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Energiezelle „JOHANN“

Final Report

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“ENERGY CELL JOHANN”

Energy Cell “JOHANN” – seasonal storage technology with multi-modal and multi-functional applications

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2. Executive Summary

The "Energy Cell Johann": A Breakthrough in Hydrogen Storage Technology in the Context of the Energy Transition

In times when the urgency of climate change is ever increasing, the quest for sustainable energy sources and solutions becomes paramount. The transition from fossil fuels to renewable energies is underway, and the energy transition offers us the opportunity to respect our planetary boundaries while maintaining our quality of life and technological progress. However, renewable energy sources like wind and solar are not always available – they are inherently intermittent. This is where the significance of energy storage comes into play.

Energy storage systems can be likened to the "Swiss Army knife" of the energy transition. They help balance the irregular flow of renewable energies and ensure that power is available even when the sun isn’t shining or the wind isn’t blowing. But not all energy storage solutions are created equal. While battery technologies are making rapid strides, storing energy in the form of hydrogen is a promising arena that has the potential to radically alter the way we store and use energy.

In this context, we introduce the "Energy Cell Johann" – a groundbreaking technology based on hydrogen. This novel cell promises not only high energy density but also efficiency, longevity, and safety in its application. Named after Johann, the visionary Archduke of Styria, this innovative product holds the promise of revolutionizing our energy storage capabilities.

The "Energy Cell Johann" could be the bridge effectively linking renewable energy sources and our everyday energy needs. By harnessing the power of hydrogen, we may enter an era where clean, green energy is not only generated but also efficiently stored and retrieved on demand.

This research marks another step towards a more sustainable, cleaner, and efficient energy future for all of us. It is not just a matter of technology, but also a testament to human ingenuity and the desire to preserve our planet for future generations.

3. Introduction

Within this chapter a brief introduction into the main content and challenges is given and the applied overall methodology is explained. Furthermore, a first indication and the structure of the work is included.

The logic of this research project follows, on the one hand, the progressive technology development by the provider and consortium partner, EEG Elements Energy GmbH, combined with the demonstration of three different use cases with end customers and in collaboration with energy providers (Energie Steiermark AG, EW Bad Radkersburg GmbH, and Burgenland Energie AG). In addition, the two research partners (TU Vienna and Joanneum Research) address the defined research questions. In the interplay of all activities, this project bridges the gap between research and economy, and the Energy Cell Johann will be ready for market launch.

a. Focal points of the project

The focus points of the project are also reflected in the project structure. In the area of technology development, the goal is to increase the TRL 4/5 (project start) to 8/9 (project end), and in addition, the interfaces as well as the software algorithms have to be adapted to the specific demonstrators. For the three planned demonstrators, in addition to the need for optimal customer integration, there is also the challenge regarding the necessary official approvals. The research questions are based on the areas of "technology assessment and expected impact." Furthermore, care is taken to coordinate well with the overarching flagship region "Green Energy Lab" and to leverage any synergies with other R&D projects of this initiative.

b. Placement in the Programme

The project addresses the following program objectives:

- Development and model use of local energy and energy-related transport technologies for the large-scale field testing of intelligent system solutions in live operation
- Strengthening and developing Austria as a lead market for innovative energy and energy-related transport technologies and services
- Involvement and active participation of users

c. Overall methodology

The methods used serve to achieve the project objectives and are thematically structured as follows:

- (certified) Project Management

- Technology Development (Customer-focused development; simulation modeling; technical research and hardware design; design sprints)
- Implementation / Demonstration (Design thinking and lean startup approach, Business incubation (proof of concept, field trial, interview techniques relating to customer satisfaction including acceptance of technology), Business model canvas)
- Research (Technology assessment, macroeconomic modeling, global value chains, life cycle assessment. Evaluation and calculations, Life Cycle Analysis, Model-based macroeconomic analysis)

d. Structure of the work

This report documents the essential contents, results, and conclusions of the research project "Energy Cell Johann". The individual sections also reflect the different perspectives (technology, economy/demonstration, and research), meaning they are structured according to the work packages of the project.

4. Content presentation

a. Implementation (use cases)

In the first step, detailed planning for the three use cases was created. The basis for this planning was a template to record the exact requirements for the locations and the installation.

- Farm yard (lower austria)

In Pischelsdorf in Lower Austria there is an old and dilapidated farm, which in the future will serve as a center and meeting point for the owner family. For this purpose, the farm will be completely revitalized and equipped with a new heating and energy system in order to be prepared for the changes in the energy market. Because of the unsteady use of the Farm, the initial situation arises, that sometimes over longer periods of time (up to 2 months) there is a very low demand for heat and electricity, which increases sharply during the periods when it is used.

Figure 01: Line-up of the energy cell Johann at the farm yard in Pischelsdorf (Lower Austria)

- Riding stable (Burgenland)

Burgenland Energie operates a PV system with a total output of 170.2 kWp on the roof of the riding hall including the stable. The roof area was rented for this purpose. During the day, hay is steamed for the horses twice for two hours each time. The power of the evaporator is about 6000W. In winter, among other things, the horse troughs are heated with heating cables to prevent them from freezing, so that a constant supply of water is guaranteed, and watering system is not damaged.
Furthermore, the stored energy produced by the PV system during the day could be used for the riding hall and the entire system lighting, as these are mainly used in winter from 4 pm to about 9 pm and in summer from 7 pm to about 10 pm and represent a very high proportion of the energy requirement of the riding stable. In bad weather conditions, the lighting is already operated from 6 o'clock until the daylight is sufficiently bright. A saltwater chamber with oxygen ionizer is additionally operated in summer. With the waste heat of the energy cell, the large tack room can be heated, so that this energy source is used efficiently, as well.

Figure 02: Overview, Usecase "riding stable" (Burgenland)

- School (Styria)

For the use case in Bad Radkersburg an energy cell of the type JOHANN will be installed in the area of the garbage yard of the HTL in order to buffer the PV power surplus of the existing photovoltaic system. At the same time, projects with the classes of the HTL can be carried out with the help of the energy storage unit in order to gain knowledge about economic efficiency and self-sufficiency.
In preparation for implementation, the first two systems (JOHANN energy cells) were delivered in spring 2022 and the installation was prepared. Unfortunately, the implementation and monitoring of the energy cell Johann could not be finished in accordance with the application. This is due to the fact that official approval for the installation of the three Johanns had not been granted by the end of the project.

Figure 03: Line-up of the energy cell Johann at the school in Bad Radkersburg, Styria

A significant part of the implementation was therefore also the subsequent considerations regarding suitable business models. The Business Model Canvas is a management tool for the visualization and analysis of a business model. It was developed by Alexander Osterwalder and Yves Pigneur in 2010 and published in the book Business Model Generation. The concept is based on the idea of systematically collecting all the elements that characterize a business model on a canvas and thus showing how they interact and create added value.

Key Partners	Key Resources	Value Proposition	Customer Relationship	Customer Segment
Which partner do I need to sell my product? Suppliers of hydrogen and for storage material in general Providers of PV systems, Electricity providers → for packages, service performance, as well as the application of storage Authorities (standardized procedure, preparation e.g. provide reference ("it was made in this and that way") Network operator/-Partner- Smart Meter, Data evaluation Shipment/installation/ maintenance	*What resources do I need?* Necessary resources for storage itself Staff that is familiar with official channels/permits e.g. guidelines (for this we offer- fill in assistance, what you need, Counseling center (staff) Staff for installation Staff for maintenance *(Maintenance contract- 24h contract)*	*Which additional value do I offer to my customers?* Storage of electrical energy provisioning in the form of electricity and heat **(USP= Provision in both forms)** Both short term and long-term storage e.g., a long-lasting emergency power supply (i.e. leave a certain current share) Storage of solar power (increase of own use, CO2 entrenchment) Grid optimization (possibly combined with SmartMeter) Divide self-sufficiency into small parts → Security of supply Through higher self interest in solar power or mains current at lower rates savings opportunity (realistic because of scaling?) Offer other products apart from the storage itself: • Initial consultation: how can I convert storage? • Storage usage as a service (license) • Service package for everything that has to do with storage (installation, maintenance, administrative channels etc. - combinable as needed)	*What relationship do I have towards my clients?* Service oriented model creates customer loyalty and removes inhibitions (as a provider I am also the contact person in the office) Customer loyalty – by means of maintenance contract - Remote maintenance (real time monitoring) Every 3 years the hydrogen bottles must be checked - Duty!	*For which customers do I generate added value?* 4 application areas (see pilots) • Apartment building or one family building • KMU • Public buildings (community schools) • Agricultural businesses
	Key Activities *Which activities are necessary to make the added value available?* Find partners who can take over installation/maintenance, combination with the PV systems or services and advertise the storage system in combination with the respective products.		**Channels** *How do I reach my customers?* Up till now only dircet marketing is considered → through complicated administrative channels, effort and lack of awareness difficult, therefor: • Cooperation with distributors from PV • Over electricity providers (service package) • Bring key partners with on board (planned for later) • Offer at trade fairs Then reach to the market	

Cost Structure	Revenue Streams
Investment cost for the storage itself Running cost for the firm Cost for installation (Foundation, fences and delivery) Staff/ Work for Service packages	The principal source of income: sale of storage Service packages, installation, etc. as a package or license model (storage remains property of the company, maybe leasing or hire purchasing)

Figure 04: Business Model Canvas (Overview)

b. Development of Technology and Optimization

The JOHANN energy storage system is a very complex system that can only be operated efficiently and effectively if not only a large number of technical components are perfectly coordinated with each other, but also and above all, if the software components and controls are specifically designed for the individual hardware components. The challenge of the technology development and optimization was thus to identify, implement and successively optimize different optimization options of the individual hardware and software components of the existing JOHANN energy storage system - not only singularly, but in their complex interaction for the three use cases carried out in the project. Due to the complexity of the systems and the variety of parameters involved, these optimizations had to be carried out in an iterative process, in which a "trial and error" approach had to be adopted in some cases, since the improvement of one parameter often led to a barely predictable deterioration of another parameter. Also, these optimizations were to be carried out primarily with the help of the experience and data generated in live operation of the use cases, although considerable challenges arose in this area in particular due to the technical, economic and legal framework conditions.

Essentially, the interdisciplinary project team was confronted with two different challenges in solving the technology development and optimization - namely legal organizational issues and technical challenges. On the one hand, the very cost-intensive and slow progress of the legal approval process for the H2 plants not only led to severe delays and unexpected additional expenses in the project schedule, but also to necessary restructuring in the entire project process, since the installation of individual use cases was not approved during the project period. Therefore, one system had to be installed at EEG on a trial basis instead, in order to be able to implement the corresponding HW and SW optimizations on a test basis and optimize them step by step.

