



TANDEM

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Final SAC recommendations report

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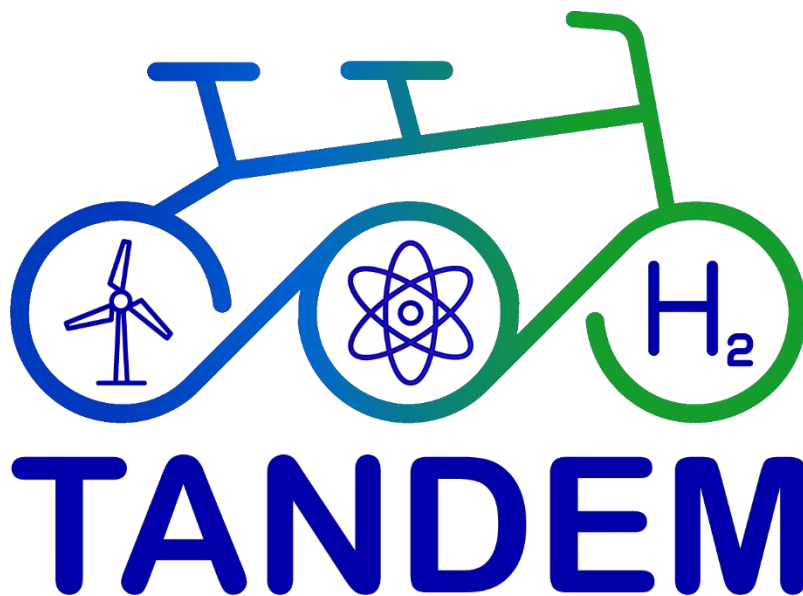
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D7.5 – Final SAC recommendations report

WP7 - Task 7.2

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Abbreviations and Acronyms

Acronym	Description
AMR	Advanced Modular Reactor (Generation IV technologies)
CAPEX	CAPital EXpenditure
EPJN	European Physical Journal on Nuclear Sciences and Technologies
EPRI	Electric Power Research Institute
E&T	Education & Training
EU	European Union
GIF	Generation IV International Forum
H2 TCP	Hydrogen Technology Collaboration Program
HES	Hybrid Energy System
HTSE	High Temperature Steam Electrolyzer
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
INERIS	Institut National de l'Environnement Industriel et des Risques [French National Institute for the Industrial Environment and Risks]
INL	Idaho National Laboratory
IT	Information Technology



IUG	Industrial User Group
LNG	Liquefied Natural Gas
MIT	Massachusetts Institute of Technology
MOOC	Massive Open Online Course
NEA	Nuclear Energy Agency
NEANH (now NECA)	GIF Task Force on Non-Electric Applications of Nuclear Heat, now GIF Working Group on Non-Electric and Cogeneration Applications
NC2I	Nuclear Cogeneration Industrial Initiative, one of the 3 pillars of SNETP
NPHyCo	Nuclear Powered Hydrogen Cogeneration
OECD	Organisation for Economic Cooperation and Development
OPEX	Operational EXpenditure
SAC	Scientific Advisory Committee
SMR	Small Modular Reactor
SNETP	Sustainable Nuclear Energy Technology Platform
VHTR - HP - PMB	GIF Very High Temperature Reactor - Hydrogen Production – Project Management Board
WP	Work Package



Executive Summary

This deliverable constitutes the SAC final recommendations report. It compiles all recommendations made by TANDEM's Scientific Advisory Committee, from the start of the project to its end point. For each recommendation, a brief analysis is provided by the project on how it has been implemented. In addition, the deliverable includes a summary of SAC recommendations on technical ideas for new projects and initiatives beyond the completion of TANDEM.

Keywords

TANDEM, recommendations, Scientific Advisory Committee, SAC, final report



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1 Introduction

The main goals of the TANDEM project are to:

- Develop an integrated vision of energy systems through the implementation of nuclear HES,
- Develop tools and methodologies to study these HES,
- Analyze the role/benefits of multipurpose SMR integrated into these energy systems for the energy transition.

Considering their near-term deployment in Europe (around 2035), the project is mainly focussed on light-water technologies. However, the project also aims to provide perspectives, whenever possible, for the integration of AMR into HES.

The project has set up two external groups, a SAC and an IUG, and regularly interacts with them. The expectations of the TANDEM project from the SAC are to:

- provide feedback and recommendations on the results, scientific choices and orientations of the project;
- support interactions with other European and international initiatives which the SAC members are involved in and which are related to the activities of the project.

The expectations of the TANDEM project from the IUG are to engage in a constructive dialogue on:

- the technological feasibility of HES incorporating SMRs,
- the different energy markets and their particularities,
- regulatory, societal and economic issues related to the implementation of such systems.

The objective of this deliverable is to present the SAC recommendations for TANDEM, from the start of the project to its end point, and to explain how they have been implemented.

After a brief presentation of the positioning and the composition of the SAC, the recommendations associated with each WP are listed and commented on by the project (WP leaders and coordinator). The end of the deliverable includes a summary of SAC recommendations on technical ideas for new projects and initiatives.



