D5.5 – Summary of the recommendations of the Industrial User Group

WP5 - Task 5.1

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Abbreviations and Acronyms

Acronym	Description
AMR	Advanced Modular Reactor
AOO	Anticipated Operational Occurrences
BoP	Balance of Plant
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CZ	Czech Republic
DH	District Heating
DBA	Design Basis Accident
E&T	Education & Training
E-SMR	European SMR (reference study model)
EU	European Union
HES	Hybrid Energy System
HTSE	High Temperature Steam Electrolyser
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IUG	Industrial User Group
KPI	Key Performance Indicator

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LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Heat
$LCOH_2$	Levelized Cost of Hydrogen
LTE	Low Temperature Electrolysis
LW-SMR	Light Water Small Modular Reactor
NC2I	Nuclear Cogeneration Industrial Initiative
NPHyCo	Nuclear Powered Hydrogen Cogeneration
RES	Renewable Energy Sources
SAC	Scientific Advisory Committee
SMR	Small Modular Reactor
SNETP	Sustainable Nuclear Energy Technology Platform
SOEL	Solid Oxide Electrolyser
SOEC	Solid Oxide Electrolyser Cell
TES	Thermal Energy Storage
TSO	Technical Safety Organisation
WG	Working Group
WP	Work Package

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Executive Summary

A summary of the interactions of the Industrial User Group of the TANDEM Euratom project between September 2022 and August 2025 is provided in this document. It enables to summarise the perceptions and the recommendations expressed by the industry and energy stakeholders representative members of this Industrial User Group related to the integration of Small Modular Reactor into Hybrid Energy Systems. The project focuses on light-water technologies for a near-term deployment. However, when the results are technology-neutral, they are extended to Advanced Modular Reactors of Generation IV.

Keywords

TANDEM, SMR, Hybrid Energy System, synthesis, industry, recommendations

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1 Introduction

The TANDEM project (Small Modular ReacTor for a European sAfe aNd Decarbonised Energy Mix)[1] is a Horizon-Europe project funded under the Euratom research and training program – work program 2021-2022. The overall ambition of the project is to *promote multi-purpose Small Modular Reactors (SMRs) integrated into hybrid energy systems as reliable, resilient, and affordable clean energy options in Europe*. The project focuses primarily on light water SMR technologies for a near-term deployment in Europe by 2035 but also aims to support the deployment of Advanced Modular Reactors of Generation IV by 2050 when technology-neutral outcomes are identified.

The intrinsic key feature of the TANDEM project is the development of an integrated vision of the low-carbon energy mix on a local/regional scale (an urban area or an industrial zone). Indeed, the project considers nuclear energy as an electricity and heat source to supply industrial processes and district heating – as in other Euratom projects working on nuclear co-/poly-generation – but also studies coupling (also referred to as "hybridization") with renewables and energy carrier storage systems. The project addresses the technical feasibility (safety, operability and flexibility of the energy supply) and economic viability of such hybrid energy systems, as well as citizen engagement and E&T needs to prepare the workforce required for the development and deployment of SMRs integrated into Hybrid Energy Systems (HES). TANDEM provides methodologies and tools for the assessment of HES and has implemented them on demonstrative study cases of energy systems to be decarbonized.

In parallel, TANDEM has built an open and long-term community that will ensure expertise in the field of nuclear HES and support the wide acceptance of multipurpose SMRs and AMRs. This European community has forged close links with other international communities and industrial stakeholders, to develop new collaborations and foster exchanges in the field of nuclear cogeneration, non-electric applications of nuclear energy and nuclear HES. The discussions between TANDEM and these international communities clearly underline that nuclear cogeneration and its integration into hybrid energy systems is a matter of utmost importance.

The breakdown of the project's work packages is shown in Figure 1. The project has set up two external groups, a Scientific Advisory Committee (SAC) and an Industrial User Group (IUG) and regularly interacts with them.