On the other hand, the project team had to deal with the effects of massive dislocations in the global supply chains throughout the project duration, which were an effect of the global Corona pandemic and which unfortunately are still not yet completely resolved. Procurement of components (for example, electrolysis, graphite components for the fuel cells, etc.), which are essential for the JOHANN energy storage system, has been virtually impossible for extended periods of time since early 2022 due to limited global material and component availability, resulting in significant project delays and necessary adjustments to project sub-objectives in parts of the overall concept.

Despite all these challenges, it was required to implement a large number of technical optimizations to the main components of the JOHANN energy storage system during the development of this work package. These were mainly optimizations in the electrolysis (new technical processes, materials and tests with standard solutions offered on the market) and the fuel cell (material tests, durability tests, further development of standard solutions). But also the whole frame of the JOHANN energy storage system was completely renewed and the overall system was optimized with regard to the interaction of all components. These optimizations are reflected above all in the quality-relevant and customer-perceivable aspects of longevity, ease of maintenance and operability. On the other hand, the interaction of the individual components was significantly improved by a wide variety of hardware and software optimization measures, which, although not directly perceptible by the customer, is reflected in a greatly improved overall efficiency of the JOHANN energy storage system.

As already mentioned, a major focus of the project, in addition to the optimization of the physical-technical components, was on SW-specific adjustments and the optimization of the energy storage algorithm (task: optimization of the storage strategy algorithm). For this purpose, on the one hand, real-time data of the plants in operation were recorded and evaluated with the aim of creating an individualized software that checks and, in the best case, verifies the created rules of the new algorithm in several hundred scenarios. On the other hand, due to the limited availability of actual data as not all use cases could be installed on site, the optimization of the JOHANN control system in some cases had to rely more on theoretical data and simulations. Based on all these data and simulations, the software was completely revised and optimized, with the result that the described software now uses various data (e.g. annual electricity demand, load profile, power of the photovoltaic system or annual heat demand) to analyse and check, which kind of influence an energy storage JOHANN has on the defined system. The result is finally output either clearly in the form of a multi-part diagram or the corresponding individual data. The SW optimizations and changes to the algorithm were also carried out in a multiple iterative process, so that an "optimal solution" could finally be achieved. An example of such an optimized solution is the optimization in the area of “peak load management”, which compensates for occurring load peaks much more efficiently without much additional effort. As already mentioned, in order to implement these optimizations, complex technical changes and adaptations had to be made to the control logic and, in part, to the hardware and the respective system interfaces of the JOHANN energy storage system (task: implementation of interfaces and missing features).

In the course of the project the use of the JOHANN test system and several simulations showed that there are not only weaknesses in the control system and the algorithm of the JOHANN energy storage system, but also that the transparency and visualization of the processed data and the data output require substantial revision and optimization. These points could also be solved within the scope of the project execution, whereby the JOHANN energy storage system has also developed in the customer perception from a technically complicated special solution to a customer-friendly usable energy storage system. In order to be able to implement all these requirements in terms of system optimization, user-friendliness, visualization and the optimum interaction of the hardware and software components in the best possible way, it was necessary not only to change the logic, but also to adapt the control panel, which was therefore completely rebuilt.

In the adaptations made during the project, particular attention was paid to the aspects of "extensive standardization", "modularity" and "simplicity" (i.e. solving technical challenges as simply as possible without compromising the scope and quality of the technical solution) with a view to later suitability for series production and simple producibility. As a result, the project carried out by all project partners and also the consideration of the results of all work packages brought the JOHANN energy storage system a big step closer to a widely applicable series product.

All the experience gained from all the work packages of all the project partners in the course of the project in this very complex project environment of technical, economic, customer-relevant, legal, energy-technical framework conditions was - as already mentioned - integrated step by step into the product, verified or falsified and further optimized in an iterative process. This iterative procedure and the close cooperation of product and system development with the operational users ensured fast and targeted work, whereby care was taken from the outset with each further development and optimization step to ensure that these optimizations were not only in line with a possible future technical-organizational production concept for series production (task: optimize production process and prepare for mass deployment), but also that the software-supported production steps "software installation", "testing" and "commissioning" were taken into account accordingly at an early stage.

c. Technology assessment and expected impacts

This chapter describes the methodology used in the simulations, providing the mathematical formulation of the considered optimization models. Furthermore, the input data is shown to evaluate the effects of a JOHANN installation for different customer types, the optimal operation of the energy cell JOHANN and possibly other end user technologies is determined in linear optimization models with a time frame of one year and a time resolution of 15 minutes.

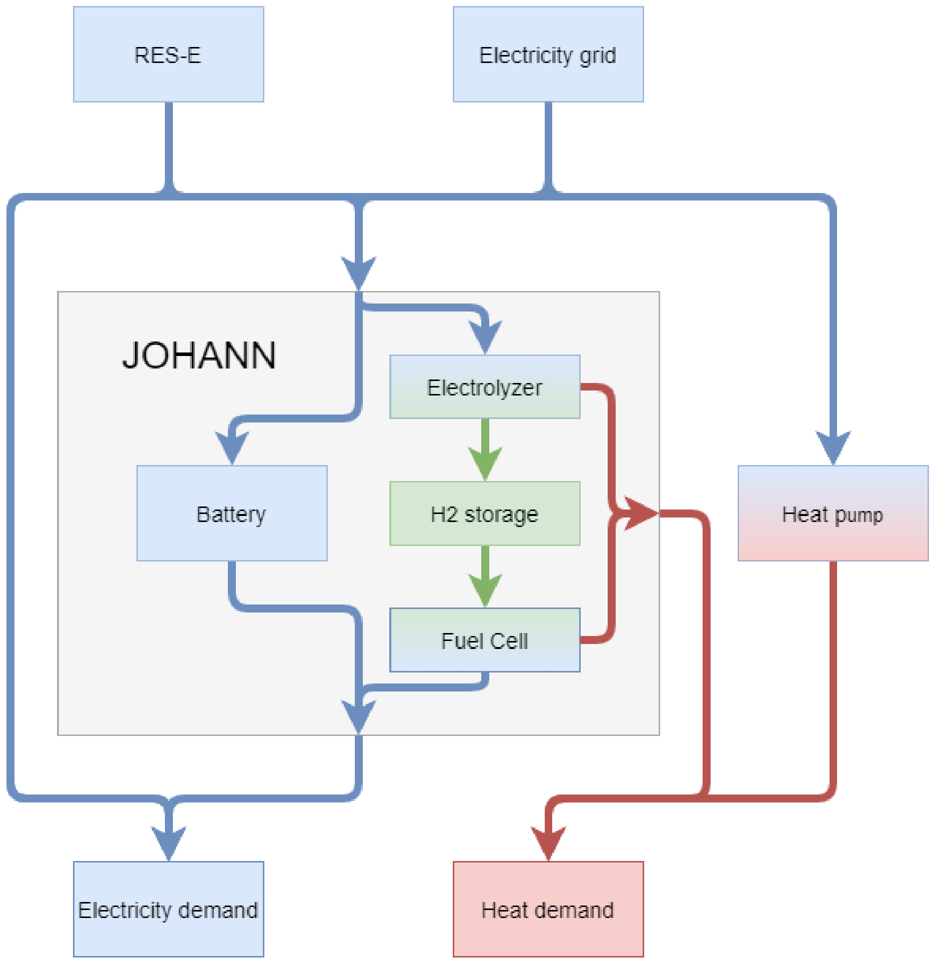

Figure 05: Flowchart of the processes depicted in the JOHANN optimization models

JOHANN can consume electricity and use it to charge the battery for short-term storage or convert it to hydrogen using an electrolyzer and store it in the H2 storage. Conversely it can discharge the battery to output electricity or use hydrogen to operate a fuel cell and provide electricity. During the conversion between electricity and hydrogen there are thermal losses that can be used to cover heat demand.

The aim of the work was to examine the potential benefits that JOHANN can provide for different customer types. This requires the definition of the customer types that are to be analysed. It is reasonable not to choose arbitrary customer types but to select sensible use cases where JOHANN offers a value proposition. To this end, first a sensitivity analysis is conducted using the optimization model presented above. In this sensitivity analysis the customer's annual electricity and heat procurement is optimized with

and without the energy cell JOHANN with varying parameters for the annual electricity demand, the annual heat demand and the installed PV system's nominal capacity.
The implementation of the corresponding optimization models requires time series data for the electricity and heat demand the PV production and the coefficient of performance (COP) of the heat pump. For the electricity load the standard household load profile (H0) for the year 2020 of Austrian Power Clearing & Settlement AG (APCS) is used. The profiles for PV production are retrieved from renewables.ninja with the coordinates for Vienna. For the heat demand and the COP of the heat pump, results from the When2Heat project for Austria are used. For the heat demand the profile of a single-family household and for the COP the profile of an air-sourced heat pump was chosen. The respective normalized load profiles for electricity demand, heat demand and PV production are illustrated for five days in May 2020 in Figure 2.