2 Positioning and composition of SAC

Numerous international cooperative initiatives have been launched to support the energy transition. Some of the most interesting initiatives for the TANDEM project, considering that these initiatives can provide input data or methodology recommendations on issues addressed by the TANDEM project, are listed below:

- *On European energy policies supporting the energy decarbonisation*: European SET Plan roadmap¹, European Green Deal², Fit for 55³, REPowerEU plan⁴, EU Net Zero Industry Act⁵,
- *On SMR safety, development and licensing*: SNETP/NUGENIA/Technical Area 6 dedicated to innovative LWR design and technology, Euratom projects ELSMOR, SANE and HARMONISE, IAEA booklet on advances in SMR technology developments⁶, IAEA Nuclear Harmonization and Standardization Initiative (NHSI), European Industrial Alliance on Small Modular Reactors, OECD-NEA Working Group on the Safety of Advanced Reactors,
- *On nuclear cogeneration for electricity and heat production*: SNETP/NC2I pillar, Euratom projects GEMINI+, EUROPAIRS, NC2I-R and GEMINI 4.0, Working Group on Non-Electric and Cogeneration Applications in the GEN-IV International Forum,
- *On technical assessments and optimizations of hybrid energy systems*: IAEA Coordinated Research Project I32012 on Technical Evaluation and Optimization of Nuclear-Renewable Hybrid Energy Systems⁷ (ongoing),
- *On techno-economic assessments of energy systems*: IAEA Coordinated Research Project I35004 on Examining the Techno-economics of Nuclear Hydrogen Production and Benchmark Analysis of the IAEA HEEP software⁸ (closed), IAEA Coordinated Research Project I35006 on Assessing Technical and Economic Aspects of Nuclear Hydrogen Production for Near-term Deployment (closed), IAEA Coordinated Research Project I12007 for Economic Appraisal of SMR Projects⁹ (ongoing), OECD-NEA/Working Party on Nuclear Energy economics.

The US Integrated Energy System program, supported by the Department of Energy's Office of Nuclear Energy (DOE-NE), has established in 2020 a roadmap (INL, 2020) for the development of hybrid energy systems integrating nuclear reactors. This program is a pioneer in the analysis of integrated energy systems and the study methodology developed in this framework represents

¹ https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en

² https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

³ https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal/fit-55-delivering-proposals_en

⁴ https://commission.europa.eu/topics/energy/repowereu_en

⁵ https://single-market-economy.ec.europa.eu/industry/sustainability/net-zero-industry-act_en

⁶ https://aris.iaea.org/Publications/SMR_catalogue_2024.pdf

⁷ <https://www.iaea.org/projects/crp/i32012>

⁸ <https://www.iaea.org/projects/crp/i35004>

⁹ <https://www.iaea.org/projects/crp/i12007>



the international State-of-the-Art for the TANDEM project (INL, 2019). US universities (Massachusetts Institute of Technology, North Carolina State University, etc) are also very active concerning the development of advanced and innovative reactors such as SMRs, the coupling between nuclear reactors and energy storage systems, as well as on SMR techno-economics.

To support the interactions with the different initiatives, the project set up a SAC that provides its feedback on the project results and is consulted by the project Executive Committee upon need. The SAC is composed of four members:

- Dr. Shannon Bragg-Sitton, Associate Laboratory Director for Energy & Environment Science & Technology, at the US Idaho National Laboratory (INL), Chair of the GIF Working Group on Non-Electric and Cogeneration Applications,
- Dr. Alina Constantin, technical officer for non-electric applications of nuclear energy, at International Atomic Energy Agency (IAEA), until March 2024,
- Dr. Michael Fütterer, senior expert at European Commission - Joint Research Centre (EC-JRC), leader of JRC project portfolio on SMR, representative of SNETP/NC2I, GIF Technical Director, member of the GIF Working Group on Non-Electric and Cogeneration Applications and of the GIF VHTR system,
- Dr. Koroush Shirvan, Atlantic Richfield Career Development Professor in Energy Studies, at US Massachusetts Institute of Technology (MIT).

3 Follow-up of the SAC's recommendations

The recommendations reported in this deliverable have been expressed during specific meetings:

- a first dedicated meeting with the SAC members was organized remotely on 8 March 2023 (TANDEM/SAC, 2023a),
- the SAC members were invited to attend the full annual project reviews in person (with a possibility of remote attendance as well):
 - in Milan (Italy) on 5 + 6 October 2023,
 - in Brussels (Belgium) on 29 + 30 October 2024,
 - in Brussels (Belgium) on 3 July 2025.

A dedicated session with the SAC members and the TANDEM management team was organized at the end of each project review (TANDEM/SAC, 2023b) (TANDEM/SAC, 2024).

Most of the recommendations have been expressed between the start and mid-term of the project. The project has assigned a priority to each recommendation, depending on whether:

- the recommendation can be implemented as part of the TANDEM work program or if it requires extra work,
- the impact of the recommendation on the project result.



Recommendations beyond the scope of the current project will have to be re-analyzed when preparing a follow-up to TANDEM (potential new Euratom project for the next call in 2026).



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3.1 General recommendations

Two general recommendations have been expressed by the SAC and are reported in Table 1.

