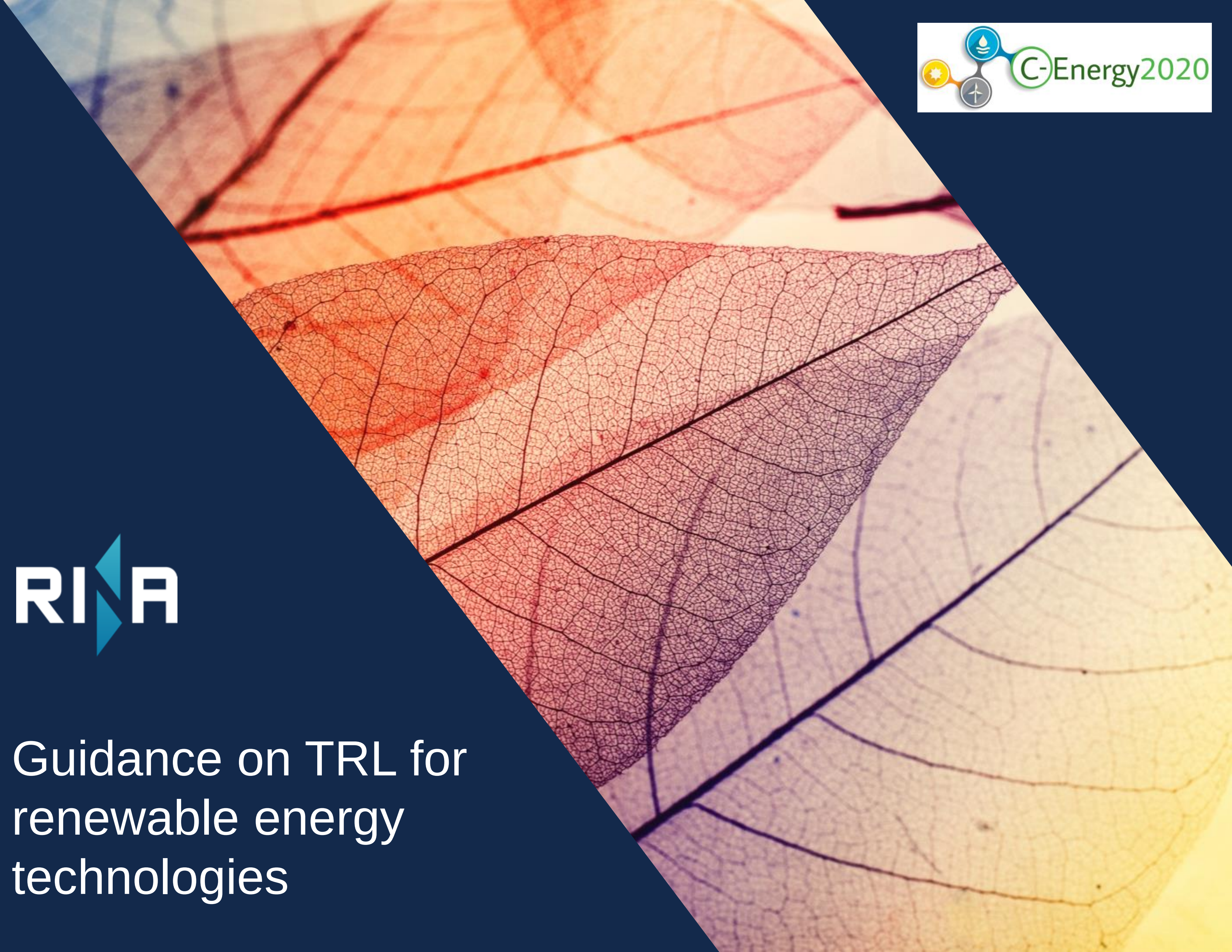
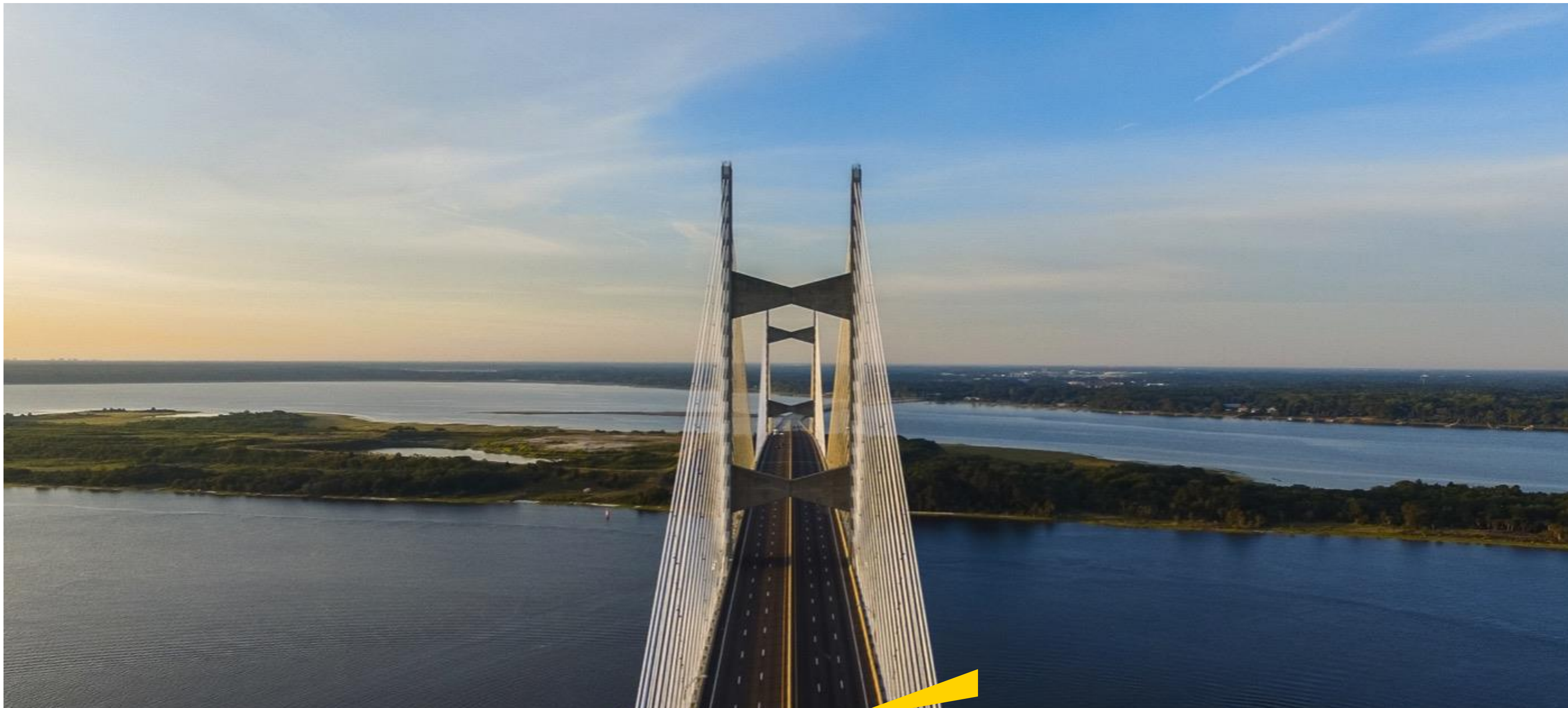