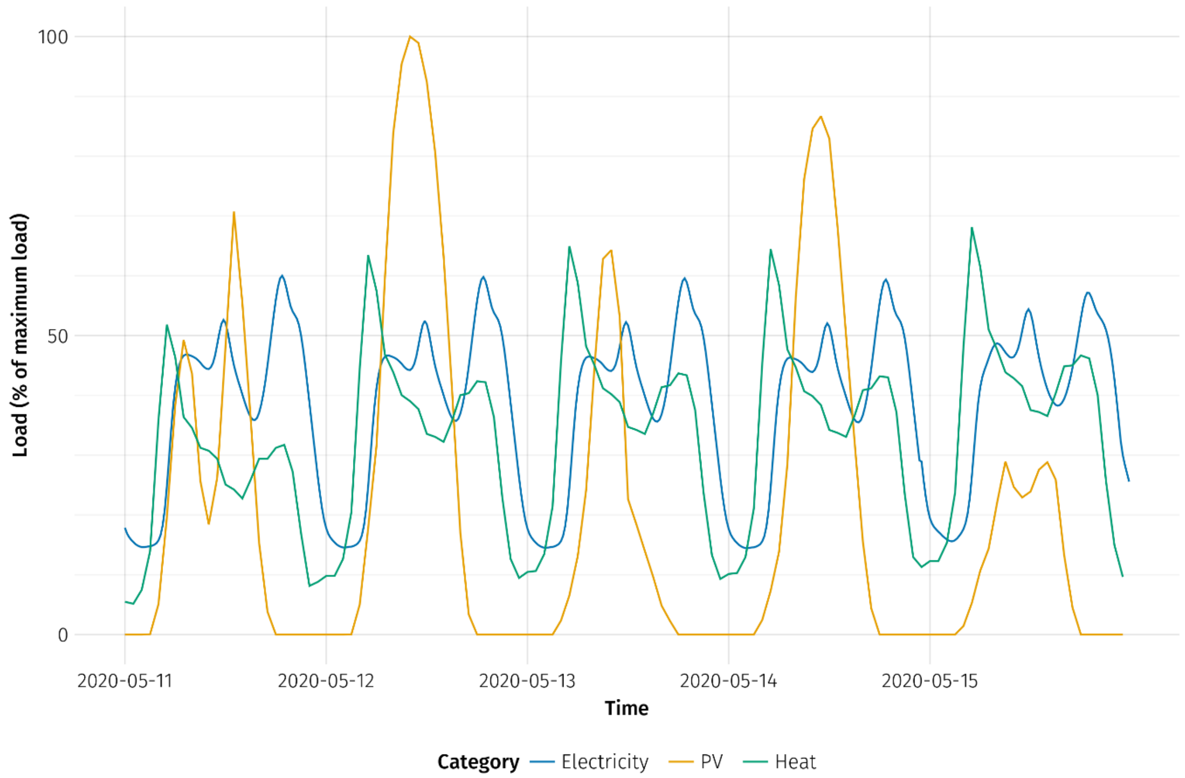

Figure 06: Normalized electricity demand, head demand and PV production profiles during five days in May 2020

Furthermore, cost assumptions regarding the electricity tariffs are required to set-up the optimization models. The end user electricity bill typically consists of three components. One part is the energy tariff paid to the energy supplier. Another part is the grid tariff paid to the system operator and the third part are fees and taxes. For the energy supply tariff, the hourly day-ahead spot market prices of the year 2020, retrieved from the ENTSOE Transparency Platform[1], are weighted with the H0 electricity load profile. The resulting price is offset by a profit margin of 3 ct/kWh for the energy supplier. The hourly market prices are weighted with the PV production profile to get the feed-in tariff. For the grid tariff, the grid usage charge

[1] https://transparency.entsoe.eu/, accessed in April 2023

and the grid loss charge for the year 2020[2] for Styria are assumed. The fees and taxes consist of the green electricity flat rate[3] (Ökostrompauschale), the green electricity subsidy[4] (Ökostromförderbeitrag) and the value added tax (VAT). The resulting tariff components used in the technology evaluation are listed in Table 1.

	ANNUAL COMPONENT	VOLUMETRIC COMPONENT
SUPPLY TARIFF	50.00 EUR	6.53 ct/kWh
GRID TARIFF	64.80 EUR	5.24 ct/kWh
FEES & TAXES	66.30 EUR	5.56 ct/kWh
TOTAL	181.10 EUR	17.33 ct/kWh
FEED-IN TARIFF		3.03 ct/kWh

Table 01: Tariff assumptions for the JOHANN technology evaluation

Next, the chosen load profiles are scaled to specific annual or maximal values. The time series for PV production is scaled to nominal capacities of 0 kW to 25 kW in steps of 5 kW. For the annual electricity demand values from 5 MWh to 30 MWh in steps of 5 MWh are considered. Similarly, the heat demand profile is scaled to an annual consumption of 0 MWh to 25 MWh. Hence, there are six different values for each of the three sensitivity parameters.

New market price scenario the prices from the year 2021 are selected. On average, these prices are significantly higher than for the year 2020. Furthermore, hourly prices from model results using the EDisOn[5] model for the years 2030 and 2040 based on the National Trends scenario of the ENTSO-E Ten Year Network Development Plan 2022[6] (TYNDP2022) are considered

The resulting volumetric energy prices are illustrated in Figure 3. The top plot shows the total energy buying price including the grid tariff, fees and taxes. The bottom plot shows the energy selling price or the feed-in tariff. Both increase in all new energy price scenarios and are significantly higher for the year 2040.

[2] https://www.ris.bka.gv.at/Dokumente/BgblAuth/BGBLA_2019_II_424/BGBLA_2019_II_424.html, acessed in April 2023
[3] https://www.ris.bka.gv.at/Dokumente/BgblAuth/BGBLA_2017_II_382/BGBLA_2017_II_382.html, accessed in April 2023
[4] https://www.ris.bka.gv.at/Dokumente/BgblAuth/BGBLA_2019_II_426/BGBLA_2019_II_426.html, accessed in April 2023
[5] Bettina Dallinger, Model-based analysis and design of an improved European electricity market with high shares of renewable generation technologies, https://doi.org/10.34726/hss.2018.25254, accessed in May 2023
[6] https://tyndp.entsoe.eu/, accessed in May 2023

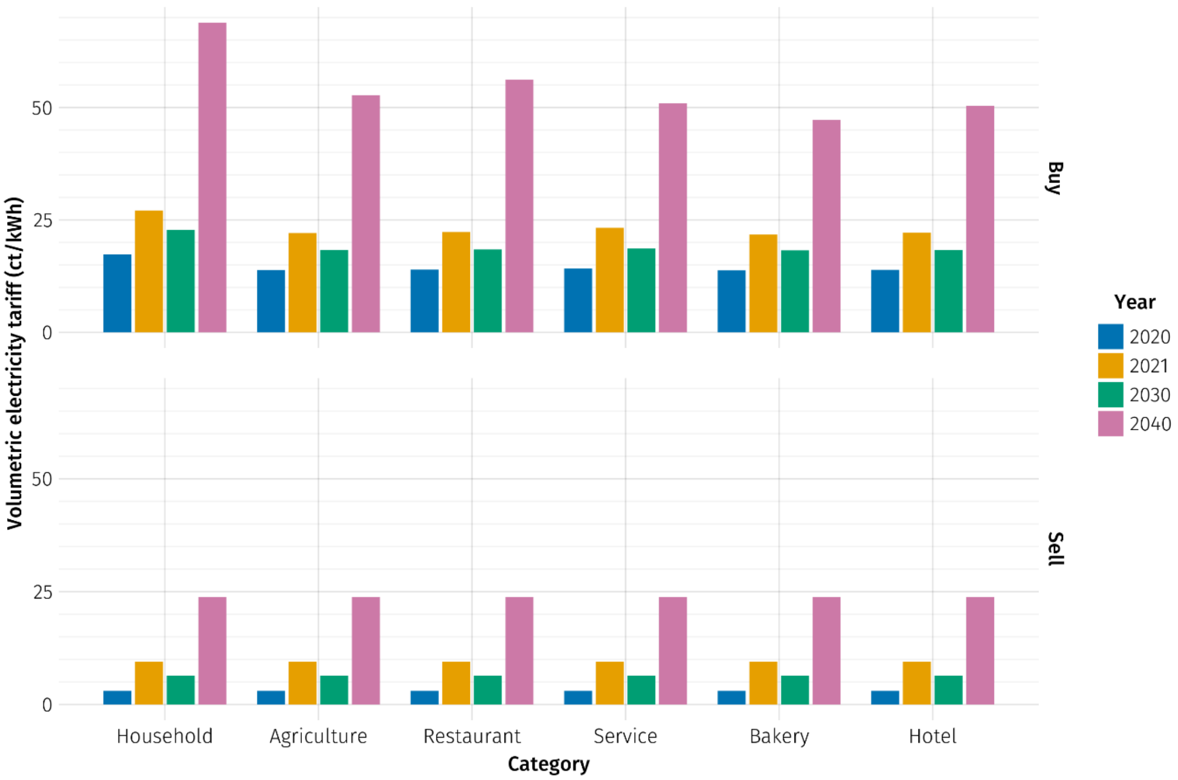

Figure 07: Volumetric electricity supply and feed-in tariff for different years and customer types

d. Economic impact assessment

To evaluate the economic impacts of the Johann Energy Cell we applied the multiregional input-output model Globe-IO. The model is calibrated to the latest IOT dataset of the OECD (2021ed). It comprises 66 countries plus one aggregate for all other countries and 45 sector aggregates. Based on this data, global interlinkages in production can be analysed in form of global value chains. This allows to trace economic impacts from its origin via different production stages and different countries. As the Johann energy cell is still under development, the analysis draws on data on the latest setup of the energy cell (as of June 2023). This includes the structure and origin of intermediary inputs as well as business data on expected revenues, costs and profits for a realistic roll-out scenario. Additionally we made use of recent literature and secondary data on investment costs for alternative configurations.

Figure 20 shows the needed investments per use case and configuration. The investment costs have a clearly ascending order, since the configurations always represent extensions of the previous ones. Due to their high energy demand the use case “Hotel” and “Bakery” show the highest investment costs.

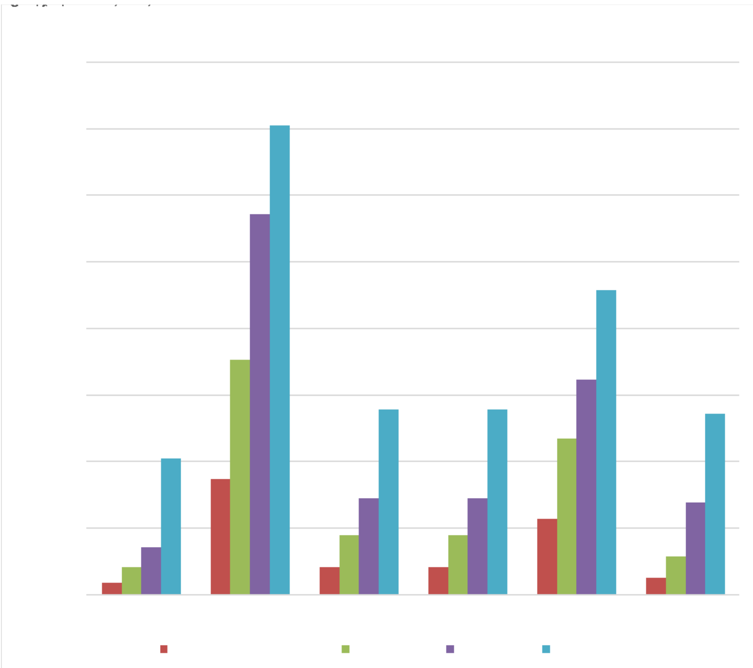

Figure 08: Investment costs per use case and configuration. Source: own calculations.