Recommendations	Date of recomm. submission	Priority ¹⁰	Status/ comments
To ensure cross-cutting collaboration and maximized impact, the Euratom projects on nuclear hydrogen production TANDEM and GEMINI4.0 have set up working groups on four topics of common interest for both projects: Safety of nuclear polygeneration; Communication and public engagement; Techno-economics and short and long-term impact of nuclear on energy decarbonisation; Flowsheet for hydrogen production. Another project (NPHyCo) will join the working groups. The objectives of the project collaboration are to explore synergies between projects, share key results, identify points of convergence and divergence. The SAC recommends extending the discussion to international initiatives, such as GIF (initially, Task Force of Non-Electric Applications of Nuclear Heat, NEANH, transitioned to be now Working Group on Non-Electric and Cogeneration Applications, NECA), IAEA or OECD/NEA, beyond the European framework on which the projects will initially focus.	05-06/10/2023	2	<p>Partially implemented.</p> <p>A joint publication (Serin, 2025) between GEMINI 4.0/ NPHyCo and TANDEM has been issued in 2025. Beyond the presentation of the projects and results, the publication highlights main common outcomes on hydrogen production via nuclear energy.</p> <p>Various activities enabled to extend the discussion to international initiatives, such as:</p> <ul style="list-style-type: none"> - the inclusion of a TANDEM presentation in the Nuclear-Hydrogen Digest prepared by NICE Future¹¹ - the presentation of TANDEM during a joint meeting of GIF/NEANH TF, GIF/VHTR HP PMB, IEA-H2 TCP/Task 44 and OECD/NEA, on hydrogen production with nuclear energy, at Idaho Falls, USA, January 22-25, 2024, - the presentation of a common TANDEM/GEMINI 4.0/NPHyCo paper at SNETP Forum 2024 in Rome.

¹⁰ Priority is defined from 1 (high priority) to 3 (low priority).

¹¹ Available at <https://www.nice-future.org/docs/nicefuturelibraries/default-document-library/nuclear-hydrogen-digest.pdf>

			<ul style="list-style-type: none"> - the presentation of the TANDEM project during an IAEA Technical Meeting on Recent Developments in Cogeneration Processes in Member States, on November 12-14, 2024, - the sharing of the TANDEM policy brief during an IAEA Technical Meeting on Specific Infrastructure Considerations for Nuclear Cogeneration Applications on April 23-25, 2025; - upon completion of the projects, JRC will produce a policy brief document integrating the findings from TANDEM/GEMINI 4.0/NPHyCo; - a joint paper TANDEM/GEMINI 4.0/ NPHyCo was proposed to the CONCORDI 2025 conference (Pasquet, 2025), but was not accepted. <p>Analyzing, publishing and communicating the results of the projects required efforts not initially foreseen by the projects (in particular no available funding of participants in working groups). This analysis required preparation and convergence of deliverables, which were scheduled only for the end of the projects. In addition useful high-level analysis would be possible only after completion of all three projects, for which most project participants would require additional budget.</p>
The TANDEM project has no formal contact with OECD/NEA for the moment. The SAC recommends that NEA interviews the TANDEM coordinator about the project activities. This may be included in the still ongoing	05-06/10/2023	2	<p>Implemented.</p> <p>The TANDEM coordinator has not been interviewed by NEA about the project activities. However, contacts have been established with</p>



scenario studies or a Stakeholder report (contact: Lucas Mir).			<p>OECD/NEA. Indeed, the TANDEM project was presented on two occasions at meetings attended by OECD/NEA representatives:</p> <ul style="list-style-type: none"> – a joint meeting of GIF/NEANH TF, GIF/VHTR HP PMB, IEA-H2 TCP/Task 44 and OECD/NEA, on hydrogen production with nuclear energy, on January 22-25, 2024, – A meeting of OECD/NEA Working Group on Hydrogen Value Chain on June 7, 2024.
SAC recommended amplifying the dissemination of the TANDEM outcomes because a lot of different communities (energy-intensive consumers, decision makers, utilities, researchers, etc.) could be interested by these results.	03/07/2025		<p>Still under implementation.</p> <p>Planned to be provided after project completion. Possible for this are related groups at SNETP (NC2I), GIF (NECA), OECD/NEA or IAEA.</p>

Table 1. General recommendations.

3.2 Recommendations for WP1

The main objective of WP1 is to define and characterise basic concepts for configuring hybrid energy systems. Two typical hybrid system configurations are selected to cover the main trends shown by the energy market evolution, i.e. a district heating network and power supply in an urban area, and an energy hub serving energy conversion systems in a regional perspective. The outcomes of this WP provide data to other WPs with the aim of drafting European energy scenarios, technical characteristics of hybrid systems for modelling, and techno-economic data for optimisation among others.

The recommendations expressed by the SAC for WP1 are reported in Table 2.



Recommendations	Date of recomm. submission	Priority	Status/ comments
The sharp increase of hydrogen use in the next decade predicted in several energy scenarios represents a market pull and should be considered in TANDEM to justify the need of widespread deployment of SMRs.	08/03/2023	1	<p>Implemented - see (TANDEM/D1.4, 2023).</p> <p>TANDEM focuses mainly on two HES configurations: a District Heating configuration and an Energy Hub Configuration. Hydrogen production is included in the Energy Hub as a must with respect to current energy markets.</p> <p>For the District Heating configuration, hydrogen production is also considered; for instance, depending on the case, the excess heat can be used for hydrogen production outside the heating season.</p>
A low and high deployment scenario, at the horizons 2035 and 2050, will be considered in the TANDEM studies as the baseline scenario and the preferred scenario to justify the need and the role of SMRs for decarbonisation. However, the SAC recommends considering even a more ambitious scenario than the preferred one envisaged by TANDEM, namely to highlight the benefits that SMRs could achieve for decarbonization reaching carbon-neutrality in 2050 in the EU.	08/03/2023	1	<p>Implemented - see (TANDEM/D1.4, 2023).</p> <p>TANDEM considers three energy contexts in its studies to show the benefits of SMR penetration for the energy transition :</p> <ul style="list-style-type: none"> - Context in 2035 with no SMR deployment (energy sources: renewables and fossil-fuel fired plants), - Context in 2035 with the start of SMR deployment (energy sources: renewables, SMRs and fossil-fuel fired plants), - Context in 2050 with no fossil-fuel fired plants (sole energy sources: a mix of renewables and SMRs). Even though 2050 context and boundary