Guidance on TRL for renewable energy technologies

Guidance on TRL for renewable energy technologies - Ref: PP-03583-2015



Webinar for C-energy2020 project
16/11/2018

Building a better working world

The presentation today

Topic	Discussion points
1. Introduction	Objective of the study Overall approach
2. Task A	Methodology and results
3. Task B – Methodology	Guide of guides; drafting process; stakeholder engagement and external review
3. Task B – Learining by doing	Oustanding issues and how we addressed them
3. Task B – Guidance documents	Presentation of the 10 guidance documents developed
3. Task B – Trends and specificities	Common trends Technical specificities
4. Lessons learnt and replicability	Update of the Guide of guides; application to other technologies

Introduction

Objective of the study
Overall approach.

RINA

Objectives of the study

Objectives and outcomes

- ✓ Assessment of the use of TRL in the field of renewable energy in the European Union
- ✓ Development of a set of guiding principles explaining how to address TRL for the relevant fields

Overall approach

RINA

Service required

Duration: 14 months; started in Oct 2016

Task A: Assess the state of play of the use of TRL in the energy field through desk research

Task B: Draft guiding principles on what is meant by ‘being at a specific TRL’ for each of the RE considered

10 validation workshops: one per each RE field, involving industrial, institutional and research stakeholders

Definition of ‘Guide of Guides’

- ✓ Backbone of the future technology readiness framework
- ✓ Guidance doc’s development plan

Well-designed stakeholders engagement

- ✓ To better inform the development of the guidance documents and raise likelihood of buy-in
- ✓ Pre-work to the workshops

External review to ensure consistency

- ✓ Both on the draft document and to validate conclusions

‘Learning by doing’ process

- ✓ Tacking stock of best practices and lessons learnt from sector to sector

Task A

Methodology
Results

Task A – Subtask division

TASK A1 – Assessment of the use of TRL in the energy field

TASK A2 – Review of the use of TRL for RE in the US DoE calls

TASK A3 – Evaluation of the use of TRL in energy R&D programmes and in industrial and commercial projects

TASK A4 – Identification of best practices

Task A - Assessment of the use of TRL in the energy field

Desk Research and phone interviews (21 EU + 9 US). Focus:

- ✓ Existing TRL scales
- ✓ key issues in their utilization and related challenges
- ✓ Other Readiness Level scales and the technology risk perspective
- ✓ Recommendations

Desk research: existing and consulted TRL scales

- ✓ US Department of Energy (DOE)
- ✓ Australian Energy Agency (ARENA)
- ✓ Government of Canada
- ✓ EC
- ✓ Organisation for Economic Co-operation and Development
- ✓ Wave energy development protocol
- ✓ Electricity Supply Boad International (and Vattenfal) TRL for wave power conversion systems
- ✓ European Association of Research and Technology Associations (EARTO): proposal for improvement of EC TRL scale

Task A1 - Assessment of the use of TRL in the energy field

Knowledge on TRL scales (30 interviews)

- ✓ > 90% are aware and use it, >60% knew it rather well, <7% show poor knowledge on TRL
- ✓ US-participants: US DoE, NASA and US DoD
- ✓ EU: H2020 scale and US DoE and DoD
- ✓ Mentioning of additional and shorter scales (3-stage scale)

Use in the energy field

- ✓ **Nearly all used it for funding or proposal assessment,** not so much used as decision making tool
- ✓ **45% internal communication, 55% external communication**
- ✓ 23% use it as planning tool, 10% use it as decision-making tool

TRL versus SRL/MRL

- ✓ 60% had never heard about SRL, 13% had heard about it but did not know the details, 25% knew SRL, nobody was using it
- ✓ 53% had never heard about MRL, 17% had heard about it but did not know the details, 30% knew MRL, nobody was using it

Task A1 - Assessment of the use of TRL in the energy field

Recommendations

- ✓ TRL scale OK for evaluator, but applicant can easily “cheat”
- ✓ Commercialisation aspects, cost effectiveness and so forth not integrated. Final market value should be part of evaluation of stage of development
- ✓ TRL not suited for complex and integrated systems (but most not aware of existance of SRL)
- ✓ Make a generic and harmonized scale
- ✓ Add examples

Best Practices

- ✓ Flexibility of US DOE TRL scale considered best practice, wording was adapted according to call
- ✓ NASA keeps descriptions updated, comprehensive and open to public
- ✓ Implementation of check points to evaluate if a certain level is reached

Task A1 - Assessment of the use of TRL in the energy field

Focus topic		Key conclusions
1. TRL scales	1.1 Knowledge	• General knowledge on TRL scales is good • Europe - EU Horizon2020 TRL scale is the best known • US - US DOE TRL scale is the best known; second, the US DOD TRL
	1.2 Use in the energy field	• Main purpose is to apply for funding or review project proposals in a call for funding • Also used for internal and external communication towards industry and clients • Less extent (research field): as a planning or decision-making tool
	1.3 Use vs MRL, SRL	• General knowledge about SRL/MRL is very limited. Similar concept are however integrated in internal programmes to complement gaps in the TRL scale. • No consistency between stakeholders with respect to pros and cons of SRL and MRL scales. Some see no added value, others claim the use of them is needed to compensate for shortcomings of the TRL scale.
2. Recommendations and best practices		• Better clarification of the scale is needed, so assessment can be done more objectively • Inclusion of examples in the scale would be an added value • Need for a simplification of the scale

Task A2 - Review of the use of TRL for RE in the US DoE calls

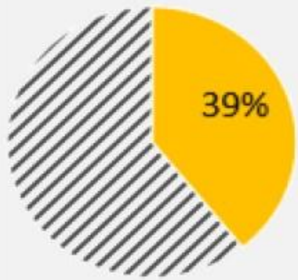
Desk Research: past and present calls of the US Department Of Energy (DOE).