Investment demand as well as differences in operational costs and revenues affect aggregated demand within the economy. For the production of the Johann energy cell detailed data is used to assign demand for intermediary inputs to industries and countries. For the evaluation of the Johann energy cell among the different configurations and use cases, we focused on impacts on value added and employment as key performance indicators. The model-based approach allows the consideration of direct, indirect and induced economic impacts. Direct impacts are directly linked to the economic impulse. Indirect impacts are generated by the demand for intermediary inputs for the production of goods and services. Induced effects come from changed consumer demand due to changes in household income.

e. Life Cycle Assessment

The goal of the life cycle assessment (LCA) was to analyse the GHG-emissions of the Johann energy cell within different use cases and the comparison to several alternative configurations. This should create a basis for evaluating the environmental performance of the Johann energy cell and to identify conditions under which the Johann energy cell can be advantageous from an environmental perspective. Therefore, a LCA was carried out in order to answer the research questions. The focus of the LCA was the potential effect on global warming due to the manufacture and use of the Johann energy cell in comparison to three other technological solutions and in six different use cases.

To identify the major environmental hotspots in the life cycle of the Johann energy cell, the components of the energy cell were first analysed, and the GHG-emissions connected to the individual materials and the production phase were determined. This allows the producers of the Johann system to identify potential improvements. Furthermore, the results of this first GHG-balance were used in the second assessment, where the Johann system was analysed in four different use cases and compared to alternative energy supply systems. Thereby, it was possible to judge on the potential ecological benefits of the different energy supply systems. The scope of the study includes the GHG-emission of the devices used in the different configurations as well as GHG-emissions that occur during their use-phase.

The results indicate significantly reduced GHG-emissions of the JOHANN system compared to fossil-based systems. In comparison of JOHANN to other renewable systems the relative difference varies, depending on the electricity and heat demand in the use cases, the GHG-intensity of the consumed electricity from the grid and future storage developments at the grid level. Overall, the JOHANN energy cell shows potential for lowering GHG-emissions, despite relatively high GHG-emissions during its production phase.

5. Results and conclusions

a. Implementation – Business Models

To estimate the annual savings potential in the Johann project, the annual electricity requirement of a single-family house with different heating requirements (HWB) and different PV systems was taken into account

- once with a PV system and heat pump

- once with a PV system, heat pump and hydrogen storage/battery storage (Johann)

Calculation with JOHANN			**Calculation without JOHANN**		
Energy demand electricity	5000	kWh	Energy demand electricity	5000	kWh
Energy demand electricity for heat pump	4333	kWh	Energy demand electricity for heat pump	4333	kWh
Energy denmand standby storage	525	kWh	Energy denmand standby storage	0	kWh
Total energy demand	**9858**	**kWh**	**Total energy demand**	**9333**	**kWh**
PV power	**22000**	**kWh**	**PV power**	**22000**	**kWh**
PV own consumption 30%	6600	kWh	PV own consumption 30%	6600	kWh
PV surplus 70%	15400	kWh	PV surplus 70%	15400	kWh
from surplus	**15400**	**kWh**	**from surplus**	**15400**	**kWh**
Grid feed 35%	5390	kWh	Grid feed 100%	15400	kWh
H2 storage 35%	5390	kWh			
Battery storage 30%	4620	kWh			
Recovery from storage	**6868,4**	kWh	**Recovery from storage**	0	kWh
Battery storage efficiency 95%	4389	kWh	Battery storage efficiency 95%	0	kWh
H2 storage efficiency 46% without waste heat	2479,4	kWh	H2 storage efficiency 46% without waste heat	0	kWh
H2 storage waste heat 32% of gross storage volume	3203,2	kWh	H2 storage waste heat 32% of gross storage volume	0	kWh
Recovery waste heat 72%	2306,3	kWh	Recovery waste heat 72%	0	kWh
Total energy for coverage energy demand	**13468**	**kWh**	**Total energy for coverage energy demand**	**6600**	**kWh**
Coverage of total energy demand	**9858**	kWh	**Coverage of total energy demand**	**9333**	kWh
from own use PV	6600	kWh	from own use PV	6600	kWh
from recovery storage	6868,4	kWh	from recovery storage	0	kWh
Balance	-3610	kWh	Balance	2733	kWh
Annual electricity cost savings with JOHANN	**2747,4**	**EUR**	**Annual electricity cost savings with JOHANN**	**0**	**EUR**
Without use of waste heat			Without use of waste heat		
PV feed	9000	kWh	PV feed	15400	kWh
Annual feed-in tariff with JOHANN	**1350,00**	**EUR**	**Annual feed-in tariff with JOHANN**	**2310**	**EUR**
Total	**4097,36**	**EUR**	**Total**	**2310**	**EUR**
Savings from Johann	**1787,36**	**EUR**			
Efficiency without use of waste heat	68,62	%	Total feed-in storage	10010	kWh
Efficiency with use of waste heat	91,66	%	Recovery storage without waste heat	6868	kWh
			Recovery storage with waste heat	9175	kWh

Figure 09: Savings opportunity Johann, high energy requirment, PV 20 kWp

Calculation with JOHANN		**Calculation without JOHANN**	
Energy demand electricity	5000 kWh	Energy demand electricity	5000 kWh
Energy demand electricity for heat pump	4333 kWh	Energy demand electricity for heat pump	4333 kWh
Energy denmand standby storage	525 kWh	Energy denmand standby storage	0 kWh
Total energy demand	**9858 kWh**	**Total energy demand**	**9333 kWh**
PV power	**5500 kWh**	**PV power**	**5500 kWh**
PV own consumption 30%	1650 kWh	PV own consumption 30%	1650 kWh
PV surplus 70%	3850 kWh	PV surplus 70%	3850 kWh
from surplus	**3850 kWh**	**from surplus**	**3850 kWh**
Grid feed 35%	1347,5 kWh	Grid feed 100%	3850 kWh
H2 storage 35%	1347,5 kWh		
Battery storage 30%	1155 kWh		
Recovery from storage	**1717,1 kWh**	**Recovery from storage**	0 kWh
Battery storage efficiency 95%	1097,3 kWh	Battery storage efficiency 95%	0 kWh
H2 storage efficiency 46% without waste heat	619,85 kWh	H2 storage efficiency 46% without waste heat	0 kWh
H2 storage waste heat 32% of gross storage volume	800,8 kWh	H2 storage waste heat 32% of gross storage volume	0 kWh
Recovery waste heat 72%	576,58 kWh	Recovery waste heat 72%	0 kWh
Total energy for coverage energy demand	**3367,1 kWh**	**Total energy for coverage energy demand**	**1650 kWh**
Coverage of total energy demand	9858 kWh	**Coverage of total energy demand**	9333 kWh
from own use PV	1650 kWh	from own use PV	1650 kWh
from recovery storage	1717,1 kWh	from recovery storage	0 kWh
Balance	6491 kWh	Balance	7683 kWh
Annual electricity cost savings with JOHANN	**686,84 EUR**	**Annual electricity cost savings with JOHANN**	**0 EUR**
Without use of waste heat		Without use of waste heat	
PV feed	1348 kWh	PV feed	3850 kWh
Annual feed-in tariff with JOHANN	**202,13 EUR**	**Annual feed-in tariff with JOHANN**	**577,5 EUR**
Total	**888,97 EUR**	**Total**	**577,5 EUR**
Savings from Johann	**311,47 EUR**		
Efficiency without use of waste heat	68,62 %	Total feed-in storage	2503 kWh
Efficiency with use of waste heat	91,66 %	Recovery storage without waste heat	1717 kWh
		Recovery storage with waste heat	2294 kWh

Figure 10: Savings opportunity Johann, high energy requirment, PV 5 kWp

With regard to energy costs and feed-in revenues, the amount of photovoltaic production in relation to the energy requirement, the size of the hydrogen storage and the specific energy consumption profile are relevant. The greater the PV output and storage and the higher the energy requirement, the greater the savings opportunities. The use of the resulting waste heat has an advantageous effect (however, this was not taken into account in the calculation). The high energy price also contributes to higher savings potential. An additional advantage could arise if the distribution network is no longer able to absorb the surplus production of PV electricity at any time in the future or if the feed-in tariffs fall to 0 euros. The level of autarky can be greatly increased by using Johann (in certain cases up to 100%). Due to the design of the cell, larger storage volumes would also be possible, which would also enable seasonal storage use cases.

b. Development of Technology and Optimization

With regard to the individual works carried out within the framework of this Workpage, the following concrete results could be achieved:

Optimization of the HW-components and the overall system of the energy cell JOHANN

Electrolysis:

- Raw material selection and vertical range of manufacture
- Lifetime and efficiency
- Integration into overall system (modularity, standardization, usability, flexibility)

Fuel cell:

- Further development and integration of an own fuel cell (based on the fuel cell technology licensed from AVL) due to technical problems (durability) with the purchased cells
- Raw material and tightness of the bipolar plates
- Maintainability and service life (modularity, standardization, usability, flexibility)
- DC/DC converter

Frame:

- Fire and explosion protection
- Ease of maintenance and corrosion resistance

Overall system:

- Optimization of the control panel and the interaction of the individual components (control and algorithm)
- Ease of operation and maintenance
- Interaction of the individual components of JOHANN and visualization of all functionalities and parameters in a management system: heat and cold management of the entire system, overall visualization, simplified operability and increased user friendliness…

Some of the further developed HW components of the JOHANN are shown in the following figure

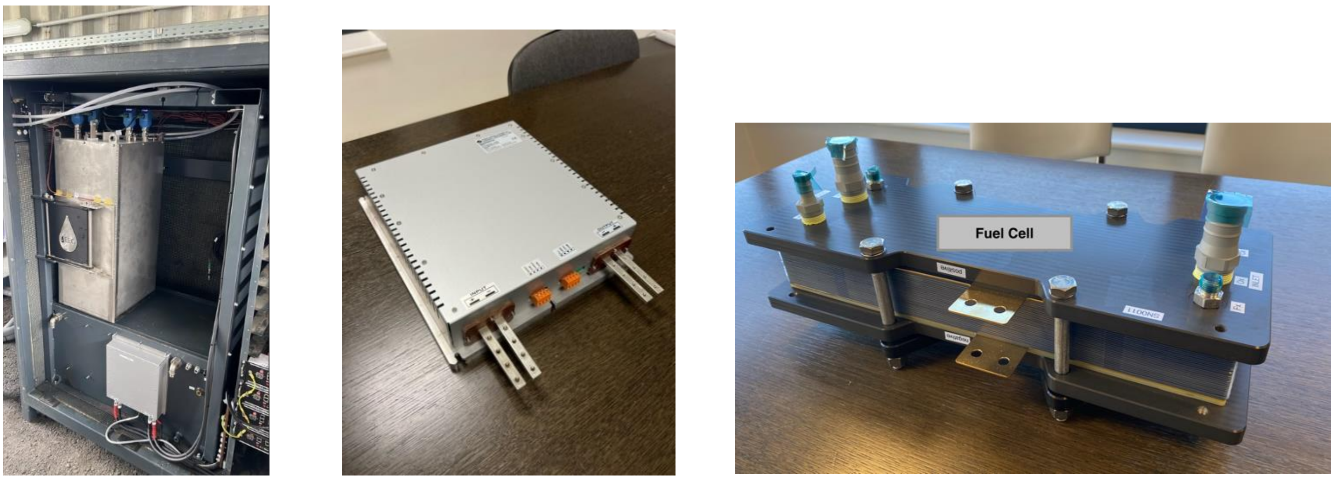

Figure 11: Further developed components of JOHANN (fuel cell (assembly in frame), DC/DC converter, partially assembled fuel cell

