

After the RISEnergy Transnational Access, Users are required to submit a User Report. This should be done within 4 weeks after the Access is completed unless otherwise agreed. The User Report will be given to the User(s) by the WP2 leader. The report contains sections related to the work performed, the main results and observations that were achieved.

This document should be completed, signed, and sent by e-mail to [risenergy@for.kit.edu](mailto:risenergy@for.kit.edu).

Summary questionnaire for Users who have been granted Transnational Access (TA) under the RISEnergy project Horizon Europe TA scheme. More information on RISEnergy TA can be found in "General Rules" and in "Access Policy" which can be found on the RISEnergy webpage.

Please complete, sign, and send this form, together with the Cost claim by e-mail to [risenergy@for.kit.edu](mailto:risenergy@for.kit.edu) with title: RISEnergy TA1.175 - reports.

General information about the project	
Project title (as used in Application)	Enabling P-HIL applications for integration of grid-forming VSCs
Project acronym (max 15 characters)	E-PHIL-GFM
RISEnergy RI(s) accessed	TA25 – ICCS-EES-lab
Keywords (up to five, free text)	Renewable energy sources, grid-forming VSCs, P-HIL, stability analysis
Arrival date (in town where RI is located)	14/06/2025
Departure date (from town where RI is located)	19/07/2025
Starting date of Access (first day at RI)	16/06/2025
Finishing date of Access (last day at RI)	18/07/2025



Number of days not using the RI (during the above period)	11
Reason for not using RI those days (describe)	Weekends
Number of days using the RI	25
Number of Users granted Access (group size)	The User Group consists of four members, however, only one researcher (Andrei Mihai Gross Muresan) accessed the RI.
Comments	<b>Stay Days: 36</b> <b>Access Days: 25</b>
<b>User</b>	
<b>User group leader or sole applicant (user group member 1)</b>	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
<b>User group member 2</b>	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
<b>User group member 3</b>	
First name	
Last name	
Affiliation / Employer	

Country of Employer	
E-mail	
User travelling to RI?	
Comments	
<b>User group member 4</b>	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
Please insert more fields if your groups had more than four members.	
<b>Access Summary Report - work performed and initial results</b>	
Brief description of the objectives of your project (up to 200 words)	
<p><i>[Please describe short the main objectives of your project]</i></p> <p>The main objective of the project is to create and validate a tool to systematically tune single-phase grid-forming converters using small-signal analysis and state evaluation around a linearized steady-state point. This procedure weighs the effect of the states that most affect the stability of the system and does the necessary adjustments to the modifiable parameters to obtain the desired response. In addition, it is intended to extend this methodology to power-hardware-in-the-loop (P-HIL) techniques for testing single-phase grid-forming converters with the aim of improving the stability and accuracy of these techniques. As a result of this study, different experimental tests have been carried out modifying those control gains identified as critical in terms of stability and dynamic response of the grid-forming converter in order to validate the obtained results. These experimental results have been carried out in two groups according to the proposed theoretical analysis: i) experimental tests of the grid-forming converter connected to an amplifier functioning as an ideal voltage source; ii) P-HIL experimental tests, integrating the dynamics of a real voltage source simulated in a real-time platform in the amplifier and connected to the grid-forming converter.</p>	
Activities performed (up to 600 words)	



*[Please summarise the work carried you (steps taken, instrumentation used, techniques employed, data sources consulted etc.)]*

Over the course of five weeks at the National Technical University of Athens (NTUA), the primary objective was to complete experimental testing related to grid-forming (GFM) control strategies, building upon theoretical and simulation work initiated prior to the stay. The first week was spent building models on the dedicated software of Triphase and performed virtual PHIL to assess the stability prior to actual experimentation. After assessing the options, it was decided to use the Triphase setup in a single-phase configuration, in combination with a Spitzenberger linear power supply controlled by an RTDS system, in order to maintain comparability with tests performed in other research stays.