Focus: find inspirational cases combining:

- ✓ Quality and consistency in the way a specific TRL scale was addressed
  - ✓ TRL clearly stated? If not, easily measurable from call?
  - ✓ Definition of TRL consistent within sector?
- ✓ Budget allocation
  - ✓ Where was most of the budget resources allocated? Across levels / across sectors
  - ✓ Link between the budget allocation and the quality of the call?

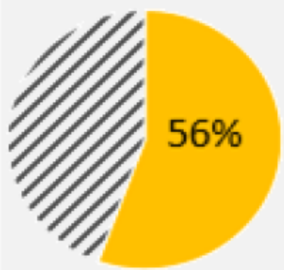
Task A2 - Review of the use of TRL for RE in the US DoE calls

Bioenergy



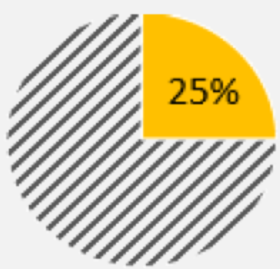
- In 39% of the calls analysed the level of TRL was clearly defined or, alternatively, easy to assess from the documents of the call (in 47% of the overall cases).
- The calls addressed TRLs from 1 to 7 and were particularly clear from TRL 6 and 7.

Wind Energy



- In 56% of the calls analysed the level of TRL was clearly defined or, alternatively, easy to assess.
- The calls addressed TRLs from 2 to 7+.
- 50% of the calls clearly stated the TRL addressed, and in 67% of the cases this was easy to assess from the documents of the call.

RE Heating and Cooling



- Only in 25% of the calls analysed the level of TRL was clearly defined or, alternatively, easy to assess.
- The calls addressed TRLs from 2 to 7.
- Only 25% of the calls clearly stated the TRL addressed, and only in 25% of the cases this was easy to assess from the documents of the call.

Task A2 - Review of the use of TRL for RE in the US DoE calls

Sector	Quality of the calls	Budget TRL								
		1	2	3	4	5	6	7	8	9
Bioenergy	M	L	M	M	L	L	H	M	na	na
Geothermal	M	na	L	M	M	M	L	L	na	na
Solar	L	na	na	L	L	L	na	na	na	na
Water	M	L	L	L	L	L	L	na	na	na
Wind	H	L	L	L	L	L	L	H	H	na
RE H&C	L	na	L	L	L	L	L	L	na	na

Quality ranges: high (H) = > 40%; medium (M) = 30%-40%, low (L) =< 30%

Budget range: high (H) = > 50M; medium (M) = 20M-50M, low (L) =< 20M

Task A3 - Evaluation of the use of TRL in energy R&D programmes and in industrial and commercial projects

Online Survey (1099 stakeholders in 10 RE fields)

- ✓ 5 technology descriptions to be assessed based on EU Horizon2020 TRL scale
- ✓ Stakeholders' personal experience with TRL scales
  - ✓ their experience on TRL
  - ✓ description of the context they use TRL in
  - ✓ whether they use other assessment scales or tools
  - ✓ familiarity with SRL or MRL scales

Geographical and sectorial coverage

- ✓ For each technology field, 3 interviews were taken, 2 EU and 1 US
- ✓ EU: maximum geographical spread
- ✓ US: 3 different research institutes (national laboratories), 1 university and 1 policy maker (from US DOE EERE)
- ✓ 60% were from research institutes, 7% from universities, 20% from industry and 13% were policy makers

Task A3 - Evaluation of the use of TRL in energy R&D programmes and in industrial and commercial projects

Online Survey

7. **Description 2: Hybrid PV for regeneration of shallow geothermal system to increase overall system efficiency**
In this living lab, high performance PV panels are being used to make hybrid PV panels. The thermal part of the panels are connected to an open cooling reservoir before flowing to the geothermal system. This allows to have a first cooling preventing high temperatures entering the shallow geothermal system and to realize a considerable drop in temperature before flowing back to the PV panels. The positive impact on the SPF of the geothermal heat is currently being compared with reference data of operation prior to connection with the hybrid PV. The impact of the reduced temperature at the back side of the PV is assessed by comparing data of a set of PV panels on the same location and not rebuilt to PVT. First results show an improved efficiency of over 3% on the electrical side.

After reading the technology description of technology development 2, can you indicate whether the description is clear?

◯ Yes

◯ No

11. Considering the description of the TRL levels in TRL scale 1, how would you rank the described technology developments?
Please rank from TRL 1 to TRL 9.

	Scale 1 - EU
Description 1: Surface water comfort cooling	
Description 2: Hybrid PV for regeneration of shallow geothermal system to increase overall system efficiency	

12. Is the allocation to a specific TRL level clear?
Please answer yes/no. Tick the box if it's clear; otherwise leave it open.

	Scale 1 - EU
Description 1: Surface water comfort cooling	☐
Description 2: Hybrid PV for regeneration of shallow geothermal system to increase overall system efficiency	☐

Task A3 - Evaluation of the use of TRL in energy R&D programmes and in industrial and commercial projects

Key findings

- ✓ Non-consistent assessment
- ✓ Large spread
- ✓ No link between technology description and spread in TRL assessment

Need for clear guidance documents on TRL scales for different technologies

Task A4 - Identification of best practices

Technology-specific TRL scale for wave power conversion systems, as developed by ESBI: 9-TRL scale containing ESBI Verification Checklist and indicative information on costs

The idea of checkpoints at each TRL level is taken up in the development of the Guide of Guides.