[1] https://tandemproject.eu/

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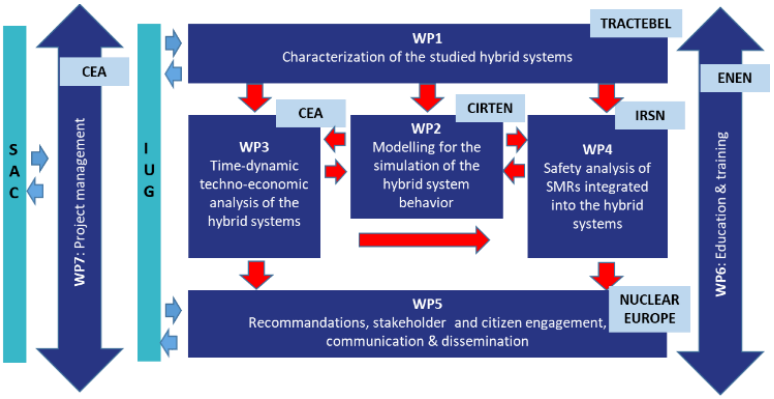

Figure 1: Work package breakdown in TANDEM.

In this report, the following sections summarize the main outcomes resulting from the interactions between TANDEM and the Industrial User Group, and provide recommendations related to technical, economic and societal issues to facilitate the development and deployment of SMRs into HES.

2 The Industrial User Group

In order to maximise the impact of the project, an Industrial User Group (IUG) was set up in correlation with the framework of Work Package 5 activities - recommendations, stakeholder and citizen engagement, communication and dissemination - to promote the creation of cross-cutting project ideas related to the hybrid energy systems and SMR integration.

Since the project aims at providing guidance in a SMR deployment perspective and to create enabling environment for SMRs in hybrid energy systems, the purpose of the IUG is to collect information from industrial end-users and more widely, energy stakeholders, and benefit from their feedback to better shape the outcomes of the project towards end-user priorities and the challenges associated with SMR deployment.

The Industrial User Group (IUG) aims therefore to engage in a constructive dialogue about:

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

The TANDEM IUG is at the end of the project composed of 14 members: Vattenfall (Sweden), NUWARD™ (France), GENVIA (France), COGEN Europe (Europe), Euromines (Europe), Eurometaux (Europe), IFIEC (Europe), Febeliec (Belgium), INERIS (France), Enel (Italy), Edison (Italy), Optit (Italy), KGHM (Poland) and EPRI (USA).

Three dedicated meetings with the IUG members were organized:

- on March 29, 2023,
- on April 5, 2024,
- on January 29, 2025.

Besides, the IUG members were systematically invited to attend the annual meetings of project review and the events organized by the project (webinars, E&T workshops, TANDEM final conference, etc).

The close interactions with the Industrial User Group will enable to identify priorities to address during and after the project. These interactions will also foster the development of cooperation with European Industrials (utilities, designers of hybrid system components, end-users, etc) and safety regulators.

3 The Industrial User Group activities

3.1 First IUG periodic meeting on March 29th, 2023

This first meeting was dedicated to launch the IUG on a two-folded approach: presentation of TANDEM and building the IUG by sharing the goals and expectations of its members. It was organized as remote meeting on March 29th with the initial core of participants as identified at the launch of the project in 2022:

- IFIEC Europe, FEBELIEC Belgium
- VATTENFALL Sweden
- EUROMETAUX Europe
- COGEN Europe
- NUWARD™ France
- GENVIA France.

However, an additional participant was also invited, OPTIT (Italy), as a result from contacts established during the ENLIT event in Frankfurt 2022 at the EU project zone where OPTIT was representing the EU-funded PLAMES project. PLAMES is aiming at the planning of multi-energy

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systems for the optimized distribution between heat and electricity. Similarities between the two projects led to include OPTIT in the IUG.

At 8 months after the official launch of TANDEM, the status of WPs is presented, focusing on WP1 which, as first WP, defines the bases and main assumptions for all the other WPs. A brief overview is given of the chosen European energy scenarios at time frames 2035 and 2050 and main guidelines for the definition of the two hybrid energy systems cases which will be studied in the project. SMR and AMR technologies have the potential to strongly contribute to the energy decarbonization for both electric and non-electric applications. The TANDEM project focuses on the study of the integration of SMRs into hybrid energy systems, including other energy sources, heat network and energy conversion systems, as well as energy storage systems, at a local scale.

Considering that the SMR deployment may start in 2030's in EU, the TANDEM project has defined three energy scenarios for the purpose of its studies:

- A business-as-usual energy scenario in 2035: only fossil fuel plants and renewables are considered as energy sources in the hybrid energy systems,
- The start of the deployment of SMRs in 2035: fossil fuel plants are progressively replaced by SMRs. The energy sources in hybrid energy sources are composed of a mix of fossil fuel plants, SMRs and renewables,
- The achievement of the carbon-neutrality in 2050: most of fossil fuel plants are replaced by low-carbon energy sources, in particular SMRs, in the hybrid energy systems.

