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Intermediate SAC recommendations report

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Intermediate Scientific Advisory Committee recommendations report

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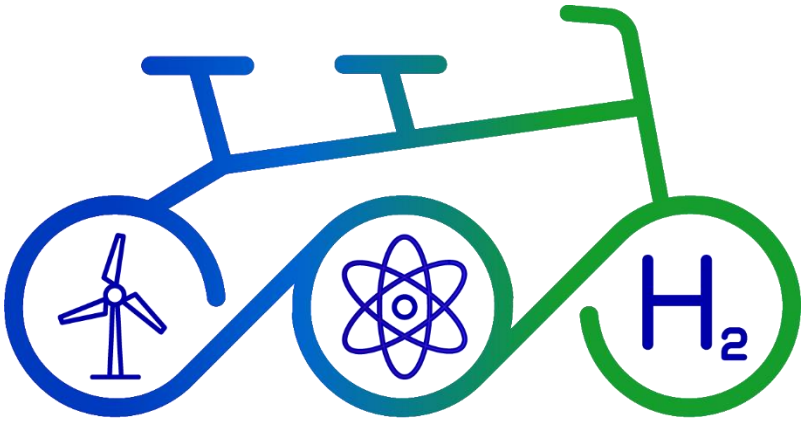

TANDEM

D7.4 – Intermediate SAC recommendations report

WP7 - Task 7.2

March 5, 2024 [M19]

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History

Date	Version	Submitted by	Reviewed by	Comments
05/03/2024	V1	Claire Vaglio-Gaudard (CEA)	Michael Fütterer (EC-JRC) Alina Constantin (IAEA)	

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Abbreviations and Acronyms

Acronym	Description
CAPEX	CAPital EXpenditure
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 [in English, French National Institute for the Industrial Environment and Risks]
INL	Idaho National Laboratory
IT	Information Technology
IUG	Industrial User Group

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MIT	Massachusetts Institute of Technology
MOOC	Massive Open Online Course
NEA	Nuclear Energy Agency
NEANH	Non-Electric Applications of Nuclear Heat
NC2I	Nuclear Cogeneration Industrial Initiative
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	Very High Temperature Reactor - Hydrogen Production – Project Management Board
WP	Work Package

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Executive Summary

This deliverable contitutes the SAC Intermediate recommendations report. It brings together all the recommendations made by TANDEM's Scientific Advisory Committee, from the start of the project to its halfway point (month 18). For each recommendation, a brief analysis is provided by the project on how it should be implemented.

Keywords

TANDEM, recommendations, Scientific Advisory Committee, SAC, intermediate 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 Hybrid Energy Systems (HES),
- Develop tools and methodologies to study these HES,
- Analyze the role/benefits of multipurpose Small Modular Reactors (SMRs) 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 Advanced Modular Reactors (AMRs) into hybrid energy systems.

The project started in September 2022. WP1 first stressed the general context of the project, directly linked with European energy policies as well as energy markets and their evolution. Then, it provided the generic configurations of the two HES to be studied by the project, a District Heating configuration and an Energy Hub Configuration, within two timeframes, 2035 and 2050. It constituted the input data necessary to start the development in the other technical WPs. WP1 was completed in summer 2023. The activities in the other WPs (see Figure 1) are ongoing.

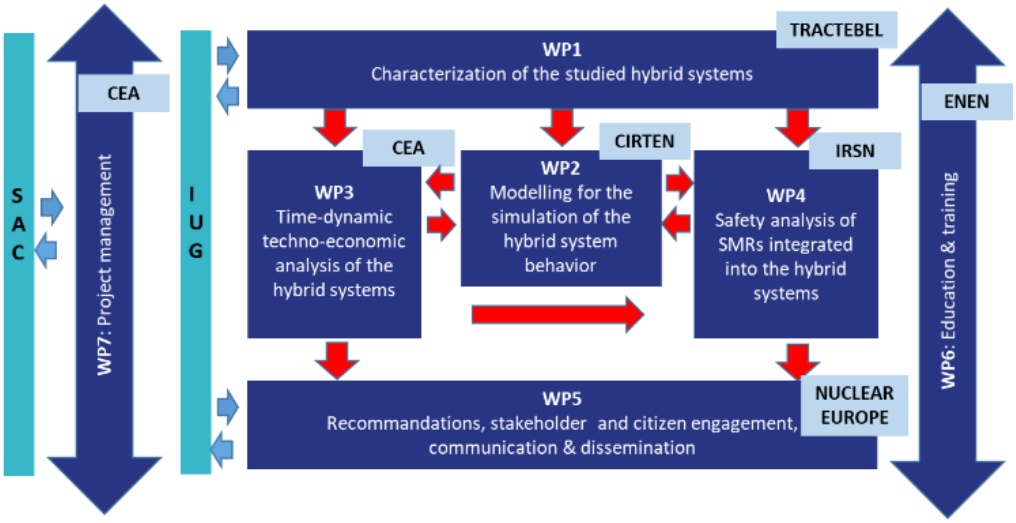

Figure 1: Work package breakdown in TANDEM and interaction with the SAC and IUG.

The project has set up two external groups, a Scientific Advisory Committee (SAC) and an Industrial User Group, and regularly interacts with them.

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The expectations of the TANDEM project from the SAC are to:

- provide feedback and recommendations on the results, scientific choices and directions 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 around:

- the technological feasibility of the hybrid energy systems 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 recommendations collected by TANDEM from the SAC during 2023 and to provide information on how to implement them.

After a brief presentation of the positioning and the composition of SAC, the recommendations associated with each WP are listed and commented on by the project (WP leaders and coordinator) in this deliverable.

2 Positioning and composition of SAC

Numerous international cooperative initiatives have already been launched or will be launched soon 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 roadmap, European Green Deal, Fit for 55, REPowerEU plan, EU Net Zero Industry Act,
- *On SMR safety, development & licensing*: SNETP NUGENIA Technical Area 6 dedicated to innovative LWR design & technology, ELSMOR and HARMONISE Euratom in-progress project, IAEA booklet on advances in SMR technology developments[1], the 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, GEMINI+, EUROPAIRS, NC2I-R Euratom past projects, GEMINI 4.0 ongoing project, Task Force on Non-Electrical Application of Nuclear Heat (NEANH) in the GEN-IV International Forum (GIF) framework,

[1] https://aris.iaea.org/Publications/SMR_booklet_2022.pdf

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- *On technical assessments and optimizations of hybrid energy systems*: IAEA Coordinated Research Project I32012 on Technical Evaluation and Optimization of Nuclear-Renewable Hybrid Energy Systems[2] (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 software[3] (closed), IAEA Coordinated Research Project I35006 on Assessing Technical and Economic Aspects of Nuclear Hydrogen Production for Near-term Deployment[4] (closed), IAEA Coordinated Research Project I12007 for Economic Appraisal of SMR Projects[5] , 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 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, 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. SAC is composed of four members:

- Dr. Shannon Bragg-Sitton, lead for Integrated Energy Systems program at US Idaho National Laboratory (INL) and lead of GIF/NEANH Task Force,
- Dr. Alina Constantin, technical officer for non-electric applications of nuclear energy, at International Atomic Energy Agency (IAEA),
- Dr. Michael Fütterer, senior expert at European Commission - Joint Research Centre (EC-JRC), representative of SNETP/NC2I and member of GIF/NEANH Task Force,
- Dr Koroush Shirvan, professor at US Massachusetts Institute of Technology (MIT) – Department of Nuclear Engineering.

[2] https://www.iaea.org/projects/crp/i32012
[3] https://www.iaea.org/projects/crp/i35004
[4] https://www.iaea.org/projects/crp/i35006
[5] https://www.iaea.org/projects/crp/i12007

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3 Recommendations

The recommendations reported in this deliverable have been expressed during two 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 review in Milan (Italy) in person (with a possibilibility of remote attendance as well), on 5 + 6 October 2023. A dedicated session with the SAC members and the TANDEM management team was organized at the end of the project review (TANDEM/SAC, 2023b).

The project has assigned a priority to each recommendation, depending if:

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

Recommendations considered to be 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 Horizon Europe program starting in 2026).

3.1 General recommendations

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

Recommendations	Date of recomm. submission	Priority [6]	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;	05-06/10/2023	2	**Under implementation.** A first step has been achieved considering:

[6] Priority is defined from 1 (high priority) to 3 (low priority).

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Communication and public engagement; Techno-economics & 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 (Task Force of Non-Electric Applications of Nuclear Heat), IAEA or OECD/NEA, beyond the European framework on which the projects will initially focus.			- the inclusion of a TANDEM presentation in the Nuclear-Hydrogen Digest prepared by NICE Future[7] - the presentation of TANDEM during a joint meeting of GIF/NEANH TF, GIF/VHTR HP PMB, IEA-H2 TCP/Task 44, OECD/NEA on hydrogen production with nuclear energy, at Idaho Falls, USA, January 22-25, 2024.
The TANDEM project has no formal contact with OECD/NEA for the moment. The SAC recommends that NEA interview the TANDEM coordinator about the project activities. This may be included in the still ongoing scenario studies or a Stakeholder report (contact: Lucas Mir).	05-06/10/2023	2	**Not yet implemented.**

Table 1. General recommendations.

3.2 Recommendations for WP1

The main objective of WP1 is to define and characterise basic concepts for configuring hybrid 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, techno-economic data for optimisation among others.

[7] Available at https://www.nice-future.org/docs/nicefuturelibraries/default-document-library/nuclear-hydrogen-digest.pdf

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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	**Implemented - see (TANDEM/D1.4, 2023).** 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 market. For the District Heating configuration, the excess heat could be used for hydrogen production outside the heating season.
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	**Implemented - see (TANDEM/D1.4, 2023).** TANDEM considers three energy contexts in its studies to show the benefits of SMR penetration for the energy transition : - 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

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			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/Deliverable 1.4).** 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.
The SAC suggests WP5 to use the existing WP1 deliverables to help answer energy policy relevant questions.	05-06/10/2023	1	**Not yet implemented.** WP5 will use WP1 deliverables in the interactions planned with stakeholders.
The SAC recommends adding EU Net Zero Industry Act to the list of ongoing energy policy initiatives.	05-06/10/2023	2	**Implemented** The next paper about the TANDEM project (for a conference or a peer-reviewed journal) will cite the EU Net Zero Industry Act as part of the European energy policy framework.

Table 2. Recommendations for WP1.

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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 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 developped 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	**Under implementation.** As the TANDEM library will be open-source, the preparation of user-oriented documentation has been identified as a very important action in WP2 and is planned by the TANDEM partners. In the deliverable D2.3, a detailed description of the models will be provided. In addition, to support the long term maintainance, the TANDEM library will include Markdown[8] documentation to provide more pratical information to the users.

[8] https://www.markdownguide.org/getting-started/

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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	**Under implementation.** 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	**Probably not implemented during TANDEM.** Due to limited resources, the development of a Modelica model dedicated to district cooling is not planned within the TANDEM framework.
SAC recommends opening up to the scientific community the hybrid energy system simulator to be developed during the project, based on the TANDEM library.	05-06/10/2023	1	**Not yet implemented.** The TANDEM library gathering models of HES components will be open-source. It is planned that the consortium provides an access available upon request to didactic examples of hybrid systems in Modelica language.
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	**Under implementation.** These typical values will be available in the Modelica file dedicated to each HES components as default parameters. Notwithstanding, this should be considered indicative and carefully used since they may not be representative of all HES configurations.
SAC suggests developing a graphical interface associated with the hybrid energy system simulator to make it more user-friendly.	05-06/10/2023	3	**Probably not implemented during TANDEM.** Due to limited resources, the development of a graphical interface is not planned within the TANDEM framework. In any case, Modelica

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			Integrated Development Environments (IDEs) usually provide a user-friendly graphical interface.
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	**Implemented.** The TANDEM library will be modular and the developpers will keep the opportunity to integrate other reactor models or other downstream component models beyond the scope of the project.
SAC recommends including modules for different temperature boosting technologies.	05-06/10/2023	1	**Partially Implemented** 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). It is not plan in TANDEM to explicitly formulate different temperature boost techniques (e.g, resistance heating, compression heat pumps, chemical heat pumps), even if they feature different performance values and have different requirements.

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 cases,
- Identification of component features and key performance indicators relevant at techno-economic and environmental levels,

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- Techno-economic analysis of the hybrid systems, optimization of the system architectures and main components sizing associated to 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 yet implemented.** TANDEM is interacting with an Industrial User Group (IUG)[9]. The objective is to engage in a constructive dialogue between the IUG members and TANDEM about several items, such as: - the technological feasibility of the hybrid energy systems incorporating Small Modular Reactors, - the different energy markets and their particularities, - regulatory, societal and economic issues related to implementation of such systems For the moment, it is not planned to interact with investors.

[9] The IUG is today composed of representatives from GENVIA, VATTENFALL, NUWARD™, COGEN Europe, FEBELIEC, IFIEC, OPTIT, Euromines.

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			However, discussions could be held in the joint TANDEM/GEMINI 4.0 working group n°3 to identify obstacles for investors.
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 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 tools (Backbone and PERSEE) implemented in TANDEM. 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.
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	**Implemented.** See Figure 11 in (TANDEM/D3.1, 2023).
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 ratio peak load to base load for electricty in the future.	05-06/10/2023	2	**Probably not implemented during TANDEM.** The TANDEM project will assume the same generation ratio between heat, hydrogen and electricity in 2035 and in 2050. If this ratio changes, the HES may need to be redesigned.

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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 be found in published work by the US Argonne National Laboratory.	05-06/10/2023	3	**Probably not implemented during TANDEM.** 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 important R&D work beyond the scope of the TANDEM project[10]. 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 increase of interest rates. Besides, it would be suitable to 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[11]. CAPEX and variable OPEX are prospective values for 2035 in €$_{2022}$ (TANDEM/D1.3, 2023); In TANDEM/D3.2 (Presentation of dynamic techno-economic analysis for each case study, under preparation), CAPEX and variable OPEX were revised upwards (+~6%) due to an update of the sources end of 2023.

[10] 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 »].

[11] https://yearbook.enerdata.net/

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			Besides, a sensitivity on these two costs will be conducted in TANDEM/D3.3 (Sensitivity of the hybrid system techno-economic analysis to uncertain key parameters, under preparation).
SAC recommends opening the data related to the description of three study cases (Northern and Central Europe cases for district heating applications, and 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.	05-06/10/2023	1	**Under implementation.** WP3 aims to include in the report the input data that led to the results. The partners involved in WP3 analyses will prepare tables summarizing the data used, and make them accessible in TANDEM public deliverables.
SAC recommends including a simple case study concept for demonstrators and first adopters.	05-06/10/2023	3	**Probably not implemented during TANDEM.** 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	**Probably not implemented during TANDEM.** 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	**Probably not implemented during TANDEM.** First of all, it is 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.

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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 potential resulting 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 the 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	**Under implementation.** WP4 leader (IRSN) and coordinator (CEA) presented the TANDEM project to the French National Institute for the Industrial Environment and Risks (INERIS) in December 2023 and proposed them to be part in the TANDEM IUG. INERIS has just confirmed its willingness to join the IUG.
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	**Under implementation.** Same comment as the previous one.

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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 relased a document about risk assessment in a light water reactor coupled with 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).	05-06/10/2023	1	**Implemented.**
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 yet implemented.** Difficulties are encountered by the project in actively engaging the IUG in the project (lack of participation in scheduled IUG meetings, little feedback from members about their energy needs and vision).

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.

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Recommendations	Date of recomm. submission	Priority	Status/ comments
SAC recommends that the assumptions and limitations of applicability of the simulations performed for the studied 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.	08/03/2023	1	**Not yet implemented.** It will be implemented in the future dissemination activities of TANDEM.
SAC stresses the importance of developing the link with the TANDEM industrial user group; 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	**Under implementation.** A first dedicated meeting with the IUG members was organized on March 29, 2023 (TANDEM/IUG, 2023). The IUG members were invited to attend the full annual project review in Milan (Italy), on October 5&6, 2023. A dedicated wrap-up session for IUG was organized during the project review. The next IUG meeting is planned for spring 2024.
SAC recommends contacting industrial companies, e.g. in Poland, to learn more about their decarbonization needs, specific frameworks and contraints, and to explain the potential of a nuclear solution. The SNETP/NC2I initiative can provide contacts, if needed.	08/03/2023	2	**Implemented.** TANDEM contacted several representatives of KGHM to be part of the IUG.

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SAC suggests taking note of the proceedings[12] 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 which is being 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	**Under implementation.** At least one paper about TANDEM will be submitted by the coordination.
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	**Probably not implemented during TANDEM.** 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 (see TANDEM/D5.3, 2023).
SAC recommends adding (potential) investors to the stakeholder group.	05-06/10/2023	3	**Probably not implemented during TANDEM.** IUG is currently composed of 8 members, and it is challenging to keep them involved. For the time being, the project prefers not to expand too much the group, in order to facilitate discussion with existing members.

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

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			However, if such investor profiles are difficult to embark, they can be added if the opportunity shows up.
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	**Need to check if the recommendation can be implemented.** IUG is currently composed of 8 members, and it is challenging to keep them involved. For the time being, the project prefers not to expand too much the group, in order to facilitate discussion with existing members. Actions will be taken to ensure the sector is kept informed of developments.
SAC recommends sustaining the IUG implemented by TANDEM beyond the end of the project. It could be done in the SNETP framework.	05-06/10/2023	1	**Under implementation.** TANDEM initiated discussions with SNETP to see how to proceed, using the SNETPForward framework through its Stakeholders Engagement Committee.
SAC recommends involving IUG members for the assessment of citizen engagement during workshops organized by TANDEM. Industrials have in general effective means of communicating their needs in terms of energy decarbonization.	05-06/10/2023	2	**Need to check if the recommendation can be implemented.** This recommendation will be discussed with IUG members and TANDEM partners involved in the assessment of citizen engagement in WP5 (this task has just started).
SAC supports the idea of organizing a workshop about licensing, as already suggested by IUG members.	05-06/10/2023	3	**Need to check if the recommendation can be implemented.**

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			This action goes beyond the work program planned in TANDEM, and could also be of interest to GEMNI 4.0 and NPHyCo. However, this recommendation will be discussed with TANDEM partners involved in WP5 to check if it is possible.
SAC members and TANDEM WP leaders share the difficulty to practically involve IUG members and to make them participating 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: ✓ 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.	05-06/10/2023	2	**Not yet implemented.** The project does not have enough resources to engage such a strategy. SNETP could be contacted to see in they can help. However, a way to enhance dissemination will be studied, probably using a much wider framework than a single Euratom project.
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 yet implemented.** The suggestion will be shared with GEMINI4.0 Excom members. It could be done through the action to sustain IUG beyond the end of TANDEM and GEMINI 4.0.

Table 6. Recommendations for WP5.

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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 (see TANDEM/Deliverable 6.2).** See the preliminary 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	**Not yet implemented** The TANDEM Summer School will provide a balance between lectures and interactive sessions where participants can directly apply the knowledge they acquire during the school to different group projects. These sessions will involve practical case studies and the outcomes of

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			each working group's efforts will be shared with the other participants. Hands-on activities may include the direct application of tools and methodologies developed within the TANDEM project, including but not limited to dynamic simulations of multiple HES architectures in the Modelica language and their techno-economic optimization concerning both operational aspects and system design.
SAC recommends thinking about specific E&T actions dedicated to regulators, since it is not adressed 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	**Probably not implemented during TANDEM.** This action goes beyond the work program planned in TANDEM.
SAC recommends preparing MOOC 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	**Under implementation.** Two webinars have been organized and recorded by the project ; at least three more will be organized and recorded. For the moment, the records are available here: http://nucleare.ing.unipi.it/it/webinars/webinars-2023-2024.

Table 7. Recommendations for WP6.

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4 Perspectives

Around fifty recommendations were issued by the SAC about TANDEM activities. The project will do its best to implement the recommendations. Justifications will be provided if recommendations are not implemented.

The project will keep on interacting with the SAC, collect other recommendations and provide a final SAC recommendations report at month 36 (end of the project).

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