Once readiness level 2 is achieved, the applied technological concept has been defined. This means:

- *definition of application*
- *manufacturing approach determination*
- *statement of interactions between technologies*
- *preliminary risk analysis*
- *preliminary market analysis*
- *preparation of investment strategy*

Task A4 - Identification of best practices

- ✓ Technology-specific TRL scale for geothermal energy in US DOE calls

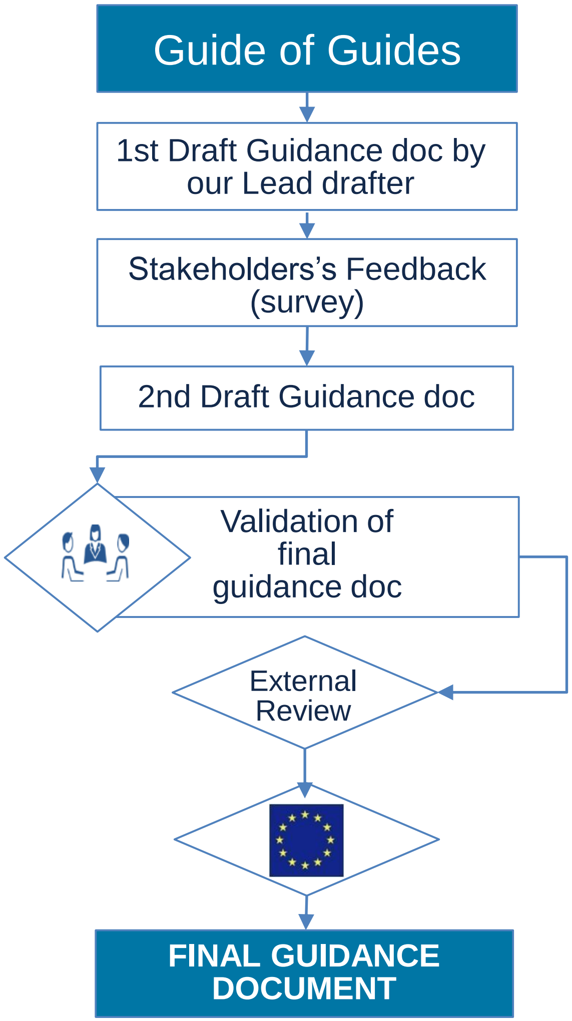
TRL 4	**Component and/or system validation in laboratory environment:** The *basic technological components are integrated* to establish that the pieces will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of ad hoc hardware in a laboratory and testing. Supporting information includes the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4-6 represent the bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on hand equipment and a few special purpose components that may require special handling, calibration, or alignment to get them to function. An example in GTP might include the operation and laboratory testing of innovative components in an improvised (e.g., small-scale) electronic submersible pump at room temperature/pressure. The goal of TRL 4 should be the *narrowing of possible options in the complete system.*
TRL 5	**Laboratory scale, similar system validation in relevant environment:** The basic technological *components are integrated* so that the system configuration is similar to (matches) the full application in almost all respects. Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/ environment. The major difference between TRL 4 and 5 is the increase in the fidelity of the system and environment to the actual application. The system tested is almost prototypical. An example in GTP might be laboratory testing of newly developed packer components in a high temperature/high pressure environment. *Scientific risk should be retired at the end of TRL 5*. Results presented should be statistically relevant.

Task B - Methodology

Guide of guides; drafting process; stakeholder engagement and external review

Task B – Methodology

The Guide of guides



GoG built from several existing readiness level scales:

- ✓ TRL scales;
- ✓ System Readiness Level (SRL) scale;
- ✓ Manufacturing Readiness Level (MRL) scale;
- ✓ Global Readiness Level (GBL) scale.

Structure made of:

READINESS LEVEL #3

Development of experimental application, identification of manufacturability and compatibility

Description

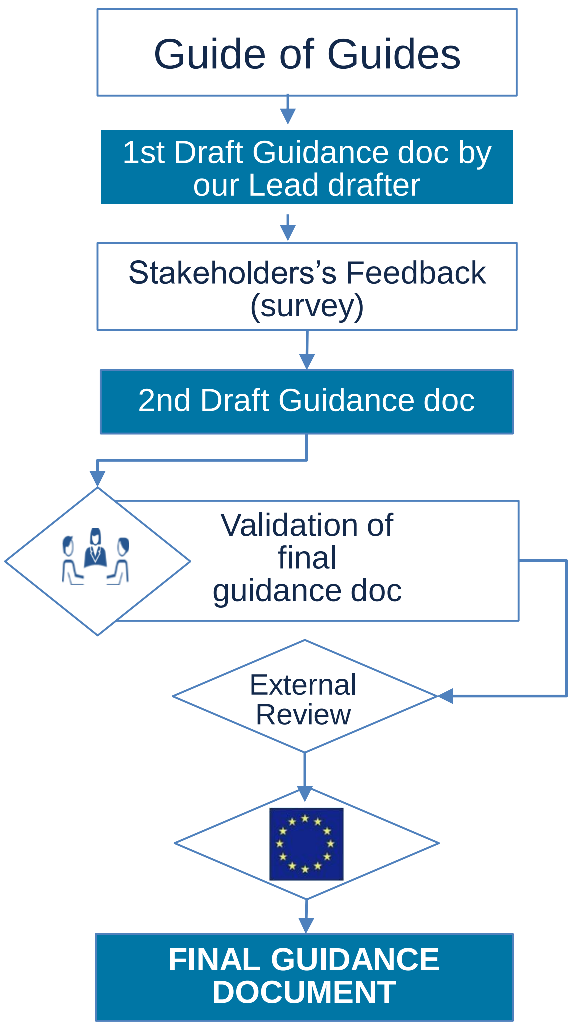
Development of experimental application is initiated: this includes studies of separate elements of the technology at laboratory level.
Identification of current producibility (i.e. ability to produce) based on laboratory studies is performed. A preliminary value analysis is carried out. A risk mitigation strategy is documented. Requirement for further successful integration is needed: two technologies should not only be able to influence each other but also to communicate interpretable data. To this end, the compatibility (i.e. the ability to make use of the same common language to exchange information) between technologies is assessed.