Initial work involved preparing and testing a simple current controller in open-loop mode, where the RTDS system did not react to the current from the device under test. This step served as the lower stage of a cascaded GFM controller and provided a straightforward starting point to familiarize with the laboratory workflow for implementing experimental controllers. Alongside these preparations, work continued on the development of a state-space model for an alpha-beta to dq transformation, addressing challenges related to system non-linearities and subsequent attempts at linearization. Several iterations were conducted to improve model accuracy without losing essential dynamic behavior, supported by meetings with colleagues to refine the methodological approach. By the second and third weeks, the current controller tested in virtual PHIL was successfully deployed on the Triphase hardware, with experimental data collected

for further analysis. Subsequently, the virtual synchronous generator (VSG) controller—serving as the GFM control strategy—was implemented. Initial trials were affected by current protection trips on the DC side, but these were resolved, allowing successful operation of the controller. Adjustments to the base power values ensured that the system operated within safe limits.

During the final weeks, systematic testing of the VSG controller was carried out, varying selected parameters to observe their influence on system performance. Open-loop tests were completed first, where the converter's output did not perturb the supplied voltage, thus isolating the effect of control parameters. From these results, a subset of configurations was selected for closed-loop testing, which involved implementing an impedance model in the RTDS to emulate a feeder at a given distance.

Closed-loop tests were executed under various Power Hardware-in-the-Loop (PHIL) conditions, starting from high-performance configurations and progressively reducing fidelity to assess the impact on control response. These tests provided valuable insights into the robustness of the GFM control under different emulation qualities. The combination of open-loop and closed-loop experiments, together with the prior simulation studies, resulted in a comprehensive characterization of the controller's behavior under different operating conditions.

In summary, the stay at NTUA enabled the successful transition from theoretical and simulation work to experimental validation of GFM control strategies. The work completed included equipment selection and setup, model development and refinement, controller implementation, and both open-loop and closed-loop testing. The collected data will serve as a solid basis for subsequent analysis and dissemination in scientific publications.

#### Scientific results (up to 800 words)

*[Summarise the (initial) outcomes of your study at the RI(s).]*

The use of small signal analysis to tune control parameters in grid-forming converter (GFMC) controllers to different types of networks from high voltage to low voltage is widely used in three-phase to three-wire systems. This type of analysis is performed in rotational coordinates  $dq$  whose magnitudes are constant in time. In this work, it is intended to extend this technique to single-phase GFMC whose main challenge is to propose a control in a system with a sinusoidal voltage and current in time and oscillating powers at 100 Hz. This leads to the need to generate a virtual system from the magnitudes of the single-phase system that contemplates continuous signals in time and constant powers to implement grid-forming control as in three-phase three-wire systems. This virtual system is typically generated by applying a filter to the original voltage and current signals of the single-phase system. The aim is to produce two virtual signals (one voltage and one current) with the same magnitude as the original signals, but with a  $90^\circ$  phase shift. In this way, the Park transform can be applied to this group of original and filtered signals to implement grid-forming control in a virtual  $dq$  coordinate



system in a similar way to three-phase systems. However, the introduction of these filters to the original magnitudes causes the dynamic response and stability of the single-phase converters to be different from the three-phase converters. This leads to the fact that the control gains of the three-phase GFMCs cannot be applied directly to the single-phase GFMCs to obtain the same dynamic response. Considering this circumstance, the first result of this project has been to perform a small-signal analysis on the single-phase GFMC, taking into account its intrinsic characteristics. This involves the application of two cascaded low-pass filters to obtain virtual signals in the sinusoidal domain. It should be noted that in three-phase systems, small-signal analyses are performed directly in dq coordinates. However, in this single-phase system, this analysis must be based on sinusoidal signals over time, since the filters are applied here to obtain and extend the virtual signals to the grid-forming control proposed in virtual dq coordinates. This presented a significant challenge to the research team when conducting the analysis, which involved considering two-time domains connected through the Park transform. The tool obtained from the small-signal analysis has allowed us to evaluate the stability of the single-phase GFMC; however, it has not allowed us to study the impact of its dynamic response. This is because when dealing with sinusoidal signals over time, there will always be poles on the imaginary axis.