Two hybrid energy systems cases under those scenarios are considered in the project; the first is related to a district heating network and power supply for an urban area, at a local scale. The second hybrid energy system is related to an energy hub serving energy conversion systems, including hydrogen production, at a local scale (harbor-like).

Each IUG member presented his/her organization and expectations regarding TANDEM and his/her participation in the IUG. The key messages conveyed by each participant can be summarized as follows (*FEBELIEC IFIEC, VATTENFALL, EUROMETAUX, COGEN Europe, NUWARD™, OPTIT, GENVIA):*

- There is a strong belief that, for most manufacturing industries in EU, no technology should be discarded for reaching energy decarbonization goals. Nuclear has a role to play in the mix for climate-neutrality;
- The technical and financial stability of low-carbon supply of electricity is an advantage of SMR technologies. For mining and non-ferreous/steel industries which want to go

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green, nothing can replace nuclear for stable pre-planned energy supply;

- Therefore interest is growing for SMRs which seem to bring all expected answers to the industry needs which are enormous;
- Being more decentralized, SMR will be closer to the user: public acceptance is therefore also an important issue to bear in mind. With the penetration of intermittent RES, flexibility will be the key and future CHP units will have to run on a flexible mode including storage;
- Cogeneration being the backbone of local and integrated energy systems, CHP using SMRs will have an important role to play, in particular in correlation with hydrogen production;
- Link with EU-funded PLAMES project for the planning of multi-energy systems for heat and electricity optimized distribution, where nuclear option has been explicitly ruled out by the German consortium partner. SMRs inclusion may be an investigation line in a post-project phase, from which it could be useful in the TANDEM perspective to look at some common scenarios;
- The expectation from TANDEM IUG is to learn better what SMR technology is and can bring, how technical cogeneration coupling with SOEL works including tech-eco analysis of hydrogen production, and also, safety considerations of co-existence of SMRs with hydrogen plants.

Besides those rather specific considerations, the common denominator between IUG members concerns focused on

- When the SMRs will be operational to meet the industry expectations and demands;
- Reactor licensing issues in Europe seem to be the largest problem if not the major obstacle to deployment, as licensing goes too slow. This calls for a workshop with TSOs and nuclear safety authorities to harmonize, encourage them for a joint approach of licensing.

3.2 Consortium meeting on October 10th 2023

At the annual consortium meeting held at POLIMI in Milano both in presence and remotely, the specific IUG session was part of the WP5 progress reporting.

Since the first meeting, the NuclearEurope's initiative to raise interest of Euromines representatives for SMR technologies led to include new members in the IUG:

- Euromines Europe,
- Boliden Group Sweden,
- KGMH Poland.

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Besides, giving the IUG members access to the WPs status and progress through the consortium presentations, the meeting offered in addition the opportunity to present answers of the project to the March 19th IUG concerns and in particular on the licensing issue. Indeed, some initiatives or facts related to licensing were shared with the audience:

- In the framework of EURATOM projects
  - Interaction between TANDEM and GEMINI4.0 as well as NPHyCo, as these two EURATOM projects, running in parallel with TANDEM, address the deployment of nuclear technologies for heat and hydrogen production;
  - Identification of convergence topics, mostly on safety aspects related to nuclear cogeneration.

- European regulators cooperation on NUWARD™ SMR licensing
  - From June 2022 to June 2023, three regulators, ASN (France), STUK (Finland) and SÚJB (Czech Republic), and their technical support organizations (IRSN for France and SÚRO for Czech Republic) have conducted a joint early review (JER) of the NUWARD™ design. This first group has been joined in a second phase by the regulators from Sweden (SSM), Poland (PAA) and the Netherlands (ANVS);
  - Major lessons were learned on the initiative and the working methodology.

- European SMR pre-partnership: European SMR pre-Partnership – Workstream 2 – Licensing 7. Actions for future steps to support pre-licensing of SMRs.

In parallel to the meeting, the SAC issued the recommendations to enlarge IUG participation (through IAEA or others WGs international audience) as end-users segment engagement is key driver for (fast) nuclear deployment. However, the TANDEM project alone is not designed to manage such a wide audience and solutions are to be sought to extend the IUG in another more suitable framework.