Checkpoints

Once readiness 3 has been achieved, the applied technological concept has been defined. This means:

- Development of experimental separate elements of the technology
- identification of new producibility
- preliminary value analysis
- compatibility between technologies
- preliminary risk mitigation analysis

Task B – Methodology
Drafting the guidance docs



Drafting based on GoG, according to the expertise

Learning by doing approach

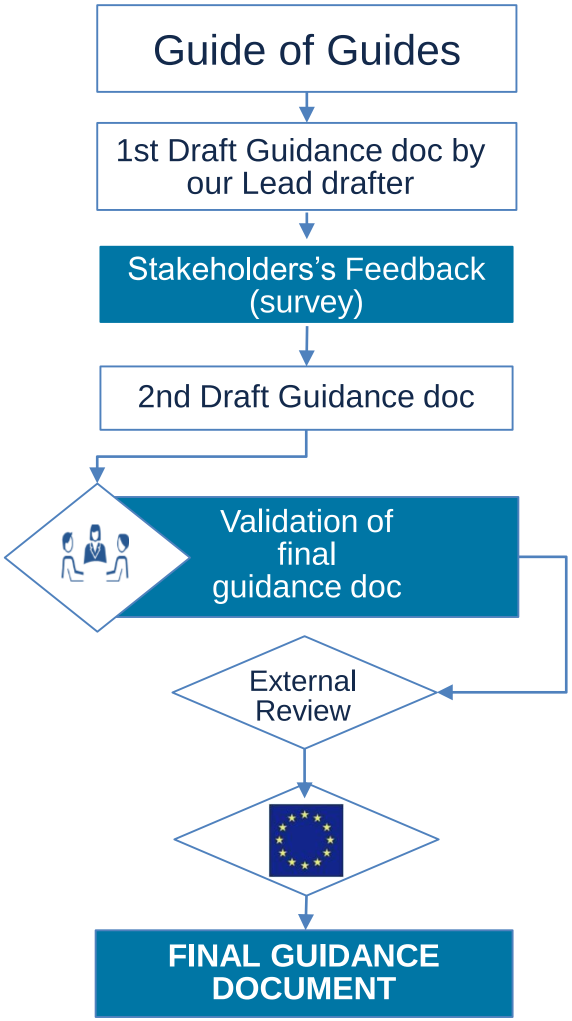
- ✓ Lead experts could also exploit the experiences gained with the guidance documents already discussed with stakeholders

Peer review of the guide

- ✓ two team members (the workshop moderators) provided advice to lead experts during the drafting process

Task B – Methodology

Stakeholders engagement and workshop organisation



Preparatory work for stakeholders: a survey

The questions were focused on:

- ✓ Agreement on the definition of the TRL, with comments
- ✓ Modification, addition, removal or movement of checkpoints provided
- ✓ Addition of any examples of technologies at that level
- ✓ Possible presence of subareas having a dedicated scale or level

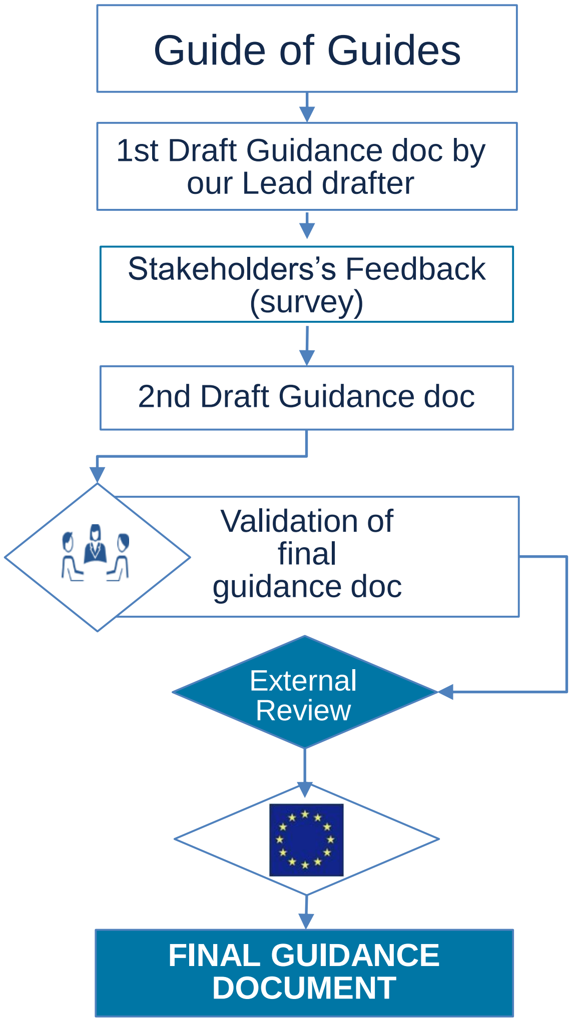
Results were compiled and incorporated in a consolidated version of the draft guidance documents.

Ten validation workshops

- ✓ Organised between March and September 2017
- ✓ Engaging a variety of stakeholders, also through category associations

Task B – Methodology

Stakeholders engagement and workshop organisation



Comprehensive comparison between the initial GoG and the ten guidance documents

- ✓ Exhaustive review of each readiness level for every technologies: extraction of key outputs.
- ✓ This comparison allows to identify common trends (i.e. common features relevant for all technologies) and specific features (i.e. distinctive from one technology to another).
- ✓ The mutual concepts have been gathered in order to make up a common core of Technologies readiness levels for the technologies considered.

Likewise, specific features have been identified.

Statement of checkpoints and milestones

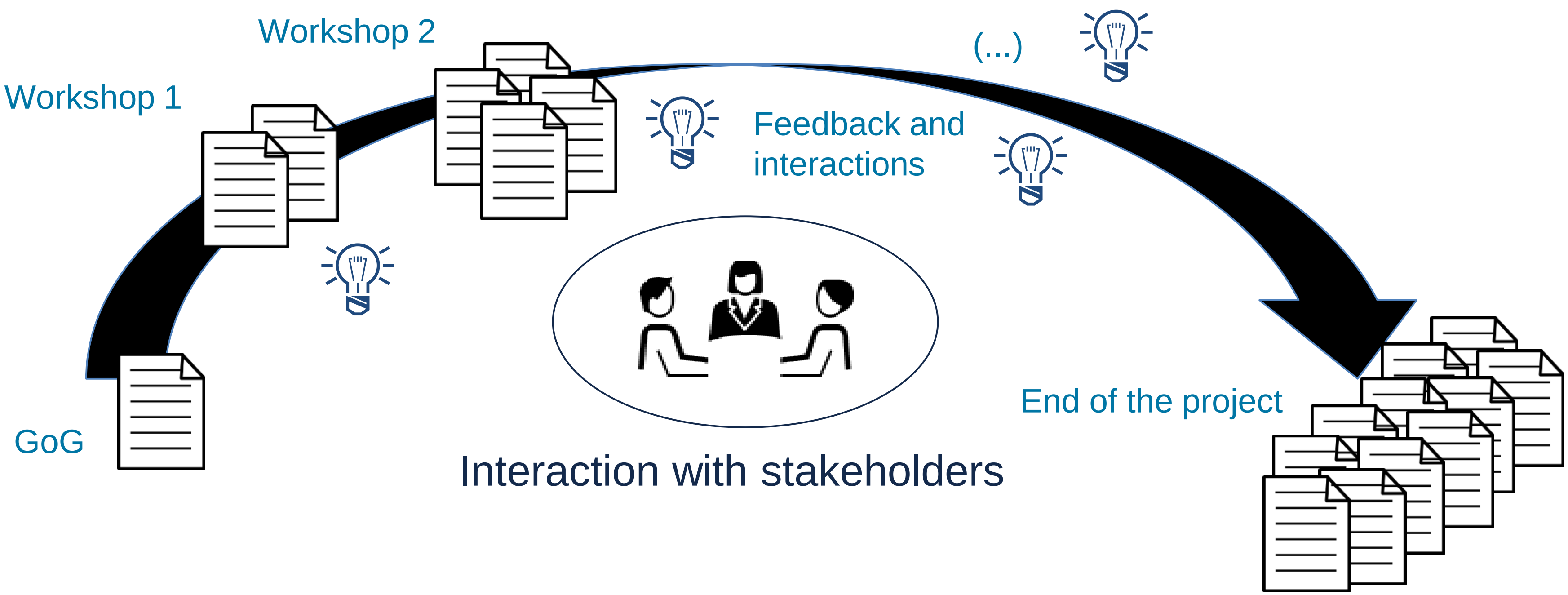
- ✓ Checkpoints and milestones have been determined for all technologies