Optimization of the storage strategy algorithm

Within the scope of the project, not only the individual components and parts, but also the control of the overall system and the algorithm of the JOHANN energy cell were improved and optimized on the basis of the simulated and collected data. Specifically, the following goals were achieved:

- Real-time analysis of the data obtained from a JOHANN battery storage system and a JOHANN H2 storage system
- Optimization of the storage strategy algorithm taking into account various input and framework parameters (e.g. annual electricity demand, load profile, power of the photovoltaic system or annual heat demand...).
- Simulation and verification of the optimized algorithm under real conditions
- Creation of an individualized software and visualization of the individual parameters.

As an example, the results of such a simulation and the visualization of an H2 storage system including power and heat management for the period of one year are presented here.

Figure 12: Results of a simulation
(H2-storage, power consumption and heat delivery of a heatpump system) Johann control unit

The corresponding evaluations and statistics were of course not only created for direct storage-specific data, but also extended to technical and economic hard facts.

Technische Statistiken

Max. Strombezug gesamt 2,76 kW	Max. Strombezug Netz 5,49 kW	Max. Strombezug JOHANN 5,2 kW	Max. Stromerzeugung PV 35,62 kW	Max. Stromeinspeisung Netz 33,32 kW
Max. Wärmepumpenleistung 4,41 kW	Max. Stand Batteriespeicher 9,61 kWh	Max. Stand H_2-Speicher 300 kWh	Max. Stand Warmwasserpuffer 23,34 kWh	

Kaufmännische Statistiken

Autarkiegrad 93 %	Systemkosten 93 001,00 €	Kosten Johann 49 000,00 €	Kosten Wärmepumpe 1,00 €	Kosten PV 44 000,00 €
Energiekosten ohne Johann 4 480,00 €/Jahr	Energiekosten mit Johann -1 301,27 €/Jahr	Energie gespart pro Jahr 4 712,98 kWh/Jahr	Geld gespart pro Jahr 5 781,27 €/Jahr	CO_2 gespart pro Jahr 1 404,85 kg/Jahr
Gepflanzte Bäume pro Jahr 41,3 Stk./Jahr	Amortisierungszeit 13 - 14 Jahre			

Figure 13: Economical and technical statistics

Implementation of interfaces and missing features

In the course of project execution, a large number of (technical) interfaces and previously missing functions of the overall system were implemented. Some of these essential interfaces and optimizations are listed here:

- Visualization: Customers thus get the very frequently requested, simple and clear visualization for electricity and heat in a single product.
- Interface GLT (building control technology): The communication with systems already existing at the customers (such as KNX, Loxonne, Siemens...) is ensured.
- Interface heat: simplification of the interface and thus prevention of operating errors by the customer (e.g. incorrect filling, frost damage, etc.) and possible replacement of the entire heating system.
- Power interface: improvement of individual components (connection terminals, transfer switching capacity, automatic bypass...), reduction of the complexity of the overall system and increase of the connection capacity by 56%.
- Internet interface: Integration with fixed IP addresses
- Connection point for charging station: preparation for 160A charging stations
- Connection point for photovoltaic: preparation for 160A photovoltaic systems
- Integration of NA protection: Possibility of integrating NA protection depending on the country-specific requirements of the network operator.

Particularly the point of visualization was given a lot of attention in the course of project execution, as it is essential for customers and users, especially in the case of technically complex solutions, that the benefits of such solutions are quickly and easily apparent and can also be recognized by technically “unsophisticated” customers. The old versus the new and much more user-friendly and fully integrated visualization for battery and H2-storage operation with multiple parameters is shown in the following figure.

Figure 14: old vs. new visualization and management system

Optimization of the production process and preparation for mass deployment

All changes made to the individual components or to the overall system of the JOHANN energy cell as part of the overall project were made with a view to later simple (series) production of the JOHANN in large quantities. This essentially involves standardization and modularization of the JOHANN product, which affects the production process as follows:

- Enabling configuration- and sales-independent (standardized) pre-assembly of individual modules
- Separation of production into technically demanding and less demanding modular work areas
- Separation of high-purity modular work areas
- Standardized and simplified final assembly incl. software-supported final inspection

The new modular structure has not only led to a significant simplification in the production process of the JOHANN, but also to a substantial improvement in the after-sales service and in the easier adaptation to future technical changes. This simplified, "tidy" and modular structure which led to an enormous improvement of the overall JOHANN is illustrated in the following figure.

Figure 15: the new, modular and "tidied" structure of JOHANN

c. Technology assessment and expected impacts

With the described methodology, this results in a total of 216 different configurations. For each of these configurations the optimization model described in the Methods section is solved once with JOHANN and once without JOHANN. Finally, the results of the two models are compared to identify the benefit of JOHANN in each parameter combination.

Cost savings

First the total annual cost for electricity purchase are compared with and without JOHANN in all different configurations. Figure 3 shows the savings in annual cost that could be achieved with JOHANN. It includes six contour plots for the six different values of heat demand. In each contour plot the x axis corresponds to the considered annual electricity demand and the y axis to the installed PV capacity. The color indicates the achieved cost savings with JOHANN. Negative values correspond to a cost increase. The black line is the isoline of zero cost change.

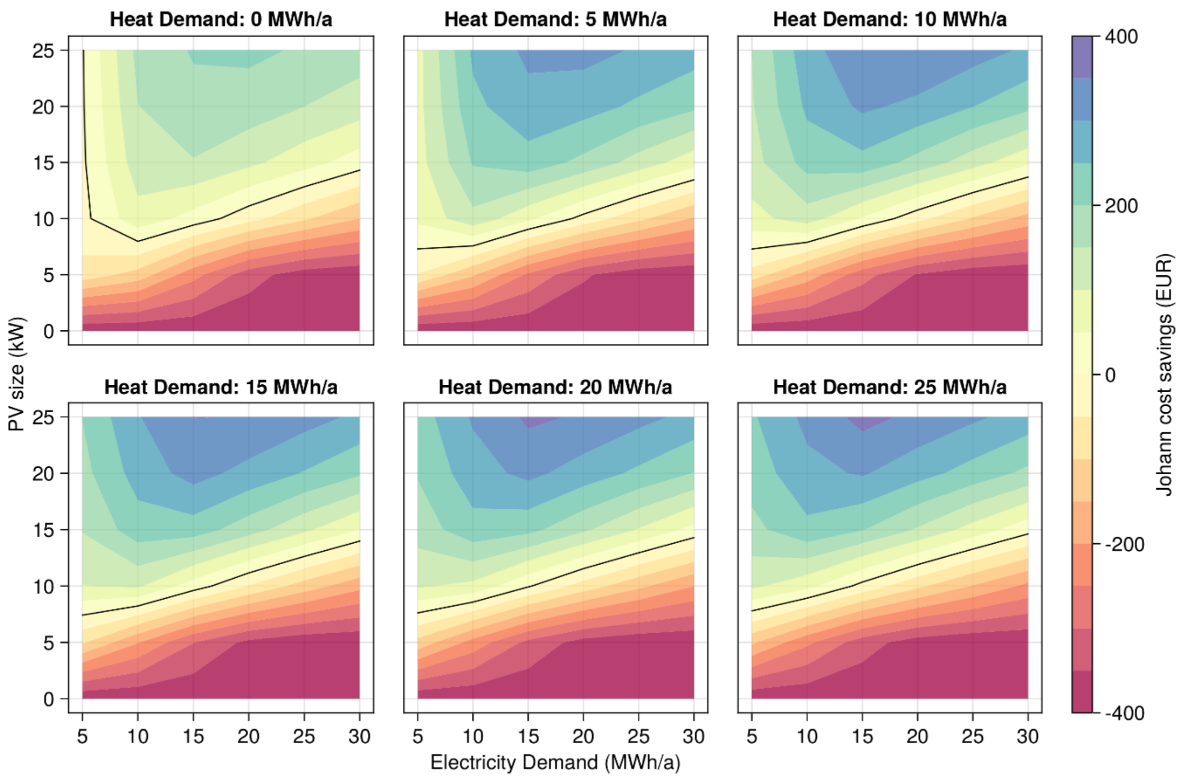

Figure 16: annual savings achieved with JOHANN for different combinations of heat demand, electricity demand and PV size.

It can be observed that the top left plot looks slightly different compared to the other graphs. It corresponds to zero annual heat demand and results in less cost savings than the others. The reason for this is that there is no demand for the excess heat from energy conversion in JOHANN resulting in lower efficiencies. For the lowest electricity demand of 5 MWh/a JOHANN is not even able to provide economic benefits with the highest installed PV capacity of 25 kW. This highlights the importance of using the excess heat from JOHANN for an efficient operation.

In general, larger PV installations result in higher benefits achieved by JOHANN. Without any local generation there is no excess electricity production that JOHANN can store. Hence, there is no demand for electricity storage and JOHANN cannot provide any benefits. For each annual electricity demand there is a minimally required PV size for an economically efficient JOHANN operation. With increasing electricity demand, this minimal PV capacity increases as well.

Adding the JOHANN energy cell does not always reduce cost but can also result in a cost increase. This might seem counter-intuitive, considering that the optimization models and the results shown here only consider operational costs and completely neglect investment cost associated to JOHANN. However, it can be easily explained with the parameter assumptions for JOHANN from Table 1. Both the battery and the hydrogen storage each have a standby electricity consumption of 30 W. For an entire year this adds up to 525.6 kWh. Furthermore, JOHANN has an annual operation and maintenance (O&M) cost of 300 EUR. Hence, if JOHANN is barely used to provide any benefits, it adds additional energy demand which results in higher cost.