3.3 Second IUG periodic meeting on April 5th 2024

This second IUG meeting gave the opportunity to share the significant achievements obtained by the project at about its mid-term. It was organized in Tractebel Brussels offices both in presence and remotely (30 participants with 8 in person) with new members:

- INERIS France
- ENEL Italy
- EDISON Italy

Commented [VGC11]: Je propose de supprimer les noms car on ne les a pas donnés pour les organisations

The agenda covered the progress status of TANDEM and all its WPs. As an introduction, the participants were also given a presentation of the status of the parent GEMINI4.0 and NPHyCo EURATOM projects related to energy market decarbonation.

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3.3.1 Related EURATOM projects

The GEMINI4.0 project supports the industrial demonstration of a cogeneration high temperature gas cooled reactor (HTGR) for electricity, process heat and hydrogen production for decarbonising the industry. The GEMINI design basis in interface between the nuclear plant and the industrial steam network produces steam at 540°C. First targets are the chemical and petrochemical sites with steam networks already in place. But in general, HTGR technology offers the potential for different heat applications such as ammonia, plastic recycling and chemical clusters. The other applications in cogeneration are hydrogen production with different means. GEMINI considers including regulators for the licensing readiness of the polygeneration mode on a site with nuclear and chemical facilities based on the separation of the nuclear island and the industrial application.

The NPHyCo (Nuclear Power Hydrogen Cogeneration) project is dedicated to the production of hydrogen from large scale low carbon hydrogen production facilities linked to nuclear power plants in order to address the full decarbonisation of the EU economy by 2050. The project addresses first the feasibility of producing hydrogen near an existing nuclear power plan, analysing the potential end-user application and the transportation routes. Key outcomes at this stage are that the technical feasibility is not in question and that the end-user interest focuses on the reliability of supply at a competitive price. Concerns exist with respect to safety, legal framework (e.g. to allow NPP production of something else than electricity) and profitability which highly dependent on the price of electricity, the price of CO2, the H2 transport possibilities and the categorisation of nuclear-powered hydrogen and related fundings. Those parameters are highly dependent on EU and national decisions and framework, and therefore the feasibility demonstration is highly site dependent. However, current generic obstacles on profitability are the price of CO2 production which is quite low and the transportation costs which are significantly large in the absence of suitable infrastructure.

A collaboration framework between the TANDEM, GEMINI4.0 and NPHyCo was identified for four topics of common interest: safety for nuclear polygeneration, communication and public acceptance, techno-economics of short- and long-term impact of nuclear in energy decarbonisation and flowsheet of hydrogen. Ad-hoc working groups were created to highlight synergies between the projects and identify points of convergence/divergence without any additional technical work. The goal is to have for the three projects as much as possible alignment on their final recommendations for the common topics.

The meeting in its members' corner offers the possibility for members to share information of common interest. At this meeting, GENVIA was presented, a company maturing, industrialising and developing industry solutions with high temperature electrolysis using SOEC (Solid Oxide

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Electrolyser Cell) technology. GENVIA key achievements and next steps were presented. A pilot line for stack manufacturing was completed, allowing to demonstrate the reliability of the technology

3.3.2 WP2 status - modelling for the simulation of the HES behavior

The development of the Modelica modules representing the different energy system components has been completed and the modules are available in the TANDEM library. The first test case for using the TANDEM library components into an hybrid energy system simulator is based on the Helsinki district heating network. A dynamic model is developed to study the operation in cogeneration mode of the Nuclear Power plant and its Balance of Plant and the study and analysis of the Thermal Energy Storage which is used as a buffer in the Transmission and Distribution Networks. This dynamic Modelica model has been coupled to the techno-economic optimization platform PERSEE (CEA). Results were obtained both for the techno-economic optimization of the architecture (TES size) and the techno-economic optimizer for the operation (power flows), providing simulation examples for the nuclear HES power flows in correlation with the DH network power flows, the DH temperature control and the TES state of charge. A PERSEE model was built to find the optimal size of the TES, techno-economic study over 20 years using as an assumption a typical one year of historic data on heat demand.

3.3.3 WP3 Status - time-dynamic techno-economic analysis of the HES

For the WP3, the techno-economic and environmental dynamic assessment of hybrid energy systems are aimed to investigate the operability profitability and environmental impact of the hybrid energy systems. For that purpose, three case studies were identified:

- Northern European case: a district heating test case architecture based on the Helsinki DH network with four main heating zones was developed by VTT using their generic energy network optimization tool BACKBONE;
- Central European case: a district heating test case architecture based on Moravian-Silesian region that aims to decarbonise the area and replace coal was developed by UJV using PERSEE;
- Southern European case: an energy hub test case based on a virtual industrial harbour at Fos-sur-Mer that aims to provide electricity and hydrogen was developed by CEA using PERSEE.