Task B – Learining by doing

Oustanding issues and how we addressed them

Task B – Learning by doing

Outstanding issues and how we addressed them – the approach



Outstanding Issues → Our solutions during the project → Recommendations for future development

Task B – Learning by doing

Outstanding issues and how we addressed them – the approach

Outstanding Issues	Our solutions during the project	Recommendations for future development
Sector delimitations	Introductory part	Different boundaries
Object of TRL assessment	Different dimensions	Parallel approach
Soft vs. hard technology	Inclusion of software development	Specific guidance for software innovations
Non-technological parameters	Assess the influence in development process	Non-binding formulations
Prescriptiveness	Enhance transparency and inclusiveness	Test the application with potential examples

Task B – Learning by doing

Outstanding issues and how we addressed them – the approach

Sector delimitations → Introductory part → Different boundaries

Boundaries and potential overlap (e.g.: renewable heating and cooling vs. geothermal)

Clarify the boundaries and definitions

E.g. with focus on the application

Task B – Learning by doing

Outstanding issues and how we addressed them – the approach

Object of TRL assessment → Different dimensions → Parallel approach

Describe the development of: a material, or a component, or an entire plant

Applicability to different dimensions

Different scales (e.g. biomass)

Task B – Learning by doing

Outstanding issues and how we addressed them – the approach

Soft vs. hard technology → Inclusion of software development → Specific guidance for software innovations

Use of the guidance for software products

Possible perspective

Guidance tailored to the scope

Task B – Learning by doing

Outstanding issues and how we addressed them – the approach

Non-technological parameters → Assess the influence in development process → Non-binding formulations

Economic, environmental, risk and social aspects

Effects on design and scale up

Inclusion at the relevant TRL

Task B – Learning by doing

Outstanding issues and how we addressed them – the approach

- Prescriptiveness
- Enhance transparency and inclusiveness
- Test the application with potential examples

Risk to make financing conditional to the fulfilment of checkpoints

Applications as examples

Not to exclude any new ideas

Task B – Guidance documents

Presentation of the 10 guidance documents developed

RINA

Task B – The 10 Guidance documents
An overview of the specific TRL guides

Photovoltaics

- ✓ Mature technology: upscale concept and mass production on TRL9

Concentrating Solar Power

- ✓ Dimensions: the guidance document should be applicable to either subcomponents or a complete system (CSP plant). No mass or serial production

Hydropower

- ✓ Applicable also to software tools. Flexible definition of scale are needed. KPIs are introduced

Wind

- ✓ Applicable also to software tools. KPIs are relevant. Producibility concept is excluded while Standardization activities are considered very relevant

Renewable heating and cooling

- ✓ Not a technological sector but it is an application sector, which rely on three different types of technologies (geothermal, solar, biomass). The guidance document is a more general guide that relies on examples

Task B – The 10 Guidance documents
An overview of the specific TRL guides

Geothermal

- ✓ Very detailed guide. An introduction clarifying the scope is needed (only electricity)

Renewable alternative fuels

- ✓ The guidance document is a more general guide that relies on examples. Social acceptance of the technology is introduced at different TRL.

Ocean energy

- ✓ The guidance covers technology producing energy from wave and tidal, ocean thermal energy conversion, currents, salinity gradient or other ones not emerged yet.

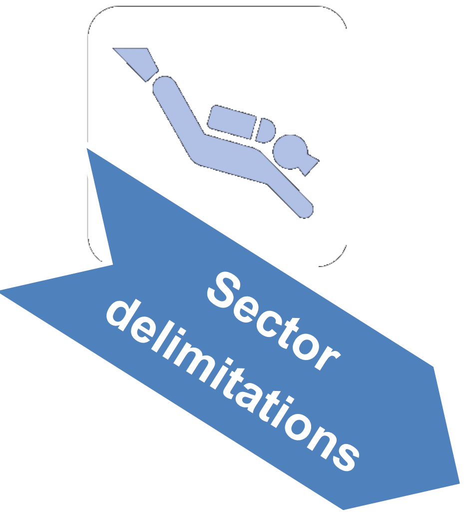
Bioenergy – biological pathway

- ✓ Production of bioenergy from biomass requires better conversion/processing technologies and development (and cultivation) of dedicated feedstocks. From TRL 5 to TRL 9, distinctions are made for the two topics

Bioenergy – thermochemical pathway

- ✓ Very similar to biological pathway. Biomass and other bio-based feedstocks were considered as potential fields for new concepts. The TRL scale up to commercialization was finally described with focus on the energy generation technologies

Task B – The 10 Guidance documents
How we addressed specific issues



RENEWABLE H&C

TRL #1	Basic principles observed
	Description Basic research. Principles postulated and observed but no experimental proof available
	Identification of the innovative scientific concepts ranging from materials up to systems, the scale of which is dependent on the scope considered, to increase and optimize the use of thermal energy coming from renewable sources for heating and cooling. This identification should be based on published research data or other sound references. Examples of results and knowledge qualifying this TRL: - Identification of innovative heat transfer thermal fluid (HTF) in terms of environmental and performance issues; - Identification of innovative and high performance insulation materials to decrease heat losses in DHC network pipes; - Innovative layout of an heat exchanger to improve heat recovery from geothermal system and to optimize the surface used by the heat exchanger; - Preliminary definition of the material and design of the thermal energy storage (TES) in terms of: thermal capacity, heat exchange, TES material compatibility

GEOTHERMAL

On the base of published theoretical studies, field and lab experimental researches, data from various sides, promising new ideas/solutions are assumed/identified/proposed with regard to:

- original theoretical concept regarding the possibility to access the earth's interior heat;
- original theoretical approach to the economical exploration and exploitation of geothermal resources;
- original theoretical way to improve the effectiveness of the traditional and "ripe" technologic components and systems relevant to the six basic phases (*site identification; surface exploration; deep exploration; well tests/field models/field evaluation; plant/field engineering; plant construction/installation/management, including operation monitoring*).