Given this limitation in the developed tool, the work team decided to perform a sensitivity analysis on those control parameters that were most critical in terms of stability to evaluate the dynamic responses of the single-phase GFMC connected to the amplifier. These parameters are: i) the proportional gain  $K_{pp}$  of the active power loop of the GFMC; ii) the virtual reactance  $X_v$  to generate the reference currents in dq axes; iii) the time constant of the low-pass filter  $\tau_{lpf}$  applied to the reference currents dq. Figure 1 shows the results of changing the reference active power from 0 to 325 W for the minimum (0.02) and maximum (0.04) values of the  $K_{pp}$  gain selected in the sensitivity analysis. This figure shows a clear trend with respect to  $K_{pp}$ : the higher its value, the greater the overshoot upon a reference change and the greater the damping at low frequencies. This can be clearly observed in the lack of power oscillation when the reference value is zero, as well as in a lesser oscillation after the first instants of the reference change.

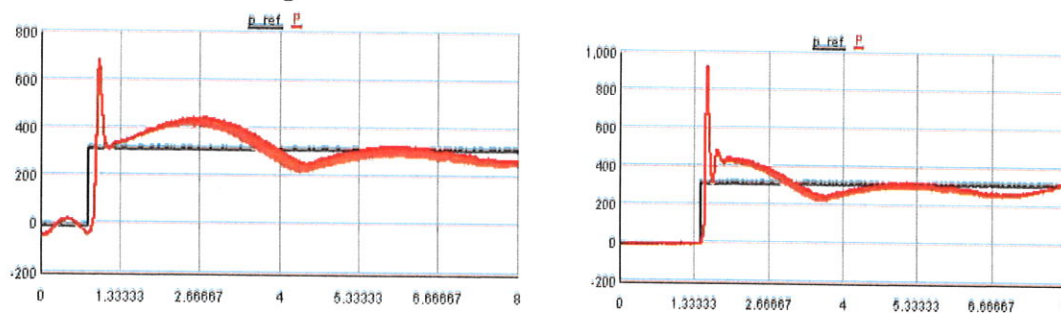


Figure 1. Left plot:  $K_{pp} = 0.02$ ; Right plot:  $K_{pp} = 0.04$

Fig. 2 shows the active power results for the same reference active power change for the selected minimum and maximum virtual reactance values. The results

demonstrate that the lower the value of  $X_v$ , the greater the overshoot with the reference change. However, the low-frequency damping remains similar regardless of the value of  $X_v$ .

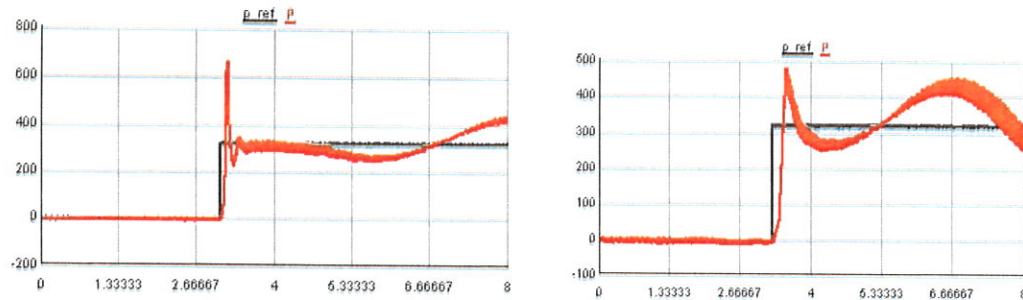


Figure 2. Left plot:  $X_v = 0.075$ ; Right plot:  $X_v = 0.3$

The evolution of the active power for the minimum and maximum values of  $\tau_{lpf}$  are represented in Fig. 3. The results show that the higher the value of  $\tau_{lpf}$ , the greater the overshoot and the lower the damping at low frequencies.