The E-SMR model used for the three study cases allows a maximum heat recovery ratio of 10% leading for such maximum cogeneration mode 310 MW of electrical power and 100 MW of thermal power. For Northern European case, the LDR-50 reactor model which is designed to produce only heat was also used.

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The VTT study on the Northern European case led to conclude that the size and capital investment required for E-SMR are significant for the Helsinki metropolitan area. The high summer to winter variability in heat demand and seasonal electricity price fluctuations in Finland impact the profitability of E-SMR. The LDR-50 reactor with its smaller size and capital requirements seems a promising option for the region. It offers a carbon free and cost effective solution for heat generation. Both reactor designs are still under development and subject to future changes. The study's findings are based on assumptions about various technological and economic factors. For the next steps, technological factors along with economical factors such as fuel prices, CO2 credit prices and additional time series were to be investigated through sensitivity analyses to also include the study of the optimum number of LDR modules in the Helsinki metropolitan area.

The UJV study on Moravian-Silesian region was enlarged by an assessment of the possibility of creation of hydrogen valley to meet the requirements of the European Commission 2040 climate target communication in the selected central European region. The selected CZ territory appropriately represents the area of the central Europe as it is partially surrounded by Polish and Slovak territories presenting the same industrial and environmental properties. The results of the CZ study case can be easily extended for the adjacent Polish and Slovak regions. The boundary conditions for the scenarios are based on publicly available data to allow checking their origin and to understand their inherent relation. The economic results of the different 2035/2050 scenarios show that it is not possible to achieve an economic return for the reference scenario (i.e. current coal sources are replaced by new ones with similar performance parameters without any SMR build and including emission allowances) under the current conditions as the price of produced commodities significantly exceeds the market price. For the reference scenario, a calculation was also performed without taking into account the effect of emission allowances which shows their significant impact on the resulting electricity price and heat.

The CEA study for the Southern European case covers a demonstration case of an industrialized harbour as such heavily complex industrialized infrastructures are most of the time responsible for a high share of the country CO2 emissions. Therefore, industrialized harbours are involved in decarbonization processes, several of them are based on H2 use penetration. The hybrid energy system methodology inspired from the industrial-port zone of Fos-sur-Mer considers a global architecture where different technologies are in competition, subject to a CO2 constraint (Global Warming Potential settings for each component consistent with the Intergovernmental Panel on Climate Change periodical updates). Preliminary conclusions by comparison with the reference case for 2035 without SMRs (business as usual) show that the introduction of one SMR combined with one HTSE unit allows to decarbonize the system up to 80% with however an extra cost of for electricity production and hydrogen production. It also shows that the flexibility offered by

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the E-SMR does not have a significant impact on the final LCOH2. Those preliminary conclusions must be challenged by further sensitivity studies, for instance by building a more realistic reference case using CCS combined to batteries and LTE hydrogen production to CCGT and by considering ranges for some uncertain settings like technical settings for heat recovery ratio for the E-SMR. In this study, the hub was at some point isolated from the grid and the selling price outside the hub was not taken into account.

In the comments, it is mentioned that some prices are unknown or proprietary and that issuing generic conclusions from demonstration models is not relevant for specific case analysis which need real data and real architecture but help in identifying sensible parameters.

It is also recommended to include the CO2 pricing.

3.3.4 WP4 Status - safety analysis of SMRs integrated into the HES

For WP4, the studies have just begun since this WP comes sequentially after significant completion of the previous ones. A general introduction on the nuclear safety concepts was given first for the IUG members unfamiliar with nuclear frameworks.

A considerable work carried out on safety for nuclear reactors operated in cogeneration already exists in the framework of the European Nuclear Cogeneration Industrial Initiative (NC2I), as a pillar of the Sustainable Nuclear Energy Technology Platform (SNETP) for (very) high temperature reactors ((V)HTR). This provides useful general safety considerations for nuclear co-/poly-generation.

For the safety approach, there is no SMRs specificity with respect to large nuclear power plants in terms of safety definition and classification. The methodology supporting the (nuclear) safety demonstration for SMRs is based on the same principles of Safety Demonstration as for the large PWR NPPs. For SMR in HES, the demonstration requires the identification of suitable Anticipated Operational Occurrences (AOO) and Design Basis Accidents (DBA) as those where poly-generation in the HES should have a major role in affecting events and appropriateness of the levels of defence, considering both the impact from the poly-generation on the SMR safety and the impact from the grid on the poly-generation and respectively the SMR.

