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CST4ALL - Support to the Activities of the Concentrated Solar Thermal Technology Area of the SET Plan

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Abstract. The Concentrated Solar Thermal Technologies (CST) sector has struggled with high-costs associated with Concentrated Solar Power (CSP) plants in Europe over the past decade. Moreover, CSP has largely been viewed only as a flexibility provider for electricity systems. To address these challenges, the CST4ALL project promotes a range of hybridization and cooperation initiatives at the intersection of CST and other renewable energy technologies, drawing on the work of various European Technology & Innovation Platforms (ETIPs). CST4ALL aligns closely with current EU priorities- such as Smart Sector Integration, Fit for 55, and Clean Energy Transition Partnership (CETP)-as well as national energy strategies. It seeks to offer solutions to pressing issues related to decarbonisation and energy security. The key outcome is a series of workshops engaging both industry and research and development (R&D) communities, fostering interaction among stakeholders at key technology interfaces with the CST sector. By analysing both industrial and R&D perspectives, CST4ALL aims to expand the network of active stakeholders in the CST Implementation Working Group (IWG) under the SET Plan and to raise awareness of CST's potential role in sustainable energy mix. This paper outlines the project's main activities to support the European Commission's cross sector approach – encouraging public and private investment in R&D and establishing the political and regulatory framework needed to implement the new CST Implementation Plan (IP) from October 2022 to March 2024.

Keywords: Concentrated Solar Thermal, Hybridization, Cooperation, European Technology & Innovation Platforms, SET Plan

1. Introduction: Overview of the Project

CST4ALL-Support to the Activities of the Concentrated Solar Thermal Technology Area of the SET Plan Project [1] follows-up on the H2020 project HORIZON STE-Implementation of the Initiative for Global Leadership in Solar Thermal Electricity (GA No. 838514) Project that provided new grounds for a novel approach to the Concentrated Solar Thermal Technologies (CST) sector in the light of the “smart system integration”. For decades, direct and indirect subsidies led Member States to make strategic investments to affect multiple sectors specifically electricity and gas systems. However, one major challenge for CST is its relatively high levelized cost of electricity (LCOE). This has resulted in a slowdown CST investment in Europe, threatening both European competitiveness and the efficient use of natural resources. The CST4ALL projects tackles these issues through a broad range of initiatives aimed at fostering collaboration across key technology areas. It also works to strengthen existing stakeholder networks and integrate different sectors through the CST Implementation Working Group (IWG) and national and European industry associations, emphasizing CST’s role in a sustainable energy future. Sector integration is becoming an increasingly strategic priority for The EU and its Member States. This strategy presents a valuable opportunity for the CST sector-not only in power generation but also in decarbonizing industrial heat and producing hydrogen. It can support the wider growth of CST technologies, encourage the development of hybrid systems (such as CST combined with photovoltaics, biomass, or geothermal), and promote cross-border energy cooperation-benefiting other renewable energy sources as well.

The main goal of CST4ALL is to support the development of strong and sustainable networks between CST and other key technology areas outlined in the European Strategic Energy Technology Plan (SET Plan) and its integrated roadmap. These networks promote efficient collaboration among ETIPs, IWGs and related stakeholders, while also supporting existing SET Plan IP-especially the CST IP. CST4ALL aims to foster more interconnected activities, both in content and in implementation. The project identifies cross-cutting factor that can accelerate the clean energy transition, contributing to the creation of a European Research Area in the energy field. It addresses this by combining research and development (R&D), industry insights, and political perspectives-particularly focusing on well- known but underutilized technology combinations across different European regions.

CST4ALL’s unique value lies in combining input from Member States on their needs and ambitions with feedback from industry and researchers regarding their current and future roles in deploying new applications. The project helps inform European citizens and policy makers about the benefits of integrated technologies and their socio economic impact, including business opportunities for both large companies and SMEs. This is expected to increase social acceptance, to simplify permitting processes for new installations, and improve access to public funding to related R&D.