Task B – The 10 Guidance documents
How we addressed specific issues

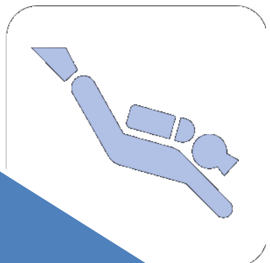
BIOENERGY –
BIOLOGICAL PATHWAY

TRL #5	Technology validated in relevant environment
	Description Large scale prototype tested in intended environment
	A large scale laboratory prototype *(for feedstocks: experimental lines)*[1] with repeatable and stable outputs under different operating conditions is developed and integrated together with other sub-systems in relevant working environment.. The technical performance of the prototype is quantified through suitable indicators, and other relevant parameters are defined (concerning scale-up, environmental, regulatory and socio-economic issues) and used to validate the previously developed concept or to define the changes required to achieve satisfactory results. Among others, feedstocks availability issues are preliminarily considered in the evaluation.

[1] In contrast to other types of renewable energy, where research is mostly directed to the development of new technologies for the conversion/processing of wind/light/waves (etc.) into energy, the production of bioenergy from biomass requires innovation on both the establishment of better conversion/processing technologies and on the development (and cultivation) of dedicated feedstocks. Given the great relevance of both aspects in the development of feasible bioenergy concepts, they have been both considered in the definition of TRLs for Biological pathways. Hence, from TRL 5 to TRL 9 the distinctions needed to refer to feedstock object are highlighted in italics.

Task B – The 10 Guidance documents

How we addressed specific issues



Soft vs. hard technology

HYDROPOWER

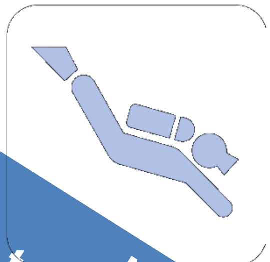
TRL #1	Basic principles observed
	Description Basic research. Principles postulated and observed but no experimental proof available
	Identification of scientific concept and interfaces Starting from relevant research and data from literature, a promising new concept related to hydro technology is identified. The fields of application may vary from power production (turbine, generator,...) electrical components (inverter, transformer, grid interfaces,...),automation, water ways and hydraulic steel structures, civil works and construction methods, communication and sensor technologies, auxiliary and security components, to software tools aiding the individuation and design or analysis of the hydropower energy conversion scheme The theoretical fundamentals of the concept are investigated; the concept is summarily described, identifying the basic technologies beyond the concept and the materials needed. The expected barriers and applications are identified. TRL 1 is defined according the following elements and features:

WIND

Experimental set-up is completed: this includes separate studies of independent elements of the technology at laboratory level, or equivalent numerical analysis in case of new software development.

The new concept integration at wind power unit/plant level (i.e. relationships with all the components: blades, towers, generators, gearboxes, transformers, wiring, etc.) is

Task B – The 10 Guidance documents
How we addressed specific issues



Non-technological parameters

BIOENERGY – THERMOCHEMICAL PATHWAY

TRL #5	Technology validated in relevant environment
	Description **Large scale prototype tested in intended environment**
	Repeatable and stable outputs are obtained under different operating conditions using an advanced prototype, operated, controlled and monitored in the relevant working environment. The performance is quantified through key performance indicators. Other relevant parameters concerning scale-up, environmental, regulatory and socio-economic issues are defined and qualitatively assessed. For example, biomass availability and land use conflicts arising from food and bioenergy production issues should be preliminarily considered in the evaluation.

	The economics aspects are proven at a near final scale/final scale level, even if for a one-off, bespoke design. By applying mass production estimates, a first estimation of the cost of energy produced by a park of tidal devices/WEC can be derived. Manufacturing processes and procedures are demonstrated: production planning is complete.

OCEAN

Task B – The 10 Guidance documents
How we addressed specific issues

CONCENTRATING SOLAR POWER

TRL #4	Technology validated in lab
	Description Small scale prototype built in a laboratory environment ("ugly" prototype)
	Small scale prototype is developed and integrated with auxiliary systems (e.g. fluid conditioning, metering, data acquisition and control). Repeatable performances are provided by the prototype.

PHOTOVOLTAICS

TRL #7	System prototype demonstration in operational environment
	Description Demonstration system operating in operational environment at pre-commercial stage
	Full scale pilot integrated and demonstrated in field (operational environment) Prototype at operational level: the full scale photovoltaic system is demonstrated in an operational environment.

Task B – Trends and specificities

Common trends
Technical specificities

Task B – Common trends and specific features
Recurring elements in all technologies

Common milestones observed at each TRL, across the ten technologies

1	2	3	4
Identification of new concept, applications and barriers	Definition of application, consideration of interfaces and commercial offer	Proof of concept prototype ready: concept is laboratory tested	Integrated small-scale prototype with auxiliary systems laboratory validated

5	6	7	8	9
Large-scale prototype completed with auxiliaries, refined commercial assessment	Technology demonstrated in relevant environment, manufacturing strategy defined	Pilot demonstrated in operational environment, manufacturing approach demonstrated	Technology in its final form, low-rate production	System fully operational and ready for commercialization

Task B – Common trends and specific features
Recurring elements in all technologies

Common trends in each TRL

TRL 1: Basic principles observed
• Identification of the new concept
• Identification of the integration of the concept
• Identification of expected barriers
• Identification of applications
• Identification of materials and technologies based on theoretical fundamentals/literature data
• Preliminary evaluation of potential benefits of the concept over the existing ones

TRL 2: Technology concept formulated
• Enhanced knowledge of technologies, materials and interfaces is acquired
• New concept is investigated and refined
• First evaluation about the feasibility is performed
• Initial numerical knowledge
• Qualitative description of interactions between technologies
• Definition of the prototyping approach and preliminary technical specifications for laboratory test

Task B – Common trends and specific features
Recurring elements in all technologies

Common trends in each TRL

TRL 3: Experimental proof of concept

- First laboratory scale prototype (proof-of-concept) or numerical model realized
- Testing at laboratory level of the innovative technological element (being material, sub-component, software tool, etc.), but not the whole integrated system
- Key parameters characterizing the technology (or the fuel) are identified
- Verification of the proof of concept through simulation tools and cross-validation with literature data (if applicable).