The approach should define if the presence of polygeneration improves or worsens the evolution of the Safety Case, especially for DBA, as most classical PWR DBAs would force a fast separation from the grid and could be solved separately without the integration in the HES.

In the definition of the transients to be analysed, the DBAs affected by the HES and/or by the cogenerating configuration lead to consider two types of events: events when the nuclear island

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may be affected by the BoP and the HES at least during the early phases of an accident and events when the cogenerating setup of the power plant may induce some significant variations to some classes of accidents.

The question arose from the audience about the difference between the safety approach for large nuclear units and the safety approach for smaller units. This is a complex answer but, in short, the principles are the same but the demonstration will have to rely on different specific amplitudes and frequencies of the events, considering the feedback of external events on the plant behaviour. However, this principle has to checked and demonstrated, which is some sort of a first of a kind supported by the project.

3.3.5 WP5 Status – communication and dissemination activities

The project reached a state where the first results were coming out and were ready to be reviewed and put together into a series of policy briefs. Policy briefs are going to look at the recommendations that are coming out from the different WPs and identify areas where policies could be improved or what policies at the EU level should be implemented in order to enhance the deployment of HES that include SMRs.

The four planned policy briefs are: finance and economics, skills, safety on a global approach (nuclear and non-nuclear considering that SMRS are to be built close to industries and populated areas) and the work on public acceptance. Due to the upcoming EU parliament elections, the policies were aimed to be issued by early 2025 to support in-person workshops with the possibility to discuss in-person those policy briefs and have EU based stakeholders, particularly policy makers.

The project is quite successful in terms of achieving its visibility. The work on citizen engagement and public perception has been launched, basically to raise awareness amongst citizens about SMRs and to see how they perceive the potential benefits and risks which SMRs can bring in terms of power and non-power applications. National or even local workshops were considered, the two first most likely to be organised in Finland. More and more organizations are including questions regarding nuclear if not SMRs in their public surveys. Early communication with all the potential stakeholders especially with citizen living close to the SMR implementation sites is the key to have the public on board. Public acceptance is therefore an important element of the TANDEM project but also in GEMINI and NPHyCo and then for the SMR alliance. Bringing all those different elements together will allow to build a comprehensive overview and a comprehensive set of recommendations on the public acceptance side.

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3.3.6 Discussion time

IUG being a dialogue forum, it was important to collect the IUG members' feedback on the contents of the meeting in the form of remarks, suggestions, points that were aligned with their expectancies or points that they would have liked to see addressed and which were not:

- All the presentations were reported to be interesting, contents and purposes of the project were clear. Great interest on the technical and economical modelling was expressed.
- A suggestion (EDISON) came to collect (real) data to support a PhD work at POLIMI on the modelling of a representative HES use case on an Italian industrial district. In Italy, it will be crucial to have the support of industrials, nuclear is not the promise of cheap energy but it brings stability and that is what the industrial customers are first of all looking for. The ambition of EDISON is to build 2 nuclear units by 2040 if conditions are right. Building a use case similar to the HES demonstration case will be valuable to support the demonstration.
- It is important to show the relevance of the tools and the methodology developed in the project, therefore there is a strong interest in benchmarking with other international tools and to study more realistic cases than the demonstration exercises achieved in the current framework. The library being open source, there are many added values in multiplying the exploitation of the TANDEM simulation toolbox.
- Due to the climate change, a question came about the scarcity of water sources in regard with the multiplication of SMR units. If SMRS are expected to be less demanding in terms of water for heat sink, proper siting needs to be conducted as it should be for any type of energy production infrastructure.
- In TANDEM, the waste has not been explicitly considered but the decommissioning prices used as modelling assumptions and boundary conditions are lumped in the OPEX costs.
- As an answer on the reference SMR model based on a typical LWR with a fixed electricity/heat production ratio, also different technologies (GenIV) or other electricity/heat ratios can also be integrated in the modelling using the modular structure of the Modelica library. However, models should be adapted if not developed to match specific characteristics.
- First results for the three cases presented being chosen at rather local/regional level, it was asked if it is feasible to apply the same tools on a national level. Even this is not the usual use of PERSEE and BACKBONE, they both can be deployed at national level.
- The possibility to transport hydrogen was discussed, especially for transportation

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usage which require very high containment pressure. Difficulties with hydrogen come with very strict specifications on mechanical fabrication standards.