Additionally, during the proposal preparation, the need to include social sciences and humanities (SSH) was recognized- given economic, social and policy challenges of the Green Deal. Relevant SSH activities are now being conducted. SSH contributes by helping to define strategies to overcome these challenges, in line with the CST sector’s goal of achieving carbon neutrality by 2050, decoupling economic growth from resource use, and ensuring a just transition that leaves no one behind.

The project is coordinated by **DLR -** Deutsches Zentrum Fur Luft - und Raumfahrt EV (the research entity in Germany with 10,000 employees at 30 locations, and representing one of the world's leading research groups in the field of CST systems with over 200 scientist and engineers). The consortium members are **CIEMAT PSA -** Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas-Plataforma Solar de Almeria (a Spanish Research and Development (R&D) center as the largest public research infrastructure in the world devoted to CST), **ENEA-** Agenzia Nazionale Per Le Nuove Tecnologie, L'energia E Lo Sviluppo Economico Sostenibile (the Italian key reference center for CST that built and operates some

of the most relevant experimental facilities worldwide for CST linear systems), **ESTELA**-European Solar Thermal Electricity Association (non-profit organization gathering members from the CST industry and research institutions in Europe, the European countries and other member countries of the Union for the Mediterranean) and **GUNAM-**Center for Solar Energy Research and Application (Turkiye's Center of Excellence (CoE) on Solar Energy and is one of the largest solar energy CoEs in the Eastern Mediterranean region).

2. Methodology

CST4ALL is a 36-month project organized into five work packages (WPs). WP1 covers the support to the IWG and monitoring of IP progress from both industry and R&D perspectives. WP2 and WP3 refer to the cooperation across sectors covered by the SET Plan/ETIPs from an industrial/market (WP2) and R&D (WP3) perspective with parallel series of workshops. WP4 contains all the activities related to addressing the Social Sciences and Humanities (SSH) aspects of the project along with the dissemination, exploitation, and communication (DEC), while WP5 focuses on general project management, coordination of internal and external meetings, as well as data management. CST4ALL organizes a series of intertwined workshops aimed at both industry and R&D communities. The goal is to develop EU-level proposal from a cross-sector perspective, encourage public and private R&D funding, and help to establish the political and regulatory framework needed to carry out the new CST IP (Figure 1).