			conditions are highly speculative, it is believed that it will be demonstrative.
The SAC recommends a careful selection of the type of fossil fuels (coal/gas) and plants which need to be decarbonized first in the TANDEM energy study cases, considering both decarbonization targets (which would put substitution of coal first) but also energy security in Europe (which would put substitution of natural gas first).	08/03/2023	2	Implemented - see (TANDEM/D1.4, 2023). The coal fired power units are currently the strongest CO ₂ emitters with a clear benefit in being replaced by SMRs if only for their CO ₂ footprint, and as such are considered as a first key target for energy sector decarbonization. However, partly because of the rather obvious conclusion for coal fired units replacement, gas fired units are preferred in the study for their significant cogeneration role in the 2035 horizon energy landscape. At the same time, the urgency regarding replacement of natural gas for increased energy security in Europe has decreased during the project duration, due to successful replacement of Russian pipeline gas by LNG from more diversified sources.
The SAC suggests WP5 to use the existing WP1 deliverables to help answer energy policy relevant questions.	05-06/10/2023	2	Implemented. TANDEM policy briefs (TANDEM/D5.1, 2025) have been prepared based on WP1 deliverables.
The SAC recommends adding the EU Net Zero Industry Act to the list of ongoing energy policy initiatives.	05-06/10/2023	2	Implemented The joint article about the GEMINI 4.0/ NPhyCo/ TANDEM projects published in the EPJN journal (Serin, 2025) cites the EU Net Zero Industry Act as part of the European energy policy framework.

Table 2. Recommendations for WP1.



3.3 Recommendations for WP2

The WP2 is devoted to:

- the identification of the modelling approach and the requirements needed by the simulation tools to be employed in SMR safety analyses (WP4), as well as in techno-economic assessment (WP3),
- the development of an Open-Source “TANDEM” model library aimed at simulating the behavior of power plants, systems and components, including SMRs, and needed to analyse the hybrid energy systems,
- the development of SMR models with both CATHARE and ATHLET safety codes to perform the safety analysis considering the integration of SMRs into hybrid energy system,
- the delivery of a hybrid system simulator to develop a coupling with the SMR CATHARE and ATHLET models in WP2, and techno-economics tools in WP3.

The recommendations expressed by the SAC for WP2 are reported in Table 3.

Recommendations	Date of recomm. submission	Priority	Status/ comments
The SAC recommends full clarity and documentation of the hypotheses and boundary conditions associated with the developed models in the TANDEM Modelica-based library, and the limits of these models. This information needs to be available for the users of the library, in the manual describing the models, so that in future they could be checked (e.g., to better understand certain modeling results) and possibly improved.	08/03/2023	1	Implemented. As the TANDEM library is open-source, the preparation of user-oriented documentation has been identified as a very important action in WP2. In (TANDEM/D2.3, 2024), a description of the models is provided. In addition, to support the long term maintenance, the TANDEM library includes Markdown ¹² documentation to provide more practical information to the users.

¹² <https://www.markdownguide.org/getting-started/>



SAC recommends putting efforts into drafting the documentation associated to the Modelica-based TANDEM library, containing numerical models of the hybrid energy systems. It will enable the library to be used beyond the project participants.	05-06/10/2023	1	Implemented. This recommendation is aligned with the previous one.
SAC recommends including production of cold (district cooling) in the Modelica models.	05-06/10/2023	3	Not implemented. Due to limited resources, a Modelica model dedicated to district cooling could not be developed within the TANDEM framework. This option is explored in a possible follow-up of the TANDEM project.
SAC recommends opening up to the scientific community the hybrid energy system simulators to be developed during the project, based on the TANDEM library.	05-06/10/2023	1	Implemented. The TANDEM library and the HES simulators developed during the project are available in a git repository ¹³ .
SAC recommends providing typical values of parameters characterizing hybrid energy system components in an open way in the TANDEM library.	05-06/10/2023	1	Implemented. These typical values are available in the Modelica file dedicated to each HES component as default parameters. However, these have to be considered indicative and have to be used carefully since they may not be representative of all HES configurations.

¹³ <https://gitlab.pam-reted.fr/tandem/tandem>



SAC suggests developing a graphical interface associated with the hybrid energy system simulators to make them more user-friendly.	05-06/10/2023	3	<p>Not implemented.</p> <p>Due to limited resources, a graphical interface has not been developed within TANDEM. In any case, Modelica Integrated Development Environments (IDEs) usually provide a user-friendly graphical interface.</p>
SAC recommends keeping the possibility open to develop other reactor models than the E-SMR concept (other light-water SMR concepts, large light-water reactors including their flexibility for load following, or AMRs) in order to implement them in the modeling of hybrid energy systems with the TANDEM library.	05-06/10/2023	1	<p>Implemented.</p> <p>The TANDEM library is modular and the developers have kept the option to integrate other reactor models or other downstream component models beyond the scope of the project.</p>
SAC recommends including modules for different temperature boosting technologies.	05-06/10/2023	1	<p>Partially Implemented</p> <p>High-Temperature Steam Electrolyzers (HTSE) for hydrogen production include a steam heater before steam entrance in the electrolyzer - see Figure 23 in (TANDEM/D3.1, 2023).</p> <p>The different temperature boost techniques (e.g, resistance heating, compression heat pumps, chemical heat pumps) have not been explicitly formulated in TANDEM, even if they feature different performance values and have different requirements.</p>

Table 3. Recommendations for WP2.



3.4 Recommendations for WP3

The techno-economic and environmental dynamic assessment of hybrid energy systems is carried out to investigate the operability, profitability and environmental impact of such systems. The WP3 objectives are:

- Detailed identification of relevant study cases,
- Identification of component features and key performance indicators relevant at techno-economic and environmental levels,
- Techno-economic analysis of the hybrid energy systems, optimization of the system architectures and main component sizing associated with operating rules,
- Selection and use of suitable tools with their models and methodologies for such an assessment,
- Analysis of the energy production flexibility required by such hybrid systems.

The recommendations expressed by the SAC for WP3 are reported in Table 4.

Recommendations	Date of recomm. submission	Priority	Status/ comments
SAC recommends establishing contacts with investors to check whether the techno-economic information produced in TANDEM is appropriate for producing business plans and applications for financing. Indeed, the results of the TANDEM projects will be science-based, they will be justifiable, and they can be helpful to convince investors.	08/03/2023	3	Not implemented. It was not possible to establish contact with investors during the course of the project. However, TANDEM did interact with its Industrial User Group (IUG).
SAC suggests thinking about a way to take into account the techno-economics data associated with the nuclear fuel cycle (in particular waste management and decommissioning) in the HES techno-economics assessments.	08/03/2023	1	Implemented. The costs associated with the nuclear fuel cycle (in particular fuel reprocessing, waste, warehousing or storage) are included in the SMR OPEX (OPERational EXpenditure) value used by the techno-economics



			<p>tools (Backbone and PERSEE) implemented in TANDEM.</p> <p>The cost associated with reactor dismantling are included in the SMR CAPEX (CAPital EXpenditure) value used by the techno-economics tools (Backbone and PERSEE) implemented in TANDEM.</p>
In the figures of the energy hub in WP3, SAC recommends systematically including a pre-heater in the representation of High-Temperature Steam Electolysis (HTSE) for hydrogen production: it will make it clearer that low-temperature steam produced by light-water SMRs needs to be super-heated for the HTSE process.	05-06/10/2023	1	<p>Implemented.</p> <p>See Figure 11 in (TANDEM/D3.1, 2023).</p>
SAC recommends taking into account in the studies growing effects of demand-side variability due to growing electrification (e.g. e-cars, heat pumps, etc.) and the evolution trend of the peak load to base load ratio for electricity in the future.	05-06/10/2023	2	<p>Not implemented.</p> <p>The TANDEM project has assumed that the production ratio (in steady state operation) between heat, hydrogen and electricity will remain the same in 2035 and 2050.</p> <p>If this ratio changes, the HES may need to be redesigned.</p>
SAC recommends assessing environmental sustainability of hybrid energy systems in the framework of WP3 activities. For the moment, only carbon emissions will be taken into account in the environmental impact assessment carried out by TANDEM. It will be necessary to collect data (related to waste, land footprint, water usage, for instance) for each hybrid energy system component, which is not an easy task. Information could	05-06/10/2023	3	<p>Not implemented.</p> <p>The techno-economics tools (Backbone and PERSEE) implemented in TANDEM do not take into account environmental sustainability as an indicator. Taking it into account would require</p>



be found in published work by the US Argonne National Laboratory.			important R&D work beyond the scope of the TANDEM project ¹⁴ . However, carbon emissions from materials recycling, for example, are taken into account when assessing the carbon footprint of hybrid energy systems.
SAC recommends checking the values and the assumptions related to the projection of the cost evolution in 2035 and 2050; indeed, the values of the variable costs in (TANDEM/D3.1, 2023) seem to be low and would benefit from adjustment due to increased inflation and interest rates. Besides, it would be suitable to be precise in the document in which countries these values are assumed to be valid/applicable, e.g., due to different labor costs.	05-06/10/2023	1	Partially implemented. The variable cost data generally come from the open literature. For example, the variable OPEX for French SMR prospective is consistent with the data provided by Enerdata ¹⁵ . CAPEX and variable OPEX are prospective values for 2035 in € ₂₀₂₂ (TANDEM/D1.3, 2023); In (TANDEM/D3.2, 2024), CAPEX and variable OPEX were revised upwards (+~6%) due to an update of the sources end of 2023. Besides, a sensitivity analysis to these two costs has been conducted in (TANDEM/D3.3, 2024): it shows that the sensitivity is quite significant to the levelized costs of electricity and hydrogen.
SAC recommends opening the data related to the description of three study cases (Northern and Central Europe cases for district heating applications, and	05-06/10/2023	1	Partially implemented. The contributors to WP3 studies presented the input data that led to the results in (TANDEM/D3.2,

¹⁴ Reflections are ongoing in a PhD work at CEA Grenoble [Diego Larrahondo Chavez, « Multi-objective optimization approach for the eco-design of energy systems: application to hydrogen technologies »].

¹⁵ <https://yearbook.enerdata.net/>



Southern Europe case for the energy hub), which could serve as benchmarks for the international community. Even if an exhaustive description of the study cases will probably not be possible, it is valuable to provide at least the input and output data for each study case. This may cover different energy products such as electricity, heat, chilled water, desalinated water etc.			2024). However, this has not been done with the aim of constituting future benchmarks for optimisation tool cross-comparisons, which requires specific efforts. The level of description of the case studies in WP3 is probably not sufficient to constitute benchmarks.
SAC recommends including a simple case study concept for demonstrators and first adopters.	05-06/10/2023	3	Not implemented. This action goes beyond the work program planned in TANDEM.
SAC suggests adding a scenario for arid regions covering generation of electricity, district cooling, desalination and air-cooled reactors.	05-06/10/2023	3	Not implemented. This action goes beyond the work program planned in TANDEM.
SAC suggests including a cost of complexity (like in IT).	05-06/10/2023	3	Not implemented. Before a potential implementation, it will be necessary to provide a clear definition of the cost of complexity, and an assessment of the possible financial penalty to be associated with this cost, which is not trivial.

Table 4. Recommendations for WP3.

3.5 Recommendations for WP4

WP4 aims to identify the specific constraints and risks that could be induced on SMRs resulting from their integration in hybrid energy systems. A methodology for assessing the resulting potential impacts on safety is proposed in WP4 and is applied to safety case studies. These studies are derived from the energy study cases and associated hybrid systems described by WP1. The main expected outputs are:



- List of safety relevant parameters potentially impacted by SMR specific operational constraints,
- A method for demonstrating that SMRs can be safely operated within a hybrid energy system,
- Exemplification of this method by selected safety cases,
- A set of validated numerical models relevant for safety assessment of the SMR as part of a hybrid energy system.

The recommendations expressed by the SAC for WP4 are reported in Table 5.

Recommendations	Date of recomm. submission	Priority	Status/ comments
SAC recommends establishing contact with nuclear regulators and non-nuclear regulators, e.g., for chemical sites. Depending on the country, different types of structures exist for non-nuclear regulators, it is quite difficult to have contact with them about topics regarding nuclear. It could be very useful if TANDEM could contribute to communication activities towards non-nuclear regulators.	08/03/2023	1	Implemented. WP4 leader (ASNR) and coordinator (CEA) presented the TANDEM project to the French National Institute for the Industrial Environment and Risks (INERIS) in December 2023. INERIS agreed to join the TANDEM IUG in 2024, and has since been a regular participant in TANDEM meetings (IUG meetings and annual consortium meetings).
SAC recommends getting in touch with non-nuclear regulators to have their feedback regarding the process to assess hybrid energy system safety, and inviting them to join the next IUG meeting.	05-06/10/2023	1	Implemented. Same comment as the previous one.
SAC recommends consulting open literature related to hybrid energy system safety. EPRI has recently released a document related to the safety of systems integrating district heating networks. INL released a document about risk assessment in a light water reactor coupled with	05-06/10/2023	1	Implemented.



electrolysis hydrogen production plants (https://inldigitallibrary.inl.gov/sites/sti/sti/Sort_67319.pdf). Further analysis had been prepared by the US NGNP Industry Alliance in the frame of different case studies (e.g. Wyoming, Kentucky).			
SAC suggests for WP4 to turn from the current issue-identification focus towards a more solution-oriented focus. Ways should be found to better engage the IUG in the project (similar problem in other Euratom projects).	05-06/10/2023	1	Not implemented. General principles related to safety conditions with a electrical load rejection, an increase or decrease of the heat demand by end-users, have been addressed in the WP4 analyses.

Table 5. Recommendations for WP4.

3.6 Recommendations for WP5

WP5 is focused on:

- the analysis of the results from the other WPs and framing recommendations (relative to technical, economic and societal issues) and policy briefs for SMR integration within a European decarbonized energy mix,
- stakeholder engagement development,
- the communication and dissemination of TANDEM results,
- a citizen engagement assessment.

The recommendations expressed by the SAC for WP5 are reported in Table 6.

Recommendations	Date of recomm. submission	Priority	Status/ comments
SAC recommends that the assumptions and limitations of applicability of the simulations performed for the studied	08/03/2023	1	Implemented.



systems be clearly highlighted, especially in the outreach and dissemination activities, as well as in the training sessions to be organized. The general lines that can be derived from these studies can also be very helpful to highlight in the communication and advocacy with the different stakeholders for the safe use of SMRs in hybrid energy systems.			This topic was addressed during the TANDEM Summer School (Lecco, Italy, June 2024) and a training workshop organized by the project (Pisa, Italy, 2025).
SAC stresses the importance of developing the link with the TANDEM IUG; this can help raise awareness of the potential of SMRs for industrial applications and better understand the associated challenges, while obtaining useful feedback on industry needs and expectations.	08/03/2023	1	<p>Implemented.</p> <p>The project strengthened the link with the IUG. Three dedicated meetings with the IUG members were organized:</p> <ul style="list-style-type: none"> - on March 29, 2023 (TANDEM/IUG, 2023), - on April 5, 2024, - on January 29, 2025. <p>The IUG members were systematically invited to attend the annual meetings of project review and the events organized by the project (webinars, Education & Training (E&T) workshops, TANDEM final conference, etc).</p>
SAC recommends contacting industrial companies, e.g. in Poland, to learn more about their decarbonization needs, specific frameworks and constraints, and to explain the potential of a nuclear solution. The SNETP/NC2I initiative can provide contacts, if needed.	08/03/2023	2	<p>Implemented.</p> <p>TANDEM contacted representatives of KGHM to be part of the IUG and appointed them as IUG members.</p>



SAC suggests taking note of the proceedings ¹⁶ of the workshop organized in Toronto, in 2022, by the GIF Task Force on NEANH). They contain valuable information regarding the industrial needs to decarbonize energy and requirements as to how to integrate nuclear. The SNETP Forum organized in Gothenburg (Sweden) in May 2023 is a further opportunity to share these needs.	08/03/2023	2	Implemented.
SAC suggests presenting activities of the TANDEM project at the first conference on SMRs and their applications organized by IAEA on 21-25 October 2024, or conferences such as Atoms4NetZero.	05-06/10/2023	1	Implemented. Several papers on the TANDEM project and activities were orally presented during the IAEA SMR conference: (Masotti, 2024a), (Masotti, 2024b), (Simonini, 2024), (Vaglio-Gaudard, 2024).
SAC recommends preparing a policy maker engagement plan to facilitate the interaction with policy makers if possible beyond the TANDEM project duration, e.g. through SNETP/NC2I.	05-06/10/2023	3	Not implemented. The preparation of a dedicated policy maker engagement plan goes beyond the work program planned in TANDEM. However, policy makers are included in the global Stakeholder Engagement Plan drafted by TANDEM partners (TANDEM/D5.3, 2023) and one of the TANDEM deliverables is a dedicated policy brief (Deliverable 5.1).
SAC recommends adding (potential) investors to the stakeholder group.	05-06/10/2023	3	Not implemented. The project did not have the opportunity to meet and bring investors on board for its IUG.

¹⁶ https://www.gen-4.org/gif/jcms/c_209137/gif-neanh-workshop-proceedings-2022-10-03



SAC recommends adding representatives of the chemical industry in the IUG because they also have challenges to meet with energy decarbonization.	05-06/10/2023	2	<p>Not implemented.</p> <p>It was quite challenging to establish active involvement and continuity in the dialogue with the IUG members. For practical reasons, most of the interactions between the IUG and the project were based on remote attendance, which does not facilitate discussions. The project preferred not to expand the group too much, in order to facilitate discussion with existing members.</p>
SAC recommends sustaining the IUG implemented by TANDEM beyond the end of the project, potentially via the SNETP framework.	05-06/10/2023	1	<p>Still under implementation.</p> <p>TANDEM initiated discussions with SNETP to see how to proceed, using the SNETPForward framework through its Stakeholders Engagement Committee.</p> <p>Other possibilities have been discussed with the SAC (TANDEM/SAC, 2024) to propose IUG members to join end-users' groups of other Euratom projects, the European Industrial Alliance on SMRs, the Non-Electric and Cogeneration Applications Working Group of the Generation-IV Forum, the World Nuclear Association or SNETP/NC2I.</p> <p>The IUG Chairman will contact the IUG members to present different possibilities to them.</p>
SAC recommends involving IUG members for the assessment of citizen engagement during workshops organized by TANDEM. Industrials have in general	05-06/10/2023	2	<p>Not implemented.</p> <p>Four citizen events supported by the TANDEM project were organized between 2024 and 2025 in</p>



effective means of communicating their needs in terms of energy decarbonization.			<p>collaboration with context-specific organizations. At least one TANDEM partner (VTT, UJV or Nucleareurope) was involved in the organisation of each event.</p> <p>The content of the events focused on providing information and increasing understanding of SMR technology, as well as fostering open discussion and dialogue between the public and experts.</p> <p>The fourth workshop organized in Belgium aimed to facilitate peer-to-peer learning and the exchange of best practices among participants regarding stakeholder engagement strategies.</p> <p>In this framework, it was not necessary to involve IUG members in the interactions with stakeholders (although some energy intensive industries were invited to join the workshop in Belgium).</p>
SAC supports the idea of organizing a workshop about licensing, as already suggested by IUG members.	05-06/10/2023	3	<p>Not implemented.</p> <p>This action goes beyond the work program planned in TANDEM, and could not be implemented.</p>
SAC members and TANDEM WP leaders share the difficulty to practically involve IUG members and to make them participate in meetings organized by the project. In order to have a more effective engagement, SAC members recommend the following strategy, even if it seems to be beyond the strict perimeter of the TANDEM project:	05-06/10/2023	2	<p>Not implemented.</p> <p>The project did not have enough resources to implement such a strategy.</p>



<ul style="list-style-type: none"> ✓ Prepare a written support to deliver to IUG members. This support will explain the SMR role in the energy decarbonisation; ✓ Organize face-to-face discussions and meet each company involved in the TANDEM IUG in their own offices; ✓ Involve the European SNETP platform to support TANDEM in the engagement of IUG members. 			
SAC recommends to merge the IUGs of GEMINI 4.0 and TANDEM, since both projects are working on polygeneration with nuclear reactors.	05-06/10/2023	2	Not implemented. Integrating the different industrial stakeholders in the EU is in the remit of SNETP/NC2I.

Table 6. Recommendations for WP5.

3.7 Recommendations for WP6

WP6 addresses the importance of adequate knowledge transfer within the domains covered by the TANDEM project. The main objectives of this WP are to:

- identify the current and expected future needs of E&T related to the SMR safety, including the implications of their coupling in hybrid energy systems,
- design, plan and deliver specific E&T actions and courses both on the subject topics and also on the specific results and findings produced in the TANDEM project,
- develop a strategy to implement future E&T requirements in these fields, in order to deliver recommendations to adequately shape the offer of courses, materials and programs so that the needs for professionals to be trained in these topics can be addressed.

The recommendations expressed by the SAC for WP6 are reported in Table 7.



Recommendations	Date of recomm. submission	Priority	Status/ comments
SAC recommends diversifying the training offer in TANDEM: it could be useful to train not only in safety and SMRs, but also in the tools and methods developed by TANDEM, and to share TANDEM results and data more widely.	08/03/2023	1	Implemented (TANDEM/Deliverable 6.2, 2023). See the agendas of the International Summer School, the two technical workshops and the webinars organized by TANDEM in 2024.
The methodology to replicate in the analysis conducted for the selected case studies can be also very useful to include in the Education and Training activities.	08/03/2023	1	Implemented The TANDEM Summer School (Lecco, Italy, 2024) provided a balance between lectures and interactive sessions where participants could directly apply the knowledge they acquired during the school. These sessions involved practical case studies and hands-on activities included the direct application of tools and methodologies developed within the TANDEM project.
SAC recommends thinking about specific E&T actions dedicated to regulators, since it is not addressed by TANDEM/deliverable D6.1 entitled "E&T Gap Analysis in the domain of safety of SMRs and hybrid energy systems".	05-06/10/2023	3	Not implemented. This action goes beyond the work program planned in TANDEM.
SAC recommends preparing MOOC (Massive Open Online Course) and e-learning courses in the framework of TANDEM. Five webinars are planned to be organized by the project; IAEA might store their records on their website (to be discussed with IAEA when the records will be ready to be shared).	05-06/10/2023	1	Implemented. Six webinars have been organized and recorded by the project. The records are available at the following address: http://nucleare.ing.unipi.it/it/webinars/webinars-2023-2024 .

Table 7. Recommendations for WP6.



4 SAC's recommendations on technical ideas for new projects and initiatives

A mail prepared by the project and summarizing the technical axes that should be investigated in future projects and initiatives after the end of TANDEM was sent to the TANDEM Research Program Officer at the European Commission and to the Secretariat of the European Industrial Alliance on SMRs (TANDEM/D5.2, 2025) in January 2025. The technical orientations are the following:

- Axis n°1: Definition of low-carbon energy solutions integrating SMRs and AMRs for the decarbonization of a real industrial energy hub in EU
- Axis n°2: Safety demonstration and regulatory framework for HES integrating SMRs/AMRs
- Axis n°3: Development of the design of SMR Balance of Plant (BOP)
- Axis n°4: First step towards a demonstrator of HES in EU

These technical orientations were discussed with SAC, who delivered the following recommendations:

Axis n°1:

- Do not envisage an overly complex configuration for a real industrial energy hub, as studies defining decarbonization paths will be very difficult to carry out and will be overly dependent on the specific case (i.e., not representative for other sites and other industries). To avoid complexity, the energy hub configuration should supply a limited number of feedstocks (among heat, electricity, hydrogen, drinking water). Industrials will then valorize these feedstocks in their processes (e.g., by producing synthetic fuels).
- Build two variations of the energy hub configuration: one open and representative of the real case, but containing no data associated with intellectual property; another one containing the real data that remain confidential. This will facilitate discussion with industry and avoid the need to share sensitive data publicly.
- Rely on the TANDEM Industrial User Group to build a real energy hub configuration.
- No single end-user should utilize a large portion of a SMR power. A SMR should support a number of end-users such that the loss of any one user would not be a significant risk. This minimizes the risks involved in developing this low-carbon solution. This provides a “plug-in” approach that should make it possible to replace an end-user intending to stop its nuclear power supply.

Axis n°2:

- Check if other initiatives (such as those led by IAEA or OECD/NEA) have already created regulatory working groups gathering nuclear regulators and non-nuclear regulators for



industrial risks. If some exist, follow on efforts should work with them rather than establish separate, project specific working groups.

- Add explicitly in this axis a topic related to the strategy/procedure to define the interface (i.e. boundary) between an SMR and industrial facilities. A rigorous assessment of the SMR Emergency Planning Zone (EPZ) will contribute to the procedure.

Axis n°3:

- Consider using measurement data from non-nuclear facilities (e.g., Combined Cycle Gas Turbine) to experimentally validate numerical models of power conversion cycles.
- Learn how industrials have validated their numerical models of Rankine cycles.

Axis n°4:

- No recommendation.

5 Conclusion

The TANDEM project thanks the SAC members for supporting the project. Twenty-four SAC recommendations have been fully implemented, and four have been partially implemented by the project, with the objective to:

- make the results understandable, reusable and scalable,
- clarify or better justify the assumptions associated with the TANDEM studies,
- strengthen the project impact,
- connect the project to stakeholders not initially targeted by the project or to other international initiatives.

Two recommendations are still under implementation. The first one concerns the amplification of the TANDEM outcome impact, and the second one is about the sustainability of the TANDEM IUG.

Seventeen recommendations have not been implemented in the project, mainly because they would require too much unplanned additional technical efforts and they are beyond the scope of the project work program. However, they do constitute ideas for future projects and new initiatives.

The SAC members were very involved in the project monitoring and E&T activities of the project. They supported the TANDEM project in starting new collaborations with other projects and initiatives on nuclear cogeneration and hybrid energy systems, providing a greater impact and international visibility of the project. These new collaborations likely would not have been possible without the setup of the SAC in the project.



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