3.4 Consortium meeting on October 29th 2024

At the annual consortium meeting organized on October 29th 2024 in Tractebel headquarters in Brussels both in presence and remotely, the IUG activities were reported as the WP5 presentation related to the stakeholder engagement follow-up.

No specific item was added to the brief reporting of the periodic IUG meeting (see 3.3) which has been organized in April 2024 with a significant participation of members of the IUG. This meeting showed a large interest expressed by the IUG members with a fruitful interaction with the TANDEM team representatives, and therefore proved to be a good communication forum.

The IUG members who were present either in presence or remotely (EDISON, INERIS, VATTENFALL, OPTIT) followed the discussions covering the WPs status and progress through the consortium presentations.

3.5 Third Periodic meeting on January 29th 2025

The third periodic meeting was organized on January 29th 2025 (only remotely) to give the opportunity to share with the IUG the significant achievements obtained by the project at date since the last meeting. The meeting saw the participation of a new member from EPRI (USA) in the person of the leader of the EPRI the Nuclear Beyond Electricity Initiative as part of the Advanced Nuclear Technology Program.

The agenda covered the progress status of the project and all its WPs. As an introduction, a presentation of the EU SMR Industrial Alliance was given in order to give an update on the EU SMR initiatives to the IUG members.

3.5.1 WP2 status - modelling for the simulation of the HES behavior

WP2 has developed an Open-Source Modelica “TANDEM” model library aimed at building customizable simulator components to reproduce the behaviour of power plants, systems and components, including SMRs, which are needed to analyse the hybrid systems. The TANDEM open-source library is now available at: https://gitlab.pam-retd.fr/tandem/tandem and the associated documentation can be found in the TANDEM deliverable D2.3: Modelica model description for the ‘TANDEM’ library.

The WP2 activities enables both techno-economics studies of nuclear HES (optimization of capacity and problem dispatchment) and safety studies through coupling with safety codes. Two

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hybrid energy system simulators for the district heating and energy hub cases are available to be employed in the techno-economics tools in WP3 . In the same time, the coupling between safety codes (CATHARE and ATHLET) and Modelica BoP models has been made operational to perform the safety analysis considering the integration of SMRs into hybrid energy system. The point of interface between safety codes and Modelica were chosen in the steam line behind the steam generator and feedwater line before the steam generator.

3.5.2 WP3 Status - time-dynamic techno-economic analysis of the HES

Progresses were made in WP3 on techno-economics studies for the energy hub (Southern European case). Due to the difficulties of accessing the detailed characteristics of the energy fluxes involving several industrials in existing European harbours, it was decided to arbitrarily set an initial architecture involving a CCGT, a photovoltaics field, an offshore wind farm, and energy storage systems, to produce constant hydrogen and electricity loads.

However, the model relies on a prospective super-structure of interesting energy mixes allowing to build an optimization problem, optimal energy mix under ideal assumptions using LCOE, LCOH, LCOH2 and CO2 intensities as parameters. Different cases and architectures were created to perform sensitivity studies to gas price and sensitivity studies to SMR main parameter. The optimization process has been implemented in the PERSEE tool: it is based on the optimization of an objective function by finding an optimal sizing of system components. The study was conducted over a 20-year lifetime span with a hourly one-year simulation. Fourteen optimal states have been run by increasingly limiting CO2 intensity (considering both CO2 grey and direct emissions).

In addition, the ECOSIMPRO model for the Energy Hub architecture resulting from Task 3.2 has been built allowing to compare and validate results with Deliverable 3.2 results and providing the possibility to make some iterations on PERSEE using the results.

3.5.3 WP4 Status - safety analysis of SMRs integrated into the HES

For WP4, activities covered the extension of conventional safety approach when SMR are integrated into hybrid energy systems. It is to be noted that the use of nuclear power plants for cogeneration is already effective for many years in several countries [IAEA, No NP-T-4.1, 2017], mainly for desalination and district heating applications. The configurations are often considered as the juxtaposition of two industrial processes with a customer-supplier relationship and a small number of interfaces. Risks are seen as independent, considering the other process as a potential external hazard.