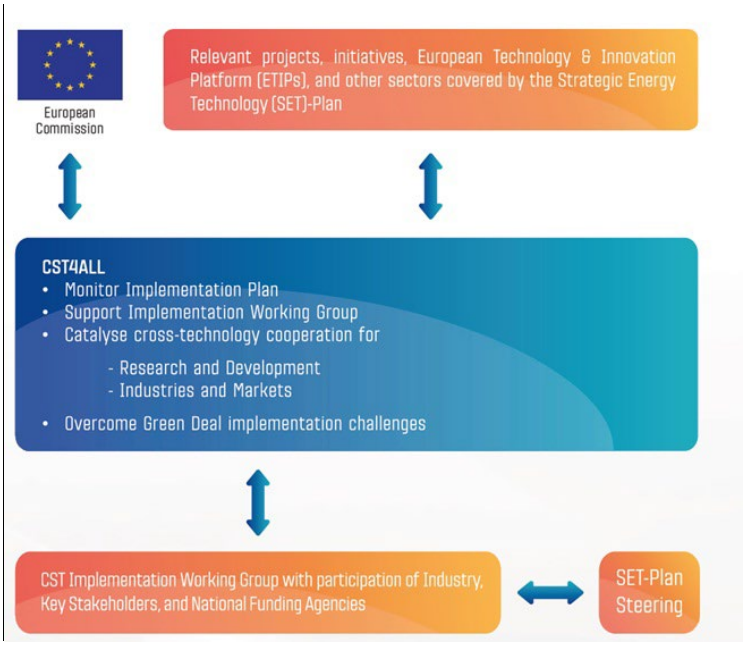

Figure 1. *Methodology of CST4ALL Project [2].*

3. Project Outcomes

Focus on boosting the cooperation between different renewable energy technologies, CST4ALL project's expected key outcomes are (i) increased awareness of and support for CST technologies from key stakeholders and the general public, and (ii) strengthened capacities and willingness of key actors from different SET Plan sectors to implement cross-cutting, integrated, and holistic solutions to shared challenges. The expected long-term impact is to accelerate the clean energy transition and achieve Green Deal by making Europe the global leader in cross-cutting solutions that perform well economically, technically, environmentally, and socially.

The core activities to realize these outcomes are industry focused and R&D focused workshops. In the period until March 2024, three workshops were organized: 1 industry focused and 2 R&D focused.

In the context of the industrial workshop, the main objective is to assess the conditions (energy policy strategies, financial conditions, specific auction design features, type of R&D supporting actions) that offer an industry-focused expanded platform bringing together CST and non-CST actors. To achieve this, the project analyzed the "integrated findings" from country reports by the HORIZON-STE project [3] and reviewed the priorities and expectations of different Member States as outlined in their 2023 draft updated National Energy and Climate Plans (NECPs) and the revised CST Implementation Plan [4].

In the period covered by this paper, the project partners, with support of the ETIP PV, organized the first **CST4ALL Industry Workshop on the Hybridisation of CST with PV**. Held online on 22 February 2024, the half-day event featured keynote presentations on hybridization opportunities and roundtable discussions on topics such as technological readiness and financial viability of projects, as well as research needs, skills, and manufacturing capacity in Europe. This workshop, brought together over 140 energy sector stakeholders from 20 countries in Europe and beyond [5].

As a part of the R&D workshop series, the main goals are to identify for joint research that address current challenges in Europe, develop strategies to reduce costs and improve the performance and durability of technologies, support the launch of new research projects to accelerate the clean energy transition, and to contribute to building a European Research Area in the Energy field. Two R&D focused workshops were held during this period:

- The first, titled "**Cross-Cutting Materials Challenges of Renewable Energy Technologies"** took place on 9 November 2023 [6]. It was attended by 227 of 271 registered participants. The event featured keynote presentation on **"Materials Challenges in CST and Other Fields**" and a roundtable discussion on **cross-cutting challenges, existing frameworks, and potential synergies**.
- The second workshop, "**R&D Challenges for the Hybridization of CST with other Renewable Energy Technologies***"* was held on 22 March 2024 [7]. It drew 166 participants out of 175 registered. The topics included were the applications for the generating electricity, producing heat and green hydrogen production.

4. Findings and Impacts: Activities to support the Concentrated Solar Thermal Technology Area of the SET Plan

First main activity to contribute to the CST Area of the SET Plan is "**To support CST Implementation Working Group activities**". This task is led by CIEMAT with participation of ESTELA and ENEA. The objective of this task is "to provide continuous formal support to the CST IWG (SET Plan), and particularly to the Chairs (Cristina Trueba, from the Spanish Ministry of Science, Innovation and Universities, and Maria Luisa Revilla, co-Chair, from the Spanish governmental organization CDTI, Centre for the Industrial and Technological Development), and to the defined Core Group of the IWG". The other objective is "to facilitate the connection and direct technical inputs or contributions, mainly from the research & technological organizations and the industry, when needed or requested". This support has been provided by CIEMAT-PSA staff since the beginning of the project, through frequently organized telcos, and by creating a specific working group formed by Ricardo Sanchez (coordinator of the EERA JP-CSP), Eduardo Zarza (PSA Former Technical Coordinator) and Julian Blanco (PSA Director). The main specific performed initiatives are described as associated with the following topics:

- CST Implementation Plan (SET Plan) [4]: CST IP was fully reviewed and updated during 2022 (from its first initial version of November 2017). The update of the CST IP was concluded in February 2023 and was endorsed by the SET Plan Steering Group in March 2023.
- SET Plan contribution and reporting: Support to the IWG Chairs has been especially effective in the case of the 2023 reporting exercises related to the CST-IWG and the Clean Energy Technology Observatory (CETO) [8]. In both cases, the interaction with the research and academia stakeholders, mainly through EERA JP-CSP (coordinated by Ricardo Sanchez) was key to providing an accurate status of the IP progress and related activities.
- Widening the scope of CST IWG to include Non-Concentrated Solar Technologies (NCST): A key development for the CST IWG is the ongoing enlargement of its scope of activities to include both concentrated and non-concentrated solar thermal technologies. Following the call for expression of interest launched on the SET Plan information system (SETIS) to join the expanded IWG, the relevant stakeholders shall work together towards the smooth transition to an integrated IP in the future covering all solar thermal technologies. This is a challenging process that offers a great opportunity to capitalize on a comprehensive and cohesive strategy for all solar thermal technologies, with close collaboration among stakeholders, including Member States representatives, funding agencies, research institutions and industry players. This collaboration should aim to coordinate R&D efforts to address both common and technology-specific challenges, increase technology attractiveness, leverage synergies, and explore ways to overcome the existing regulatory and financing barriers.
- Strategic Research and Innovation Agenda (SRIA)-Solar Energy: Telco meetings were held between CST IWG Chairs and CST4ALL staff to provide inputs to the IWG Chair to the discussion between EC and Member States involved in the Solar Strategic Research and Innovation Agenda (SRIA). Also, contributions to the final version of the SRIA, and especially to the cross-cutting issues (among PV and solar thermal topics), were collected from research and industrial stakeholders, processed and submitted. Assistance was additionally provided for the preparation of different meetings exclusively attended by government representatives.
- Clean Energy Transition Partnership (CETP) and Horizon Europe (HE) programs: Contribution to the content of the CETP Work program, the 2023 call, and the 2024 call. To this end telco meetings were organized between 2023 and 2024 to initially define a group of potential topics for the calls which were later widely consulted with research and industrial stakeholders to define the final wording submitted to the CETP TRI2 (renewable electricity) managers. As a result of the achieved success (all final contributions were accepted and included within the first draft of the call), the same procedure was also used to provide similar inputs to the EC, early in 2024, concerning the coming Work Programme 2025-2026 – Cluster 5 (Climate, Energy and Mobility).
- SET Plan Conference 2023: The SET Plan Conference 2023 was organized in Barcelona, and hosted by Spain. Due to this fact, CST IWG Chairs were fully in charge of several organization tasks, including meetings related to specific CST IWG issues (such as integration of NCST topics into the CST IWG). More telco meetings were organized to provide support from CST4ALL to these issues and also personnel staff attended the conference in Barcelona to provide additional onsite support.
- SET Plan Workshop: Participation to the workshop, organized by the EC on 19th of March 2024, as support to the CST IWG chairs in the discussion on the status of the draft SET Plan Terms of Reference that outline the SET Plan and its different structures and to highlight the role of CST technology under the Net Zero Industry Act.

Second main activity is "**Monitoring IP progress in the industrial sector**" with the task leader (and the only performer) being ESTELA. Within this task, ESTELA has monitored important events, opportunities and developments relevant for the CST sector and contributed to various initiatives. For this purpose, ESTELA performed desk research, attended meetings and events in the framework of CST IWG and other initiatives, such as the ETIPs FORUM and Solar Impulse Foundation, and gathered inputs from its members and the project partners. As

an output, ESTELA prepared and submitted a deliverable (sensitive) by analysing the following topics and their impact on cross-technology R&D activities and industry projects related to CST. Specific aspects addressed include:

- SET Plan and CST IWG: For this purpose, ESTELA contributed to the update of the CST Implementation Plan and the expansion of the IWG's scope of activities to include non-concentrating solar thermal technologies.
- Initiatives and legislative measures at EU level*:* Specifically ESTELA examined the topics of: (i) Reform of EU electricity market design, including its public consultation process launched by the EC, (ii) Revision of the Renewable Energy Directive (RED III), including the open consultation process on "Renewable energy – guidance on designating renewables acceleration areas" launched by the EC, (iii) Draft updated national energy and climate plans (NECPs) and their technical assessment of progress towards the 2030 goals by the European Commission, and (iv) Net-Zero Industry Act (NZIA).
- Updates on current regulatory conditions at national level in Spain, Italy and Germany.
- Updates on financing mechanisms including for the Horizon Europe programme, Innovation Fund, Clean Energy Transition Partnership and Cooperation mechanisms.
- Studies and Reports such as "Solar Industrial Heat Outlook 2023-2026" [9] published by the German agency Solrico and "Renewable Power Generation Costs in 2022" [10] published by the International Renewable Energy Agency (IRENA). Also, ESTELA contributed to the SET Plan Report 2023 by participating to ETIPs Forum.
- ETIPs Forum specifically for the ETIPs Input to SET Plan Report 2023 and the joint recommendations of the European Technology and Innovation Platforms on the draft revised National Energy & Climate Plans (NECPs) [11].
- Solar Impulse Foundation's recommendations to help Member States reach their goals to deploy renewable energies and increase energy efficiency [12], *Tour of EU capitals* in spring 2023 by Bertrand Piccard, Chairman of Solar Impulse Foundation, visiting several EU Ministers with the objective to increase awareness at national level and push for implementation and more ambition in the NECPs and the *Release of the manifesto "Europe 3.0: Modernise to Thrive*" [13], calling for a paradigm shift to modernize Europe and harness the potential of the Green Deal.
- New CST plants in Europe, such as CST plant at Avery Dennison production facilities in Turnhout, Belgium, CST plant at Heineken's factory in Seville, Spain and CST plant at Heineken's factory in Quart de Poblet (Valencia), Spain

Third main activity is **"Monitoring IP progress in the R&D sector"** with CIEMAT as the task leader and ENEA, DLR, GUNAM as participants. During 2023, CIEMAT contacted twenty-seven R&D entities (research centres, universities, etc.) from 10 countries to prepare the list of R&D projects related to CST technologies at both national and European levels. The survey prepared by CIEMAT-PSA and sent to the JP-CSP members contains the following information related to each project which they are involved in: (i) Project name and acronym; (ii) Geographic area of the project: National or European; (iii) Coordinator (affiliation, name and e-mail address); (iv) Industrial partners involved in the project; (v) Non-industrial partners involved in the project; (vi) Duration; (vii) IP areas related to the project; (viii) Individual budget per partner; (ix) Total project budget; (x) public funding given to the project; and (xi) web site of the project (if available). The information provided by the R&D entities was then filtered and completed by means of bilateral conversations between CIEMAT and the other entities. The list of projects is in Excel format, so there is a sheet with the list of national projects in each country, together with European projects with participation of entities from that country (i.e. ten sheets with the list of projects related to each country), while another sheet in the excel file contains the complete list of both National and European projects related to CST, without duplication or overlapping. An internal deliverable has been drafted, which provides an overall view of the R&D activity underway in Europe, according to the information received from twenty-one out of the twenty-seven entities that replied to the survey. This document provides a quick overview of the information related to national CST R&D projects. *99 national projects* have been identified, *with a total public funding of 120.649.836 €. Topics 1 ("Line-focus solar power plants technology"), 2 ("Central Receiver power plants technology"), 3 ("Thermal storage systems") and 7*

("Cross-cutting issues") of the new Implementation Plan (IP) for CST are the ones attracting more R&D effort in the national projects, while *topic 4 ("Turbomachinery developed for specific conditions of solar thermal power plants")* is the topic with the lowest number of national projects (4 projects only).