TRL 4: Technology validated in lab

- (Small scale) prototype developed and integrated with complementing sub-systems at laboratory level
- Validation of the new technology through enhanced numerical analysis (if applicable).
- Key Performance Indicators are measurable
- The prototype shows repeatable/stable performance (either TRL4 or TRL5, depending on the technology)

TRL 5: Technology validated in relevant environment

- Integration of components with supporting elements and auxiliaries in the (large scale) prototype
- Robustness is proven in the (simulated) relevant working environment
- The prototype shows repeatable/stable performance (either TRL4 or TRL5, depending on the technology)
- The process is reliable and the performances match the expectations (either TRL5 or TRL6, depending on the technology)
- Other relevant parameters concerning scale-up, environmental, regulatory and socio-economic issues are defined and qualitatively assessed

Task B – Common trends and specific features
Recurring elements in all technologies

Common trends in each TRL

TRL 6: Technology demonstrated in relevant environment
• Demonstration in relevant environment of the technology fine-tuned to a variety of operating conditions
• The process is reliable and the performances match the expectations (either TRL5 or TRL6, depending on the technology)
• Interoperability with other connected technologies is demonstrated
• Manufacturing approach is defined (either TRL6 or TRL7, depending on the technology)
• Environmental, regulatory and socio-economic issues are addressed

TRL 7: System prototype demonstration in operational environment
• (Full scale) pre-commercial system is demonstrated in operational environment
• Compliancy with relevant environment conditions, authorization issues, local / national standards is guaranteed, at least for the demo site
• The integration of upstream and downstream technologies has been verified and validated
• Manufacturing approach is defined (either TRL6 or TRL7, depending on the technology)

Task B – Common trends and specific features
Recurring elements in all technologies

Common trends in each TRL

TRL 8: System complete and qualified
• Technology experimented in deployment conditions (i.e. real world) and has proven its functioning in its final form
• Manufacturing process is stable enough for entering a low-rate production
• Training and maintenance documentation are completed
• Integration at system level is completed and mature
• Full compliance with obligations, certifications and standards of the addressed markets

TRL 9: Actual system proven in operational environment
• Technology proven fully operational and ready for commercialization
• Full production chain is in place and all materials are available
• System optimized for full rate production

Task B – Common trends and specific features

Recurring elements in all technologies

We observed that several topics occur in certain technologies, although not always at the same TRL

TOPIC	TRL								
	1	2	3	4	5	6	7	8	9
Stable Performances			WIND	PV	GEOTHERMAL				
				CSP	BIO - BW				
				HYDRO	BIO - TW				
				RE H&C					
				RE AF					
Expected Performances					WIND	RE AF			
					PV	BIO - BW			
					CSP	BIO - TW			
					HYDRO				
Manufacturing approach		OCEAN				PV	HYDRO		
						CSP	RE H&C		
						WIND	RE AF		
							BIO - BW		
							BIO - TW		
Standardization						WIND	CSP	PV	
						OCEAN	HYDRO	RE H&C	
							BIO - BW		
							BIO - TW		
Market, costs and business			RE H&C			PV			
	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL	GEOTHERMAL	BIO - BW	
			OCEAN					BIO - TW	
Sustainability		HYDRO			WIND	BIO - TW	OCEAN		
					RE AF				
					BIO - BW				
	RE H&C	RE H&C	RE H&C	RE H&C	RE H&C				
Risk Analysis	RE AF	CSP	RE H&C	GEOTHERMAL					
			OCEAN						
Simulation/ numerical models		CSP	RE H&C						
		HYDRO							
		WIND							
		GEOTHERMAL							
		RE AF							
		OCEAN							
		BIO - BW							
		BIO - TW							
SW included	HYDRO	OCEAN				GEOTHERMAL			

Lessons learnt and replicability

Update of the Guide of guides
Application to other technologies

Common trends and differentiating factors

Common milestones

1	Identification of new concept, applications and barriers
2	Definition of application, consideration of interfaces and commercial offer
3	Proof of concept prototype ready: concept is laboratory tested
4	Integrated small-scale prototype with auxiliary systems laboratory validated
5	Large-scale prototype completed with auxiliaries, refined commercial assessment
6	Technology demonstrated in relevant environment, manufacturing strategy defined
7	Pilot demonstrated in operational environment, manufacturing approach demonstrated
8	Technology in its final form, low-rate production
9	System fully operational and ready for commercialization

Differentiating factors?

→ **Dependency of the readiness level on the operational environment**

Categories of TRL scales: closeness to the operational environment	
Low	RE alternative fuels
	Bioenergy technologies
Increasing dependency of the readiness level on the operational environment	Solar and heating/cooling technologies (PV, CSP and RE heating and cooling technologies)
High	Hydro, Geothermal, Ocean, Wind

Replicability of the exercise

Replicability: robust framework of the GoG

- ✓ The approach carried out during the project is actually replicable to other technologies
- ✓ When integrating additional technologies to the existing TRL framework, some features could be slightly modified until reaching an asymptote

To go further

- ✓ Technology Readiness Reference Architecture Model or “TRAM” in order to characterise and categorise, in a user friendly and illustrative way, TRL of several technologies.

Overall conclusions

- ✓ Stakeholders shown engagement and active participation.
- ✓ The outcome generated a consolidated convergence for TRL specific milestones, while raising and solving some RE sector specific assessments.
- ✓ The SoW mainly addressed definitions of R&D Projects stages, taking into account technical specificities of RE technologies.
- ✓ Based on our observed core stakeholders' focus across the RE sectors, a more detailed industry-specific understanding of the TRL could integrate:
    - ✓ At Lower TRL: standard feasibility and strategic value assessment
    - ✓ At Mid TRL: risk analysis, financial attractiveness
    - ✓ At Higher TRL: manufacturing, capability, cost-optimisation to ensure competitiveness

Thanks for your attention!

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