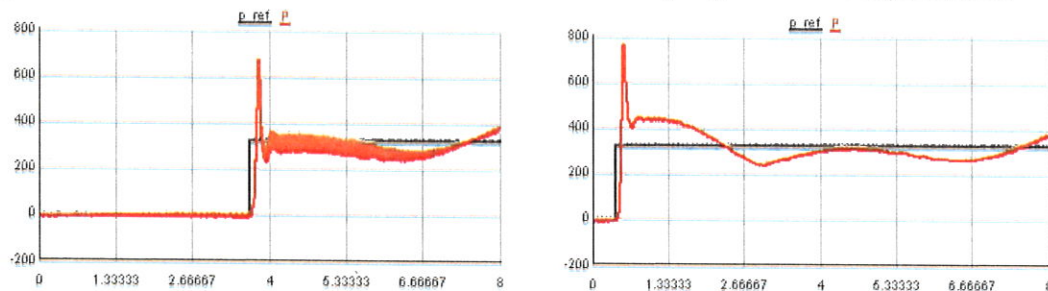


Figure 3. Left plot:  $\tau_{lpf} = 0.01 \text{ ms}$ ; Right plot:  $\tau_{lpf} = 0.04 \text{ ms}$

Based on these results, the values that lead to the lowest overshoot and highest damping are selected for the P-HIL tests. These values are  $K_{pp} = 0.03$ ,  $X_v = 0.2$  y  $\tau_{lpf} = 0.01 \text{ ms}$ . With respect to the values of the actual voltage source in the simulator, the chosen values are: resistance  $R = 0.085 \text{ } \Omega$ , inductance  $L = 0.25 \text{ mH}$ , and a low-pass filter with a cutoff frequency of 300 Hz for the current sent from the converter to the simulator. The simulation execution step is selected at  $10 \text{ } \mu\text{s}$  and the converter controller at  $62.5 \text{ } \mu\text{s}$ . The amplifier delay is  $3 \text{ } \mu\text{s}$ . Under these conditions, a change in the active power reference is performed, observing an acceptable overshoot and damping considering the evolution of the active power and angular frequency of the single-phase grid-forming controller as shown in Fig. 4.