Concerning the *European CST R&D projects,* a total number of *53 projects* have been reported and analyzed in the survey. The effort devoted at European level is more evenly distributed among all the topics, with the exception of topic 4 ("Turbomachinery developed for specific conditions of solar thermal power plants"). *Each topic is included in at least 10 projects*, with the exception of topic 4 ("Turbomachinery developed for specific conditions of solar thermal power plants"), which has only 3 European projects associated.

5. Conclusion and Future Planned Activities

CST4ALL Project highlights and follows EU's smart system integration strategy. The main aim of the project is to support the creation of strong and sustainable networks between CST and other relevant technology areas covered through the European Strategic Energy Technology Plan (SET Plan) and its integrated roadmaps. These networks facilitate efficient and direct collaboration among ETIPs, IWGs, and similar stakeholders, while supporting the ongoing SET Plan Implementation Plans. In CST4ALL key factors for speeding up the clean energy transition are being identified in the context of European Energy Research Area. CST4ALL stands out by bringing together the goals of the Member States with inputs from industry and research on how to use new clean energy technologies now and in the future.

The project's key outcomes primarily focus on enhancing collaboration among various renewable energy technologies, raising awareness and support for CST, and reinforcing the capacities and commitment of key players across different SET Plan sectors. The primary activities to achieve these outcomes include industry-focused and R&D-focused workshops. The main goal of the industrial workshop is to evaluate the contextual conditions that provide an expanded platform for collaboration between CST and non-CST stakeholders. The R&D workshops aim to identify joint research areas that address current opportunities and challenges in Europe, develop strategies to reduce costs, enhance performance and durability of the involved technologies, and support the implementation of research projects to accelerate the clean energy transition. Until March 2024, one industry-focused and two R&D-focused workshops were organized, with over 500 participants attending.

Moreover, in this period in addition to workshops, several activities to support the CST Area of the SET Plan were performed including supporting the CST IWG activities by monitoring IP progress in the industrial and R&D sectors. These are the main tasks performed under the work package one of the CST4ALL project mainly dealing with CST IWG and IP mainly in the first reporting period of the project (October 2022 to March 2024).

The next period of the project, from April 2024 until the end of the project in September 2025, includes 4 Industry Focused Workshops and 2 R&D Focused Workshops. The industrial focused workshops are:

- Industry Workshop on the "Hybridization of Concentrated Solar Thermal Technologies with Biomass" was held on May 7, 2024 and over 90 stakeholders from the energy sector across 17 countries within and outside Europe participated the event.
- Industry Workshop on the "Hybridisation of Concentrated Solar Thermal Technologies (CST) with Heat Pumps" which is planned to be held on 29 October 2024,
- Industry Workshop on the "Hybridisation of Concentrated Solar Thermal Technologies (CST) with Geothermal" which is planned to be held in the second half of January 2025, and
- Industry Workshop on the "Hybridisation of Concentrated Solar Thermal Technologies (CST) with Batteries" which is planned to be held in March 2025.

The R&D focused workshops are:

- *R&D workshop on Meteorology* which will be held on 11 December 2024, and
- *R&D workshop on Future Energy Mix with 100% Decarbonisation Level* which is planned to be held in February 2025.

To reach the overall target of boosting collaboration in diverse renewable energy technologies and CST at European Level and to give further recommendations by integrating the discussions in all these workshops, one report incorporating cross-technology roadmaps and one report about key findings on R&D cross-cutting issues and cooperation options will be prepared to finalize the project.

Data availability statement

The main source of this paper is Technical Report (Part B) of Reporting Period 1 (Duration: 01/10/2022 to 31/03/2024) Report.

Author contributions

All authors equally contributed to conceptualization, data curation, formal analysis, funding acquisition, investigation methodology and project administration. Y.E. Topal, H. Eryılmaz, D. Baker, K. Genikomsakis and D. Benitez contributed more in writing the original draft and reviewing and editing the final draft.

Competing interests

The authors declare that they have no competing interests.

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