [Online]. Verfügbar unter: https://zenodo.org/records/14628519

[2] „Entwurf 2024-01-10 Bundesgesetz zur Regelung der Elektrizitätswirtschaft (Elektrizitätswirtschaftsgesetz – ElWG)“. Zugegriffen: 12. Februar 2025. [Online]. Verfügbar unter: https://www.ris.bka.gv.at/Dokumente/Begut/BEGUT_98A64318_7EC0_4A83_9396_B69707E01C9D/BEGUT_98A64318_7EC0_4A83_9396_B69707E01C9D.html

[3] Hembach, F., Glatt, A., Sequeira-Taxer, V., Fuchs, E., Fanta, S., Hemm, R., Zobernig, V., „Industry4Redispatch Deliverable 3.3 Definition of Processes for the Provision of Redispatch“, 10. Januar 2025, *NEFI*. Zugegriffen: 12. Februar 2025. [Online]. Verfügbar unter: https://doi.org/10.5281/zenodo.14628647

[4] Traninger, M., Knöttner, S., Schützenhofer, C., Teufner-Kabas, M., Teufner, F., Hembach, F., Sequeira-Taxer, V., „Industry4Redispatch Deliverable 3.4 - Estimated Industrial Redispatch Potential“, 10. Januar 2025, *NEFI*. Zugegriffen: 12. Februar 2025. [Online]. Verfügbar unter: https://doi.org/10.5281/zenodo.14627931

[5] „Keynote speech by Simson at Smart Energy Europe event“, European Commission - European Commission. Zugegriffen: 12. Februar 2025. [Online]. Verfügbar unter: https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_24_2991

[6] V. Grimm, A. Martin, C. Sölch, M. Weibelzahl, G. Zöttl, „Market-Based Redispatch May Result in Inefficient Dispatch“. Zugegriffen: 12. Februar 2025. [Online]. Verfügbar unter: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3120403

[7] L. Hirth und I. Schlecht, „Market-Based Redispatch in Zonal Electricity Markets: Inc-Dec Gaming as a Consequence of Inconsistent Power Market Design (not Market Power)“.

[8] „konzepte-fuer-redispatch.pdf“. Zugegriffen: 12. Februar 2025. [Online]. Verfügbar unter: https://www.bmwk.de/Redaktion/DE/Publikationen/Studien/konzepte-fuer-redispatch.pdf?__blob=publicationFile&v=

[9] K. Poplavskaya, J. Lago, und L. de Vries, „Effect of market design on strategic bidding behavior: Model-based analysis of European electricity balancing markets“, *Applied Energy*, Bd. 270, S. 115130, Juli 2020, doi: 10.1016/j.apenergy.2020.115130.

[10] *Elektrizitätswirtschafts- und -organisationsgesetz 2010 - ElWOG 2010*. [Online]. Verfügbar unter: https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=20007045

[11] F. Hembach, V. Sequeira-Taxer, S. Fanta, V. Zobernig, K. Poplavskaya, T. Gaal, G. Taljan, E. Zlabinger, L. Derler, „Industry4Redispatch Deliverable 3.2 – Regulatory Analysis“, 10. Januar 2025, *NEFI*. Zugegriffen: 12. Februar 2025. [Online]. Verfügbar unter: https://zenodo.org/records/14628594

[12] European Commission, *Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a guideline on capacity allocation and congestion management*. 2015, S. 24–72.

[13] *Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (Text with EEA relevance.)*, Bd. 158. 2019. Zugegriffen: 25. Januar 2022. [Online]. Verfügbar unter: http://data.europa.eu/eli/reg/2019/943/oj/eng

[14] T. Esterl, A. Zegers, J. Spreitzhofer, G. Totschnig, S. Knöttner, S. Strömer, S. Übermasser, F. Leimgruber, H. Brunner, R. Schwalbe, D. Suna, G. Resch, F. Schöniger, S. von Roon, T. Hübner, K. Ganz, F. Veitengruber, L. Freiberger, A. Djamali, „Flexibilitätsangebot und -nachfrage im Elektrizitätssystem Österreichs 2020/2030", 7. Februar 2022. Zugegriffen: 2. November 2022. [Online]. Verfügbar unter: https://www.e-control.at/documents/1785851/1811582/20220207_Flexibilitaetsstudie_Bericht_FINAL.pdf/244c4f3c-c8a2-1114-c287-6d6b81d07817?t=1650436768857