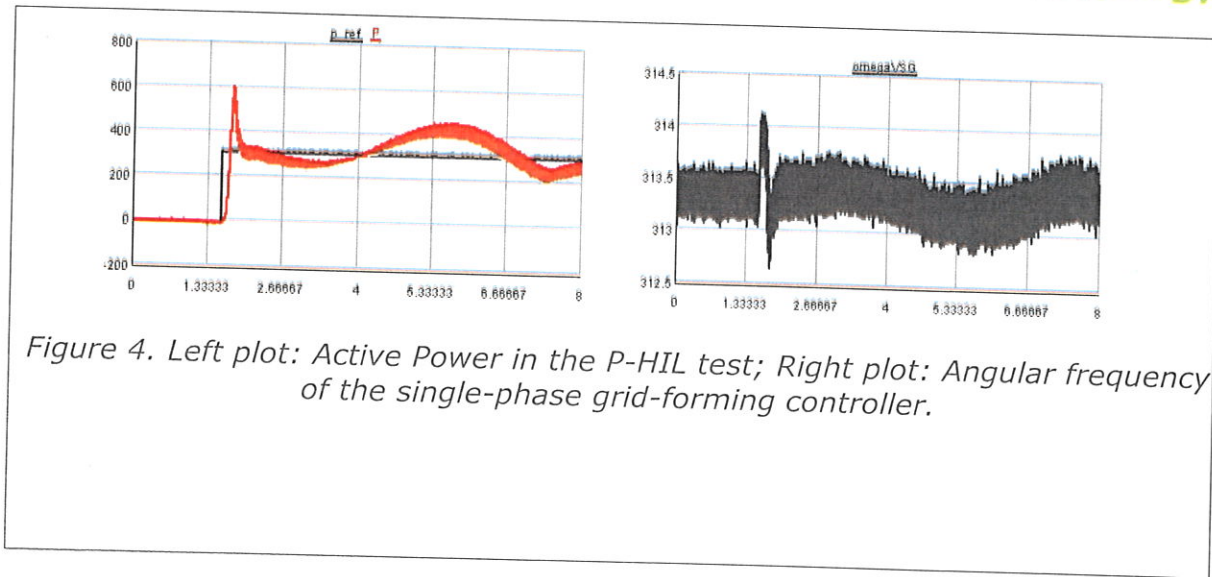


Figure 4. Left plot: Active Power in the P-HIL test; Right plot: Angular frequency of the single-phase grid-forming controller.

#### Interpretation of the results (up to 400 words)

*[Discuss the data obtained and describe the major scientific conclusions drawn.]*

The results obtained allowed us to identify which control parameters are most relevant for reducing overshoot and improving damping in single-phase GFMCs. This was achieved thanks to the tool developed for performing small-signal studies. A multitude of tests were performed on the control parameters identified as most critical in terms of GFMC stability. The previous section shows some of these results to demonstrate the impact on the dynamic response for extreme values in the selected control gains. These tests included a sweep from low to high values that ensure stability in the developed model. Furthermore, these values were validated through Virtual PHIL tests in the dedicated software of Triphase before carrying out the experimental results. Voltage, current, power, and frequency values were recorded in the converter and in the simulator, demonstrating that the selection of control parameters through sensitivity analysis led to a good dynamic response of the GFMC. From our point of view, the main scientific conclusions that can be drawn from this work are: i) the need to improve the tool that allows evaluating the stability and dynamic performance of single-phase GFMC, considering the presence of sinusoidal signals over time. Our tool has allowed us to evaluate stability but without the ability to perform a dynamic response analysis. To evaluate the dynamic response, a sensitivity analysis had to be performed on the most critical control parameters as discussed in the previous section. ii) Reconsider the control of single-phase GFMC with respect to three-phase GFMC. The inclusion of low-pass filters to generate the virtual system in single-phase systems and the implementation of identical controls as in three-phase systems have a high impact on the dynamic response: higher overshoot and lower damping. This raises the need to make some modification to the single-phase GFMC to compensate for this additional dynamic response, or to consider a single-phase GFMC control that avoids this conversion to a virtual system. iii) Tuning the GFMC parameters when connected to the linear amplifier maintains a dynamic response similar to the results when performing P-HIL tests using P-HIL loop stabilization techniques by including a low-pass filter in the currents sent from the converter to the simulator.

#### Main achievements during the TA related work (up to 250 words)

*[Describe the main achievements during your stay at the site(s), Outputs (results, publications, models, etc.), conclusions, next steps, potential impact]*

The major achievements are the following:

- Small-signal modeling of a single-phase GFMC, considering all the dynamics included in the system. This allowed for stability analysis.
- This small-signal analysis was used to identify the single-phase GFMC control parameters that have the greatest impact on its stability.
- Validation of the dynamic response of the control parameters identified through sensitivity analysis using experimental results.
- Selection of control gains through sensitivity analysis for performing P-HIL tests.



From the theoretical analysis and the experimental results obtained, the host and user group have decided to submit a joint publication for the 8th International Conference on Smart Energy Systems and Technologies (SEST'26): <https://www.sest2026.com/>. These results represent an advance on the work carried out by both groups regarding single-phase GFMC and presented at SEST'23: "Assessment of Control Strategies for Single-Phase Grid-Forming Voltage Source Converters", which evaluated this approach in isolated systems without theoretical analysis such as the one developed in this work. Therefore, this work will shed light on the safe and robust deployment of single-phase GFMC of high relevance in low-voltage systems such as microgrids.