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Main achievements at date focus on:

- Overviewing the operating flexibility and cogeneration management in various countries
- Development of a methodology for assessing the potential resulting impacts on safety for integration of SMRs into hybrid systems with identification of specific constraints and risks that could be induced on SMRs consequently to such integration, the identification of a list of safety relevant parameters potentially impacted by specific operational constraints and recommendation of an approach
- Definition of representative safety case studies

  Based on the input from WP 1, 2, and 3, a set of relevant safety cases for assessing cogenerating SMR safety against the safety criteria are defined. The cases will involve postulated initiating events mainly of the AOOs (Anticipated Operational Occurrences) or DBAs (Design Basis Accidents) type. The specifications include the initial and boundary conditions for the nuclear and cogeneration plant as well as major events and assumptions.

By coupling the CATHARE E-SMR model and the Modelica balance-of-plant model, CEA is analysing two transient scenarios: a design basis accident (load rejection followed by loss of offsite power) and a normal operation transient (load rejection followed by house load operation).

4 IUG outcomes

The IUG activities took benefit from a large involvement from all members and “cumulative” interest. The IUG showed to be a good communication forum between the project and the representatives of key industry sector and energy stakeholders for the potential deployment of SMRs technologies.

Some important messages were collected along the IUG meeting participations:

- Industry must strive to become climate neutral, ideally by 2050. **Electrification** of processes **is a key part** of achieving this goal;
- Industry will require **significant amounts** of carbon-neutral electricity to power these processes;
- While **renewables** can contribute, they have **drawbacks** such as intermittency, high grid connection costs, and the need for backup solutions;
- To ensure competitively priced and secure electricity availability, a **complementary**

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technology to RES is essential;

- Industrial companies need stable volumes of electricity at a stable price and a stable regulatory environment to remain competitive;
- The **urgency for affordable energy** and a stable framework is high if we want industries to remain in EU.

The following takeaways can be highlighted from the discussions between TANDEM and IUG:

- Nuclear has a role to play in the mix for climate-neutrality;
- The technical and financial stability of low-carbon supply of electricity is an advantage of SMR technologies;
- Decentralized SMR will be closer to the users: public acceptance is therefore also an important issue to bear in mind;
- With the penetration of intermittent RES, future CHP units will have to run on a flexible mode including storage;
- Cogeneration being the backbone of local and integrated energy systems, CHP using SMRs will have an important role to play, in particular in correlation with hydrogen production;
- The question is always when SMRs will be available;
- Decarbonizing the manufacturing sector is challenging. Therefore, no low-carbon energy sources can be ignored and SMRs are seen as potentially providing a solution for this sector;
- SMRs are seen as a potential solution for electro-intensive industries, but also for those dependent on heat, steam and other energy sources (e.g. hydrogen);
- Some Member States (e.g. Sweden) are considering SMRs for regions with significant heavy industries (including the steel and mining sectors);
- Some Member States (e.g. Finland or Czech Republic) are considering SMRs for DH applications;
- However, concerns were raised regarding the time it takes to license nuclear projects. Reactor licensing issues in Europe seem to be the largest problem, licensing goes too slow.

Inspired from the IUG considerations and takeaways, some general recommendations can be drawn, aligned with those of the Scientific Advisory Committee (TANDEM/D7.5, 2025):

Recommendation n°1: It was suggested to organize dedicated workshops about SMR licensing with TSOs and nuclear safety authorities to encourage harmonization and to accelerate SMR emergence for industrial applications.

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Recommendation n°2: The Modelica open-source library of TANDEM proved to be an efficient tool-box for modelling and analysing HES. It is recommended by the IUG to demonstrate further the relevance of the tools and the methodology developed in the project by studying realistic hybrid systems based on dedicated techno-economic data, preferably supporting potential industrial projects.

Recommendation n°3: It would be beneficial to establish contacts with investors to check whether the techno economic information produced in the simulations is appropriate for producing business plans and applications for financing. The results of the HES simulations using the TANDEM tools will be science based, they will be justifiable and they can be helpful to support nuclear technologies in investment roadmaps.

Recommendation n°4: The IUG proved to be a good communication forum with industry and energy stakeholders representatives about nuclear technologies integration in HES and it is recommended to sustain the IUG principles beyond the end of the project. However, an appropriate framework remains to be defined and perhaps the implementation could take place in the framework of the European Industrial Alliance on Small Modular Reactors

Recommendation n°5: Citizen engagement is very important to support nuclear technologies integration in HES. It is recommended to involve industry and energy stakeholders representatives for the assessment of citizen engagement during workshops as they usually deploy effective means of communicating their needs in terms of energy decarbonisation.

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5 Bibliography

(TANDEM/D7.5, 2025) C. Vaglio-Gaudard et al, Final SAC recommendations report, Deliverable 7.5.

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