Reduction in CO2 emissions

During each hour of the year certain power plants are operating to produce electricity and. At the same time most power plants produce CO2 emissions. From the total emissions and the total electricity production an average emission factor t CO2/MWh for electricity from the grid can be calculated. Using hourly data for electricity generation per power plant type from the ENTSOE Transparency Platform[7] and typical emission factors for electricity production from Annex III of the 5th Assessment report of the IPCC[8] a time series for emission factors from the electricity grid was calculated for the year 2020. This emission factor profile is used to evaluate the emissions associated to electricity consumption of a household with or without JOHANN.

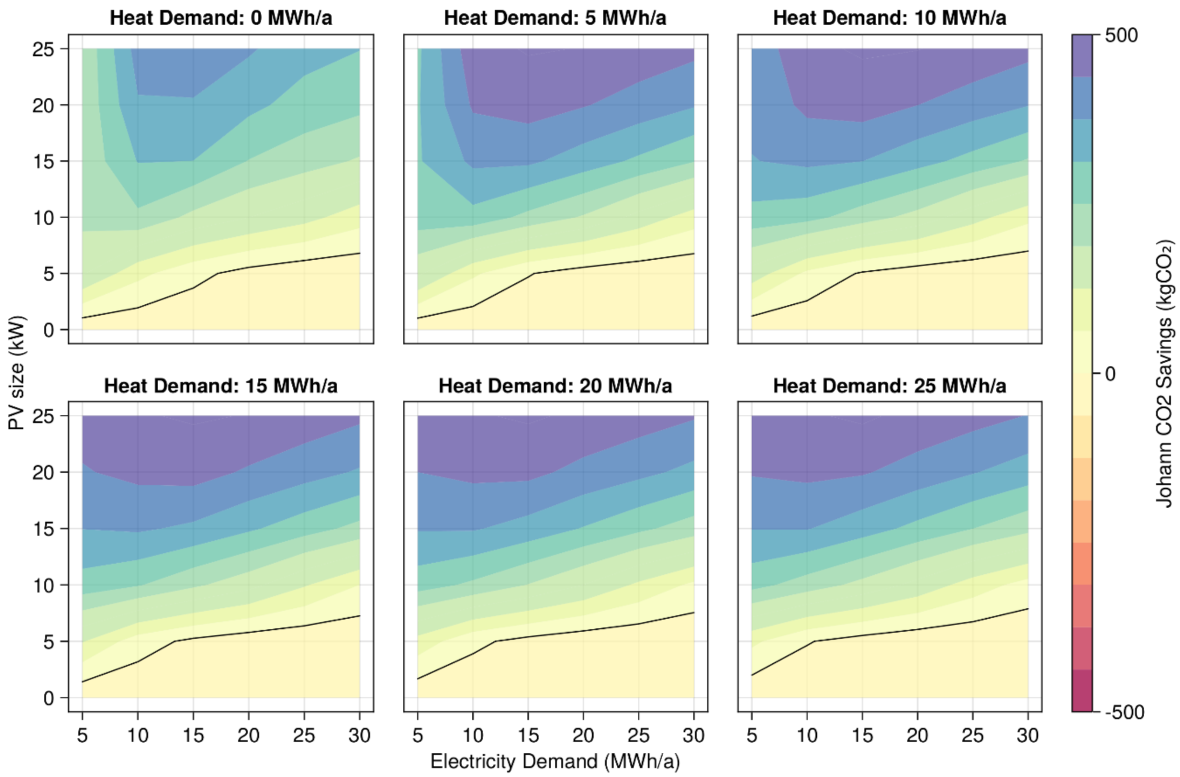

Figure 17: annual reductions in CO2 emissions achieved with JOHANN for different combinations of heat demand, electricity demand and PV size.

The figure shows the reductions in CO2 emissions associated with electricity consumption of a household with JOHANN compared to a household without JOHANN for all combinations of electricity demand, heat demand and PV size considered in this sensitivity analysis. By comparing the different contour plots it can be observed that JOHANN can achieve higher reductions in emissions with a higher heat demand. The most significant step is between no heat demand and 5 MWh/a.
The black line in Figure 4 shows the zero isoline corresponding to no change in emissions with the addition of the JOHANN energy cell. Hence, there are also setups where JOHANN increases the CO2 emissions.

[7] https://transparency.entsoe.eu/, accessed in April 2023
[8] Schlömer S., T. Bruckner, L. Fulton, E. Hertwich, A. McKinnon, D. Perczyk, J. Roy, R. Schaeffer, R. Sims, P. Smith, and R. Wiser, 2014: Annex III: Technology-specific cost and performance parameters. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf, accessed in April 2023

This can be explained again by the extra standby demand of the JOHANN components in the cases with low local generation. In general, it can be observed that the amount of avoided emissions increases with increasing PV size. The minimal PV size for JOHANN to have a positive effect on emission reductions increases with the annual electricity demand.

Autarky

Autarky means the share of energy demand that can be met by local self-generation. JOHANN can increase this factor by storing excess generation and providing it at a different time to avoid grid consumption. This means that more local production and less electricity from the grid is used to meet the energy demand.

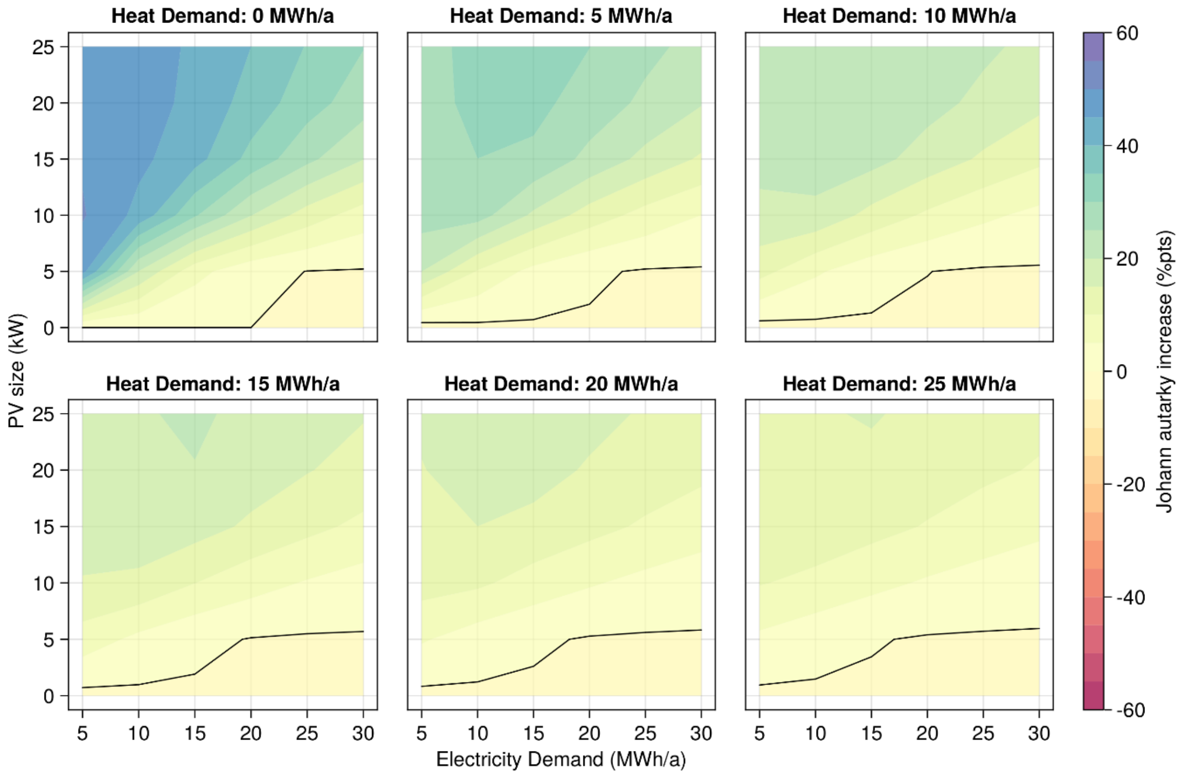

Figure 18: Change in autarky in percentage points achieved with JOHANN for different combinations of heat demand, electricity demand and PV size.

The figure shows the change in autarky caused by JOHANN in percentage points for the different setups in the sensitivity analysis. The amount of energy that can be stored and used at a different time is limited by the technical parameters of JOHANN and the available excess generation. This amount also limits the potential increase in demand met by local generation. So, naturally, with increasing heat and electricity demand the increase in autarky in percentage points achieved by JOHANN decreases.

Conversely, the available local generation increases the the amount of energy that JOHANN can store and provide at another time. Thus, the contributions of JOHANN to autarky increase with higher PV sizes. There are again minimal PV sizes for different electricity and heat demands that are required for a positive contribution to autarky by JOHANN. For insufficient local excess generation JOHANN just increases the electricity demand and, hence, reduces autarky.

PV self-consumption

The self-consumption share of an end user with a PV system is the share of local PV production that is used locally and not fed into the grid. JOHANN can significantly increase this factor by storing excess generation. The impact of adding JOHANN on the self-consumption share in percentage points is illustrated in Figure 6. First, it can be observed that JOHANN only has a positive impact on the self-consumption share. It will never increase the grid feed-in.

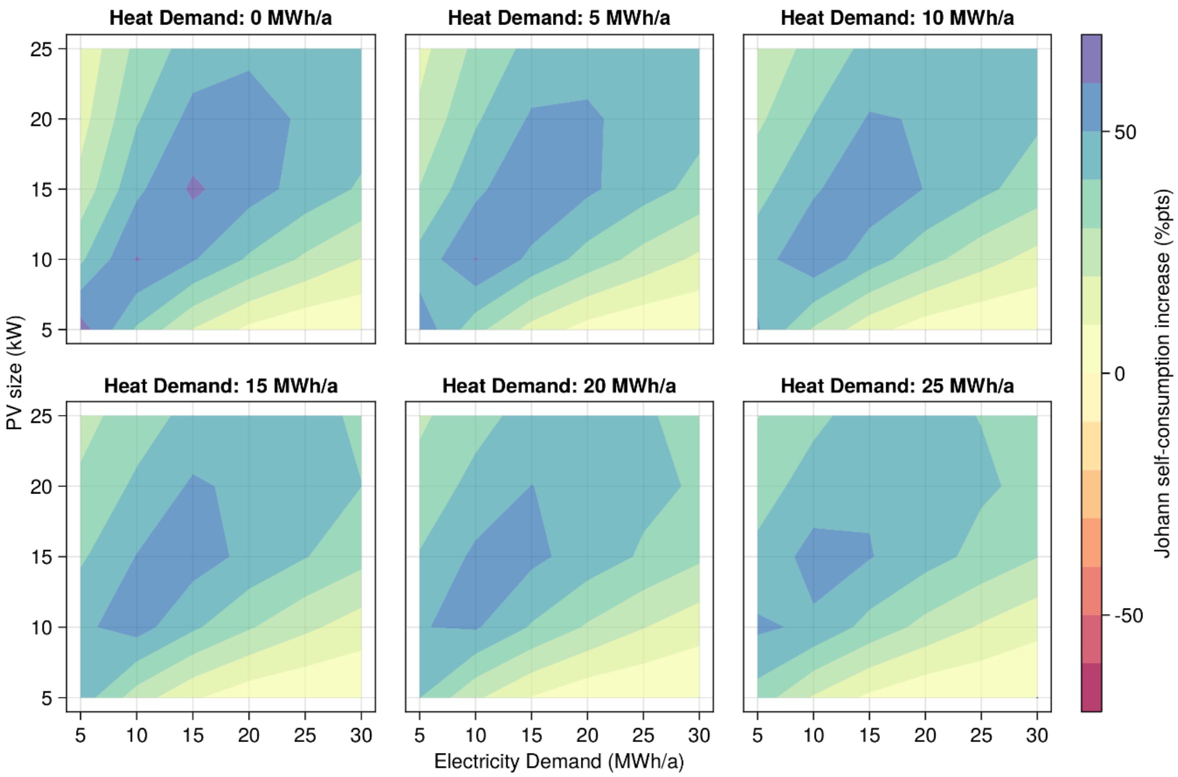

Figure 19: increase in thePV self-consumption share in percentage points achieved with JOHANN for different combinations of heat demand, electricity demand and PV size.

Now consider a fixed energy demand. The self-consumption share is already high for small PV sizes without JOHANN. Thus, JOHANN cannot increase it that significantly as for higher PV sizes. However, at some PV capacity JOHANN has reached its technical potential to shift excess production. Thus, with further increasing PV sizes the contribution of JOHANN to the self-consumption share in percentage points decreases.

Conversely, consider now a fixed PV capacity. If the energy demand is too low, the household can already achieve a very high degree of autarky without using the full technical potential of JOHANN. In this case, it does not make sense to store more excess generation. Hence, at first the contribution of JOHANN to the self-consumption share increases with increasing energy demand. However, with further increasing energy demand higher self-consumption shares are achieved even without JOHANN and the contribution that JOHANN can provide to increase of the self-consumption share starts declining again.

Impact on value added

To assess the overall macroeconomic impacts, the investment phase and the operational phase have been taken into account. The compared configurations show an increasing investment need because each configuration is an extension of the previous one. Therefore the total investment costs are the highest in the “Johann” configuration, whereas the “Basic” configuration has the lowest investment need. As operational phase the time span from 2021 to 2040 was considered. To compare the different investment options the net present value was calculated assuming an average interest rate of 3%.

Figure 22 shows the value added impact per use case and configuration in relation to the baseline (basic configuration).

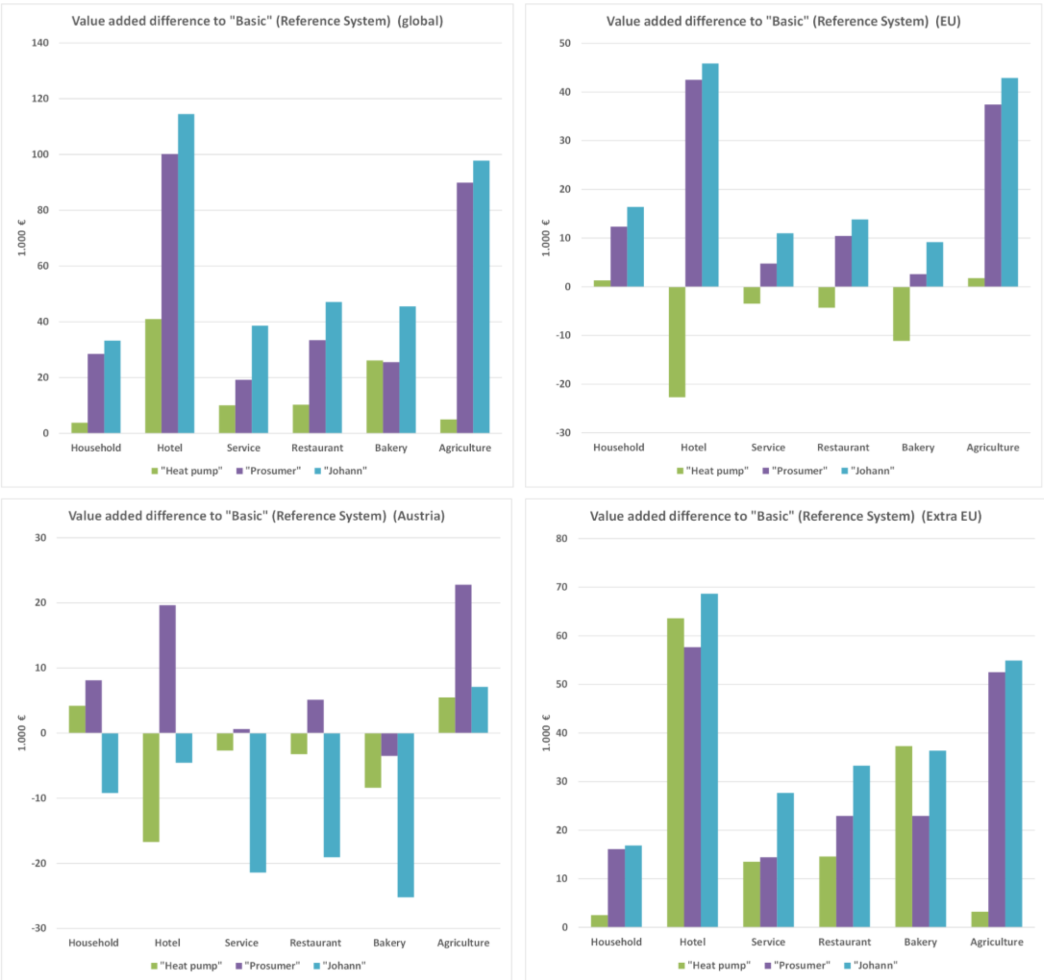

Figure 20: Value added per use case and configuration in relation to the baseline (basic configuration)

The results show that on a global perspective the “Johann” configuration has the highest value added impact compared to all other configurations. This is also true for the European Union. For Austria, the “Prosumer” configuration has the highest positive value added impacts. The results are based on the actual configuration of the Johann energy cell. As it is still under development the regional structure of intermediary inputs might change. This will also change the regional distribution of impacts of the Johann energy cell.

Life cycle assessment

Concerning the Johann energy cell itself, we found that the hydrogen storage was a major hotspot regarding the GHG-emissions, followed by the steel and aluminium frame, and the included batteries. To reduce the GHG-emissions of the Johann energy cell in the future, a change to less GHG-intense materials/to reduce the material demand is a promising starting point.

We found that the emissions during the use-phase highly depends on the assumed context, such as the energy demand of the supplied facility, or the size of the PV-panels. Figure 1 depicts the GHG-emissions of the different technical configurations in the six use cases.

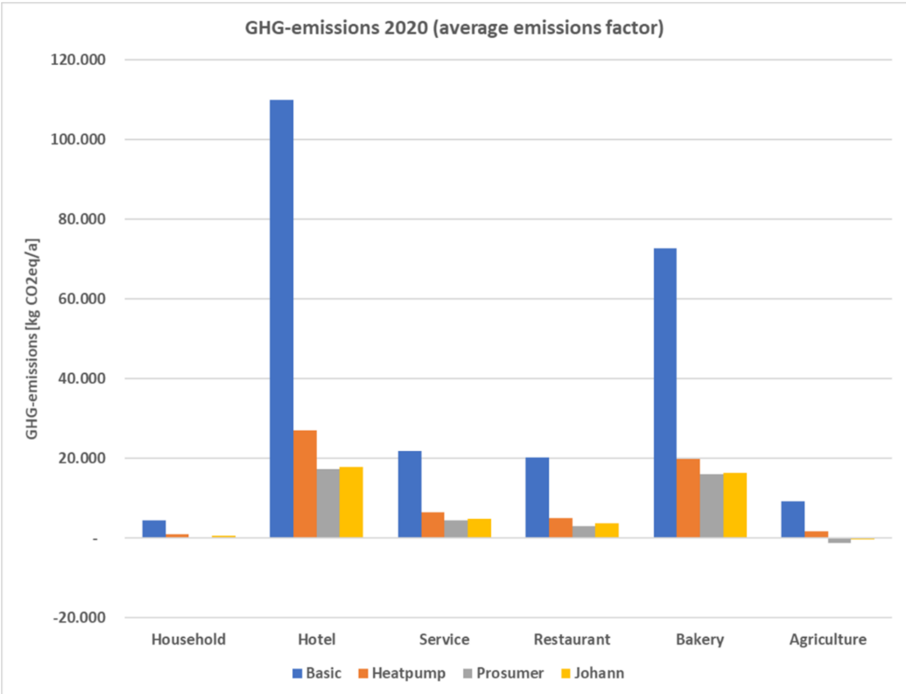

Figure 21: Overview of GHG-emissions in the different use cases and configurations 2020. Depreciation of GHG-emissions due to plant construction over 20a. Credit for the supply of electricity to the grid. Grid mix based on ENTSOE.

It can be seen from the diagram that the “Basic” configuration causes the highest emissions in all use cases. This is mainly due to the high amount of natural gas used for the heating demand. The configuration “Heatpump” still has high emissions as compared to the “Prosumer” and “Johann” configuration. The configurations “Prosumer” and “Johann” show similar GHG-emissions, however, the emissions of “Johann” are slightly higher throughout. This is due to the GHG-emissions that occur during the production phase of the Johann energy cell. Furthermore, the higher energetic losses due to the electrolysis process in comparison to the credit for the direct electricity feed-in of the PV-panels contribute to the higher emissions of Johann. The diagram shows, that especially in the use case “Agriculture” the credit for feed in is higher than the emissions that occur from other activities.

Our data suggest that the Johann energy cell leads to significantly reduced GHG-emissions in all use cases, as compared to the basic configuration using natural gas and electricity from the grid only. However, also the “Prosumer” configuration, also using a PV-panel and a heat pump, but without storage capacity, might lead to lower overall GHG-emissions, when a credit for recycling is assumed. However, the comparison of “Johann” and “Prosumer” is not fair, as volatile renewable energy carriers will also require additional energy storage systems (such as Johann) in the future. Hence, our study indicates that the Johann energy cell is – from an ecological point of view – an interesting option to save GHG-emissions as compared to the current fossil-based systems. However, the advantage in terms of GHG-emissions depends on the field of application and the GHG-intensity of future power storage systems at the grid level.

6. Outlook and recommendations

a. Market Outlook

The prices for 2030 are on average slightly lower than for the year 2021. For the year 2040 electricity production from 100 % renewable energy sources is assumed and the market prices are significantly higher than in the other scenarios.

The resulting volumetric energy prices are illustrated in the figure below. The top plot shows the total energy buying price including the grid tariff, fees and taxes. The bottom plot shows the energy selling price or the feed-in tariff. Both increase in all new energy price scenarios and are significantly higher for the year 2040. A higher energy buying price increases the savings per kWh of output from the JOHANN battery or fuel cell. Hence, it could be assumed that JOHANN provides more economic benefits in the new price scenarios. However, Figure 14 indicates the opposite. It shows the change in total annual cost for electricity purchase with JOHANN for each customer type and the four different energy price scenarios.

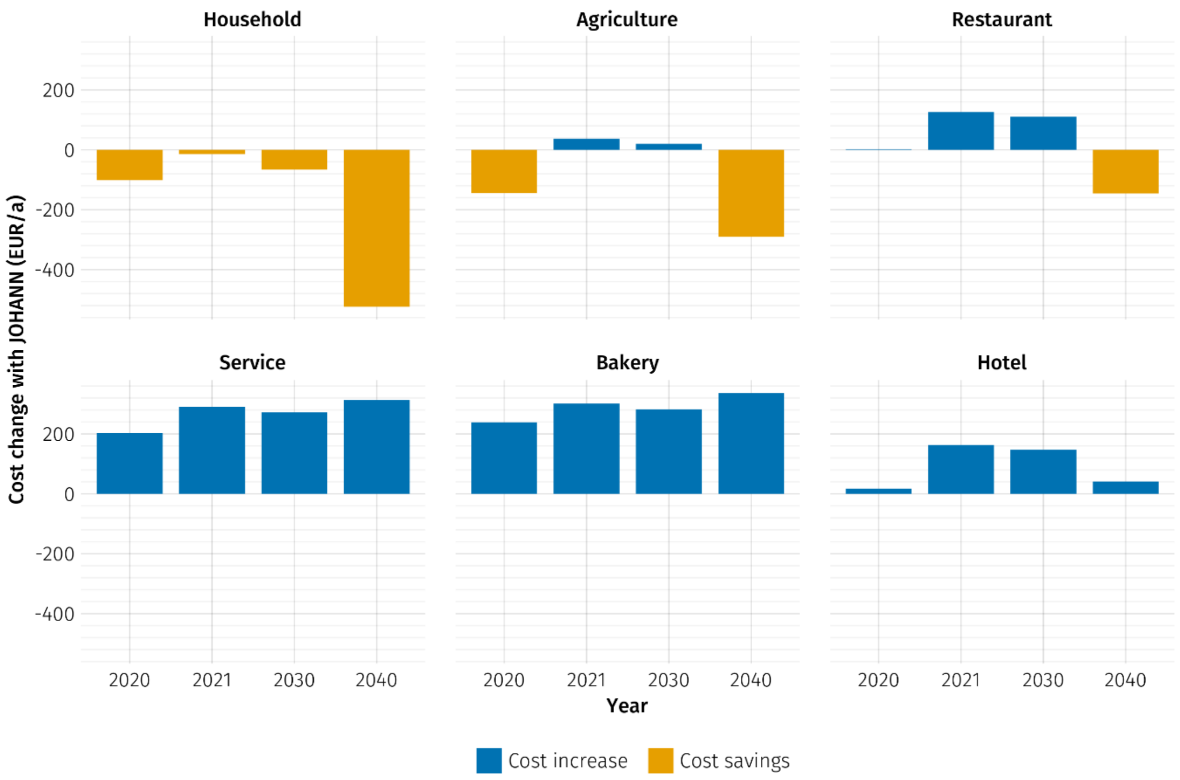

Figure 22: Cost savings with JOHANN for different customer types and price scenarios
The household is the only customer type that achieves a cost reduction in all price scenarios. Both agriculture and restaurant can reduce their cost with JOHANN with the energy prices from 2040. However, all remaining new price scenario simulations result in a cost increase with JOHANN.

The technology evaluation of the energy cell JOHANN has shown that a JOHANN installation only makes sense from an economic perspective if there is local variable electricity generation and, specifically, excess generation that would have to be fed into the grid or curtailed. Furthermore, the analyses have shown that the possibility to use the excess heat from conversion between electricity and hydrogen, results in higher economic and energy efficiency. Hence, a use case with heat demand is recommended for the installation of JOHANN.

Among the investigated customer types in the roll-out scenario, households and agriculture can achieve the best economic results with a JOHANN installation. Compared to the other considered customer types, they have the lowest demands, and more importantly the lowest self-consumption and autarky shares. Hence, JOHANN is able to provide more benefits.

The sensitivity analyses regarding the market prices showed that the operational economic value proposition of JOHANN is very sensitive to energy prices. Especially, for the hydrogen module of JOHANN, which is characterized by lower conversion efficiencies than the battery module, the relative price spread, between electricity and selling price turned out to be the key determinant for the economic efficiency of a JOHANN installation. The majority of investigated price scenarios do not result in operational economic benefits for most customer types. While JOHANN can generate benefits in almost all cases by increasing self-consumption and autarky, the additional stand-by demand increases total electricity demand and the corresponding extra cost outweigh the benefits in most cases.

Nevertheless, the energy cell JOHANN provides valuable flexibility potential. In all simulation runs JOHANN improved the autarky and the PV self-consumption. Furthermore, a JOHANN installation reduces the CO_2 emissions associated to the electricity consumption of a customer. Hence, JOHANN can help reducing CO_2 emissions.
In the presence of suitable incentives, JOHANN can also be operated grid-friendly and help reduce peak loads. A peak-load pricing component in the electricity grid tariff can provide such incentives. With this additional means of valorizing its flexibility, the energy cell JOHANN can provide economic benefits for all customer types in all investigated price scenarios. Furthermore, JOHANN achieves a significant reduction in peak load.

b. Macroeconomic environmental and environmental

Several factors can be identified as key factors for the profitability as well as the magnitude of the macroeconomic economic effects. Regarding energy costs and feed-in revenues the amount of photovoltaic production in relation to energy demand, the size of the hydrogen storage and the specific energy consumption profile are relevant. Based on the assumptions made, the Johann configuration is most advantageous in cases that benefit optimally from the energy storage functionality and waste heat.
For the regional distribution of economic effects the origin of intermediary inputs is highly relevant. The analysis draws on the latest data on the value chain of the Johann energy cell, but the energy cell is still under development. Future versions can have a different structure of intermediary inputs as well as different origins of acquired goods and services. For the “Prosumer” configuration the origin of the photovoltaic cell and the inverter are highly relevant. Based on the actual data on the Johann energy cell the value added impact of the Johann energy cell is slightly positive for the EU in comparison to the basic reference scenario for all analysed use cases but the “Prosumer” configuration shows the highest positive value added impacts for the EU.
One major limitation of this study is that impacts on the energy grid were not sufficiently considered. To compare all configurations from an economic and environmental perspective adequately, one would also have to consider the future expansion of the energy grid as well as the associated investment needs. Nevertheless, the cell seems to offer advantages in cases where the storage function and waste heat can be optimally used. If, in certain cases, there are also sufficient savings in network expansion costs, an additional advantage can also arise. Based on the current setup of the Johann energy cell, the project assumes a storage volume which serves mainly on daily or weekly basis. However, due to the design of the cell, larger storage volumes would also be possible. This would also enable seasonal storage use cases. Since the current setup has not yet provided for this, this has not yet been examined in the project.

c. Go-to-Market and Business Development

The goal is to offer the customer a system that guarantees maximum energy self-sufficiency (electricity and heat) at an economical price, whereby the focus here is not (only) on short-term day-night electricity storage and an economical feed-in into the public energy grid, but rather on the storage of solar energy in the summer and the use of precisely this energy in the winter months when there is little sun.

However, as has become apparent in the course of project implementation, there are still a number of challenges that need to be resolved in order to successfully implement this strategy or achieve the goal, such as:

- Permission processes: Unfortunately, it has become apparent during the implementation of the use cases that the permitting processes for such facilities can lead to massive problems and delays due to the novelty of the hydrogen issue in the context of energy storage solutions. Uncertainty among the authorities and the bureaucratic effort are currently still hampering the speedy implementation of field trials, and this has only allowed the commissioning of a single plant. With a view to the widespread sale of this technology, cooperation with the authorities at all levels must now be intensified as a matter of urgency.
- Graphite supplies and quality: the project has shown that both quality and supply problems with graphite used in the fuel cells have had a detrimental effect on the test phases. Alternatives need to be explored in the medium term to ensure quality and availability.
- User-friendliness and visualization: The near-market implementation of the technology in use cases as part of the project has shown that an even greater focus must be placed on the aspects of visualization and also networking in the future. Customers are increasingly demanding networked systems that think for themselves, and not just first-class technical solutions.

The project has contributed to the fact that the above-mentioned challenges have not only been recognized in time, but have also been initiated or partially solved over long stretches within the framework of the project. Of course, a number of technological issues remain open for the coming months, since although the project has created a substantial basis for the further development of JOHANN technology in a future-oriented and application-oriented manner, a number of questions still need to be solved in detail and verified in a test environment close to the market. These now necessary development steps were summarized in a roadmap for the coming months and a comprehensive business plan for the coming years and serve as a basis for the topics to be worked on - from technological developments to market research and concrete marketing measures. In the further development of JOHANN, even more intensified research and cooperation with external stakeholders will be essential to address specific problems even more efficiently and to make the system ready for the market. The outlook is to expand field tests under real conditions and to continuously adapt and optimize the technology in order to successfully establish the environmentally friendly and economically viable energy solution on the market. The experience and knowledge gained from the project to date will play a decisive role in further development and future success. In this way, we secure the further path to the successful establishment of JOHANN in the energy storage landscape.

7. Bibliography

8. Appendix

9. Contact details

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