This study has also opened new scientific challenges such as the need to find a tool that allows stability and dynamic response analysis considering the characteristics of single-phase GFMC. Therefore, the next step to be taken after the stay is to find the tool that allows to adequately analyze the dynamics of the single-phase GFMC to then validate the results derived from this theoretical analysis through experimental results.

#### Data Management

*[Describe the further usage and storage of project data. State where the data will be kept and name a person responsible for the data. Define data]*

The experimental results data have been stored at NTUA's own facilities and in a OneDrive folder in Andrei Mihai's work account. This folder is shared with the rest of the workgroup's users, and Andrei Mihai is responsible for storing it. The stored data includes figures in PNG and PDF formats of all the experimental results, as well as .mat files containing the numerical values of these data during the tests. The time, currents, voltages, active and reactive powers, and converter frequencies have been recorded during the tests. This data will be used to generate the results and analysis of the joint publication between the host and the user group explained in the previous section.

#### Difficulties during the TA related work (up to 250 words)

*[List problems and issues, you had, completing out your research project: Did you get access to all the necessary equipment, facilities, databases, etc.? If not, please specify the problems that occurred and list equipment that was not working or accessible.]*

NTUA equipment and facilities were available to users at all times. NTUA staff was always available to assist us during the experimental tests. The greatest difficulty in carrying out the research project arose from the difficulty of finding a theoretical model that faithfully represents the dynamics of the single-phase GFMC. This required more effort than expected in adjusting the small-signal model to match the simulations in virtual PHIL and the dedicated Triphase software, which faithfully represent the converter models. Despite this difficulty, conclusive experimental results were obtained, as shown in the previous sections, and it has allowed us to identify new lines of research that improve upon the results obtained in this work.

#### Intended publications

<p><i>[Explain where and how you expect to publish the outcomes of your project work. Include also anything already published (What and where?)]</i></p> <p>The experimental results obtained and the theoretical analysis carried out will be submitted at the 8th International Conference on Smart Energy Systems and Technologies (SEST'26): <a href="https://www.sest2026.com/">https://www.sest2026.com/</a>. This conference will allow for a discussion on the challenges of tuning single-phase GFMC to obtain a good dynamic response, as well as the tools that allow this analysis to be performed. Furthermore, this conference historically selects 70% of its papers for journal extension, which would allow further progress in the new lines of research developed during this project.</p>
<p><b>Expected impact</b></p>
<p><i>[The impact the expected results will have on current and future research or practice, public safety, European standardization, competitiveness, integration and cohesion and on sustainable growth. any follow on proposals, projects, collaborations, commercialisation]</i></p> <p>The main result of this work is the establishment of a platform that allows the validation of single-phase GFMCs and their functionalities in a P-HIL environment. This is of paramount importance for the technology transfer from research centers to industry, as validation in P-HIL is considered as one of the preliminary steps for the development of technologies and new control proposals in the field. In addition, the close collaboration between the user group and the host RI, obtaining satisfactory experimental results in the laboratory with single-phase GFMCs, encourages the submission of a joint project proposal, mainly at European level, where the validation of single-phase GFMCs by means of P-HIL is part of the experimental validation.</p>
<p><b>Conclusions / additional comments</b></p>



*[Provide any other comments you might have on your work]*

The project proposal was highly ambitious thanks to the prior experience the user and host group had with single-phase GFMCs from ERIGrid 2.0. This prior work primarily identified the need for a tool that would allow for a dynamic study of the control proposal and better understand the dynamic response of single-phase GFMCs. Furthermore, this tool would extend the dynamics involved in P-HIL techniques to include new approaches. The current work has addressed this need by performing a sensitivity analysis using the dedicated software that models the Triphase converter (virtual PHIL) and through PHIL experiments. This has allowed progress to be made in identifying the key control loops and gains needed to ensure the stability and operation of single-phase GFMCs at PHIL. Furthermore, the theoretical analyses performed prior to the visit have opened up new research challenges and opportunities, aiming to find small-signal models that capture the dynamic behavior of single-phase GFMCs.

Did you complete the European Commission User questionnaire  
<https://ec.europa.eu/eusurvey/runner/RIsurveyUSERS>

Yes

**Feedback – HSE, Ethics and Satisfaction**

Please rate on a scale from 1 (excellent) to 5 (poor). Feel free to provide additional comments

Practical information on how to apply for Transnational Access and the overall application process

1 (excellent)	2	3 (neutral)	4	5 (poor)
x	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

*Comment*

Information provided, once your project was accepted, on how to proceed

1 (excellent)	2	3 (neutral)	4	5 (poor)
x	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

*Comment*

Support received at the site(s) regarding technical/scientific matters and logistics

Have you got sufficient support from the RI staff during the project? If not, please, specify the problems. x Yes  No

*Please specify any problems*

<p>RI extension / upgrades required</p>	<p>In your opinion, is the RI needed to be upgraded? If yes, please give an explanation.  <input type="checkbox"/> Yes    <input checked="" type="checkbox"/> No</p>
<p><i>Please specify</i></p>	
<p>Problems with local regulations</p>	<p>Have you had any problems with regulations of the visited RI owner (HSE, lab working hours, etc.)? If yes, please, specify  <input type="checkbox"/> Yes    <input checked="" type="checkbox"/> No</p>



<i>Please specify</i>	
Health and safety issues	Did you encounter any health or safety issue during your research? Please provide details. <input type="checkbox"/> Yes   x No
<i>Please provide details</i>	
Environment & Ethics	Did your research involve the use of elements that may cause harm to the environment, to animals or plants? Please provide details. <input type="checkbox"/> Yes   x No
<i>Please provide details</i>	
Environment & Ethics	Did your research deal with endangered fauna and/or flora and/or protected areas? Please provide details. <input type="checkbox"/> Yes   x No
<i>Please provide details</i>	
Environment & Ethics	Did your research involve the use of elements that may cause harm to humans, including research staff? Please provide details. <input type="checkbox"/> Yes   x No
<i>Please provide details</i>	
Environment & Ethics – Dual use	Does your research have the potential for military applications? Please provide details. <input type="checkbox"/> Yes   x No
<i>Please provide details</i>	
Environment & Ethics – Misuse	Does your research have the potential for malevolent /criminal/terrorist abuse? Please provide details. <input type="checkbox"/> Yes   x No
<i>Please provide details</i>	

Environmental issues	Were any potentially dangerous substances (materials / gases etc.) released into the environment (atmosphere, water, or land)? Please provide details. <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				
<i>Please provide details</i>					
Ethics issues	Are there any other ethics issues that should be taken into consideration? Please specify <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				
<i>Please provide details</i>					
Overall impression of communication and interaction after finishing your TA and related work	1 (excellent)	2	3 (neutral)	4	5 (poor)
	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Comment</i>					
Suggestions for facilities not included in RISEnergy which you would use for your research					
[Please provide suggestions for specific type of facilities missing (RI gaps) or measurement / experiments you would like to perform which can not be done on current RISEnergy facilities.]					
Suggestions how RISEnergy can improve future TA programme, how to make the TA more impactful and how to enable the achievement of high TRL levels					
<i>[Your suggestions]</i>					
<b>Feedback – Pro-active Innovation Support</b>					
Awareness	Did you know about the pro-active innovation support of RISEnergy? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				

<i>[Please specify how you learned about the pro-active innovation support]</i>						
Personal experience		Have you taken advantage of or benefited from the pro-active innovation support? <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No				
<i>[Please provide details]</i>						
Information/service provided by the pro-active innovation support?		1 (excellent)	2	3 (neutral)	4	5 (poor)
		<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>[Please provide details]</i>						

I declare that the above provided information and especially that information on the number of days visited the RI is correct.

*x I have read the [RISEnergy privacy policy](#) for participation in the RISEnergy TA and consent to participation and the associated data processing.*

Your full name:

Your signature: