Draft list of key international Research Infrastructures, selected methodologies and proposed aspects of complementarities to analyse in the energy sector

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Abstract

This paper presents a draft list of key international Research Infrastructures within the field of Energy Research. The paper is written as part of the RISCAPE-project, evaluating European Research Infrastructures in the global landscape, and it will be used as a starting point for the upcoming international landscape analysis of Energy Research Infrastructures. This document supplements the European Energy RI sector report which is written in parallel with this document.

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Moderated by:	Jari Kaivo-Oja, Mikkel Stein Knudsen	UTU / WP6	06.11.2017
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TERMINOLOGY

A complete project glossary and acronyms are provided at the following pages:

- *RISCAPE*: European Research Infrastructures in the International Landscape
- *RI*: Research Infrastructure
- *AIST*: National Institute of Advanced Industrial Science and Technology (Japan)
- *ALCA*: Advanced Low Carbon Technology Research and Development Program (Japan)
- *AMPEA*: Advanced Materials and Processes for Energy Applications
- *ASEAN*: Association of Southeast Asian Nations
- *BRICS*: Brazil, Russia, India, China, South Africa
- *CCS*: Carbon Capture and Storage
- *CFETR*: Chinese Fusion Engineering Testing Reactor

- *CERN*: European Organization for Nuclear Research
- *CSP*: Concentrated Solar Power
- *CORDIS*: Community Research and Development Information Service (Research portal of the European Union)
- *ECCSEL*: European Carbon Dioxide Capture and Storage Laboratory
- *EERA*: European Energy Research Alliance
- *EFRCs*: Energy Frontier Research Centres (US)
- *ERA*: European Research Area
- *ERIC*: European Research Infrastructure Consortium
- *ESFRI*: European Strategy Forum on Research Infrastructures
- *ETP*: European Technology Platforms
- *FCH*: Fuel Cells and Hydrogen
- *FP*: Framework Programme (EU's science programmes)
- *G7*: Group of Seven (the 7 largest advanced economies in the world)
- *GEA*: Global Excellence-driven Access
- *GDRIs*: Globally distributed Research Infrastructures
- *GRI*: Global Research Infrastructures
- *GSO*: Group of Senior Officials
- *GVCs*: Global Value Chains
- *ICRI*: International Conference of Research Infrastructures
- *IEA*: International Energy Agency
- *IP*: Intellectual Property
- *IRENA*: International Renewable Energy Agency
- *ITER*: International Thermonuclear Experimental Reactor
- *JAEA*: Japanese Atomic Energy Agency
- *JET*: Joint European Torus
- *JST*: Japan Science and Technology Agency
- *MERIL:* Mapping of the European Research Infrastructure Landscape
- *MI*: Mission Innovation
- *MRFs*: Major Research Facilities (Canada)
- *NFGIs*: National facilities of global interests
- *NREL*: National Renewable Energy Laboratory (US)
- *NWTC*: National Wind Technology Center (US)
- *RD-PUNE*: Agreement between the European Atomic Energy Community and the Government of the People's Republic of China for R&D Cooperation in the Peaceful uses of Nuclear Energy
- *RIGR*: Research Infrastructures of Global Relevance
- *RSGIs*: Real single-sited global facilities
- *SDGs*: Sustainable Development Goals
- *SERIUUS*: Solar Energy Research Institute for India and the United States

- *STI*: Science, Technology and Innovation
- *US DOE*: United States Department of Energy

Contents

Executive summary

For the project European Research Infrastructures in the International Landscape (RISCAPE) a major component of the project is to map key international Research Infrastructures (RI's) within different research sectors. This report concerns the preliminary global mapping of Energy Research Infrastructures.

The paper utilizes the recent GSO-framework with 14 key criteria for research infrastructures. This methodology will be utilized further in the landscape analysis to be completed at a later stage of the RISCAPE-project, in which the complementarities between identified European RIs and identified international RIs will be also evaluated.

The mapping of international RIs is based on literature analysis, desk research, a previous workshop with participation of key European RI stakeholders, and will be supplemented by the use of questionnaires.

For the draft list a total of 45 international RI's has been selected. It is expected that as the project progresses further there will be both additions to and subtractions from the current list.

Based on the hitherto research major focus is expected to be on (non-EU) G7-countries and BRICS-countries. In addition we will try to cover regions such as Australia, New Zealand, ASEAN, Latin America (beyond Brazil) and Africa (beyond South Africa). It is our discovery that some European RI's feel they have gaps in knowledge about these regions, and it can be one valuable result of RISCAPE, if we can help fill those gaps.

1 Background

This paper supplements the sector report on European research infrastructures which is currently available in a draft version. A refined version will be made available during the course of the RISCAPE-project in a manner such that the European sector paper and this international sector paper will complement each other.

1.1 Introduction to the Energy Research Infrastructures

Energy research infrastructures are essential for top-level academic and industrial energy research activities. Throughout the successive framework programmes (FPs and Horizon 2020) of the EU, various actions have been gradually developed to support researchers in accessing top-level European energy research infrastructures located outside their own country and also to better coordinate and integrate these infrastructures Europe-wide, enabling better research services. At the same time, energy RIs pave the way for the development of scientific and technological advances in energy industries and markets.

In Europe the main legal framework for major Research Infrastructures is the establishment of an European Research Infrastructure Consortium (ERIC).

To be awarded ERIC status research infrastructure (RI) must meet the following requirements:

- It is *necessary for the carrying out of European research programmes and projects*;

- It *represents an added value in the strengthening and structuring of the European Research Area (ERA)* and *a significant improvement in the relevant scientific and technological fields at international level*;

- *Effective access*, in accordance with the rules established in its statutes, is granted to the European research community, composed of researchers from Member States and from associated countries;

- It contributes to *the mobility of knowledge and/or researchers within the ERA and increases the use of intellectual potential throughout Europe*; and

- It *contributes to the dissemination and optimisation of the results of activities in Community research, technological development and demonstration* (European Commission, 2009, 2010).

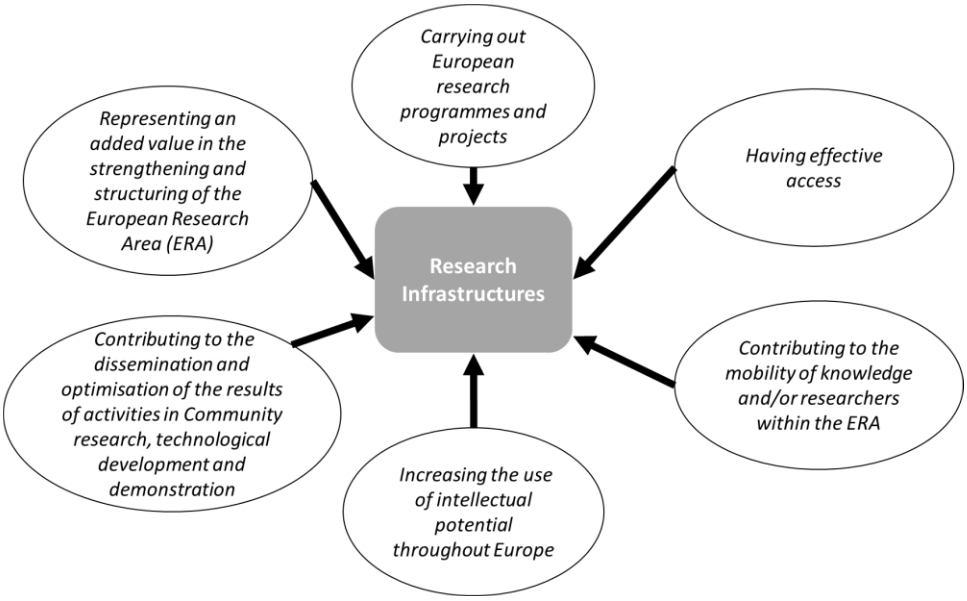

Figure 1. The ERIC status research infrastructure (RI).

Thus, ERIC status represents *the **high profile** European research infrastructure*, whereas the MERIL inventory can be viewed as *a **more inclusive list of research infrastructures***. In reality, the difference between RIs with ERIC Status and RIs within the MERIL inventory is clearly visible. There is only one Energy ERIC (ECCSEL, officially awarded ERIC-status mid-2017), while 50+ energy RIs in the MERIL database. Both approaches are relevant for the analysis of Energy RIs, but when mapping global Energy RIs only large-scale research infrastructures with a 'global impact' will be considered. Figure 2 below show the range of research infrastructures, and the focus of this RISCAPE-deliverable aiming at international research infrastructures.

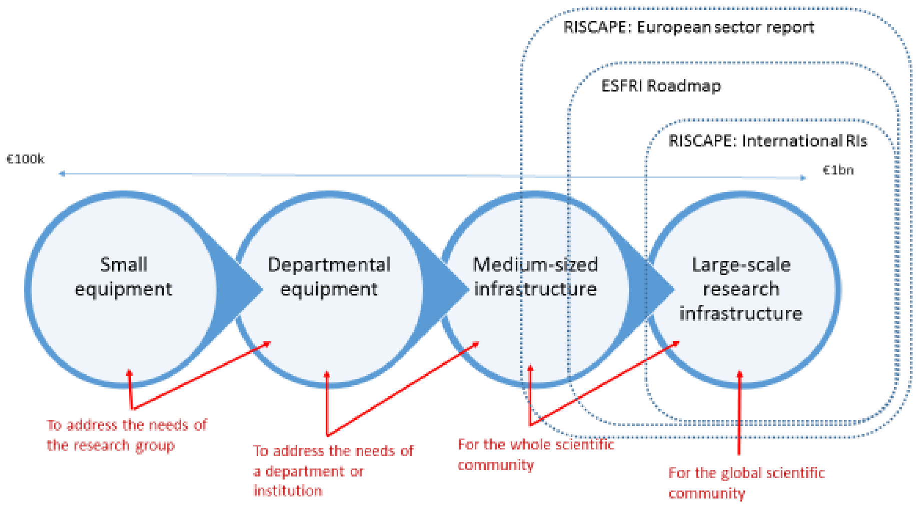

Figure 2. The range of research infrastructures, adapted from Department of Science and Technology, 2016

1.2 What is 'Energy Research'?

There are different way of typologising the energy sector and its subsectors.

The ESFRI landscape analysis of 2016 divides the sector into five main technology areas, which in themselves group a number of specific energy technologies: Smart energy networks and storage, efficient energy conversion and use, renewable energy, nuclear energy and cross-sectional energy Research Infrastructures[1].

The general typology of the ESFRI landscape analysis can be utilized in order to compare the identification of specific energy research fields and technologies across relevant European and international energy actors. Below is by own production listed the categories used in the ESFRI roadmap and landscape analysis 2016, the 17 Joint Programmes of the European Energy Research Alliance[2], the 39 Technology Collaboration Programmes of the International Energy Agency (IEA) [3] and finally those technologies of which the International Renewable Energy Agency (IRENA) has published specific technology briefs or handbooks[4].

Table 1. Energy subsectors.

	ESFRI	EERA JPs	IEA TCPs	IRENA briefs
Cross-sectional Energy RIs	Materials / Computing and Simulation	Advanced Materials and Processes for Energy Application (AMPEA)	Climate Technology Initiative	
			Energy Technology Systems Analysis	
Renewable energy			Renewable Energy Technology Deployment	
	Bioenergy	Bioenergy	Bioenergy	Biomass for Heat and Power
				Biomass Co-firing
				Bio-methanol prod.
				Bio-Ethylene prod.
				Liquid Biofuel prod.
	Photovoltaics	Photovoltaic Solar Energy	Photovoltaic Power Systems	Solar Photovoltaics

[1] http://www.esfri.eu/sites/default/files/20160308_ROADMAP_single_page_LIGHT.pdf, p. 92.
[2] https://www.eera-set.eu/eera-joint-programmes-jps/list-of-jps/
[3] http://www.iea.org/media/impag/TCPwebsites.pdf
[4] http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=283

	Concentrated Solar Power	Concentrated Solar Power	Concentrated Solar Power	Concentrating Solar Power
			Solar Heating and Cooling	
	Wind Energy	Wind Energy	Wind Energy Systems	Wind Power
	Geothermal	Geothermal	Geothermal	
	Ocean Energy	Ocean Energy	Ocean Energy Systems	Ocean Energy
	Hydropower		Hydropower	Hydropower
Nuclear energy	Fusion energy		Environmental, Safety, Economic Aspects of Fusion Power	
		Nuclear Materials	Fusion Materials	
			Nuclear Technology of Fusion Reactors	
			Plasma Wall Interaction	
			Reversed Field Pinches	
			Spherical Tori	
			Stellarator-Heliotron Concept	
			Tokamak Programme	
	Fission energy			
Smart energy networks and storage	Smart Grids	Smart Grids	Smart Grids	
	Storage	Energy Storage	Energy Storage	Thermal Storage
			Demand-Side Management	Electricity Storage
		Energy Systems Integration	High-Temperature Superconductivity	Renewable Energy Integration in Power Grids
Efficient energy conversion and use	Use in industry	Energy Efficiency in Industrial Processes	Industrial Technologies and Systems	Solar Heat for Industrial Processes
			Energy Efficient End-Use Equipment	Desalination Using Renewable Energy
			Heat Pumping Technologies	Heat Pumps
	Smart Cities	Smart Cities	Buildings and Communities	Solar Heating and Cooling for Residential Applications
			District Heating and Cooling	
	Fuel Cells and Hydrogen (FCH)	Fuel Cells and Hydrogen (FCH)	Advanced Fuel Cells	

			Hydrogen	
			Advanced Materials for Transportation	Renewable Energy Options for Shipping
			Advanced Motor Fuels	Biofuels for Aviation
			Clean and Efficient Combustion	Biogas for Road Vehicles
			Hybrid and Electric Vehicles	Electric Vehicles
			Clean Coal Centre	
			Enhanced Oil Recovery	
			Fluidized Bed Conversion	
		Shale-Gas	Gas and Oil Technologies	
	Carbon Capture and Storage (CCS)	Carbon Capture and Storage (CCS)	Greenhouse Gas R&D	
Cross-sectional Energy RIs	Socio-economic impact	Economic, environmental and social Impact (e3s)		

A number of preliminary remarks can be made based on table 1 above:

1) The ESFRI roadmap appears less focused on the end use of energy, especially within the transportation sector compared to the technological research focuses of the International Energy Agency and International Renewable Energy Agency. *This can possible be explained by the number of public and private research actors involved, limiting the need for expenditure on major research infrastructures, or the short time-span of innovations limiting the use of long-running research infrastructures.*
2) While it includes Carbon Capture and Storage, the ESFRI roadmap has limited focus on research on conventional fossil fuels. *This can be seen in line with the overarching energy policy of the European Union as well as the Strategic Technology Plan which aims at underpinning it.*
3) A lot of effort is made by the International Energy Agency on fusion energy, while fission energy receives less focus. *This might be explained by the difference in the maturity of the technologies, while also underpinning the point that advancements in nuclear fusion might depend more on strategic investments in long-term research infrastructures.*
4) The sector of bioenergy can be seen as including a large number of subsectors which may not be caught under the catch-all phrase of bioenergy. *Further exploration will most likely show, however, that the maturity of the bioenergy-subsectors, and for this reason perhaps also the need for supporting research infrastructures, will vary widely.*

These findings are relevant when the aim of mapping international research infrastructures is to analyse complementarities with European research infrastructures. For example, the apparent lack of European interest in fossil fuels-related research infrastructures also makes international research infrastructures in this field (in case they exist) less relevant for the RISCAPE-project.

1.3 What is not 'Energy Research'?

An important part of defining the scope of the study is also to demarcate what will not be included. In terms of analysing the energy research sector, a number of research fields is overlapping or bordering other science domains. Figure 3 below illustrates of some of these overlaps:

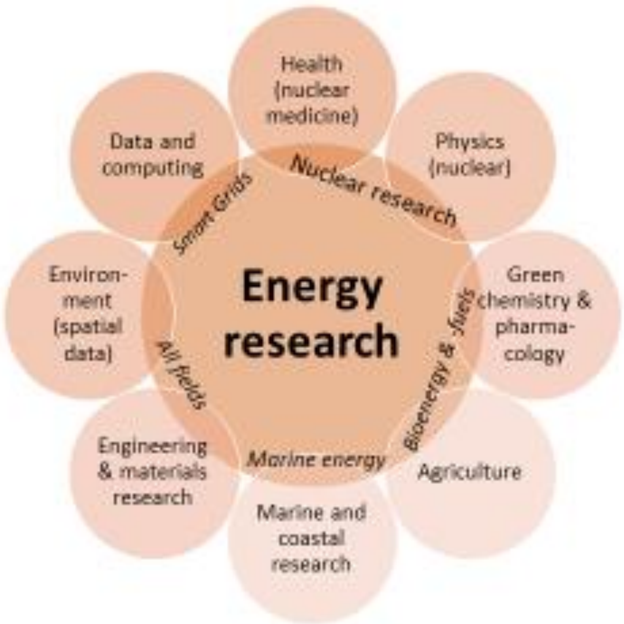

Figure 3. Selected overlaps of energy domain with other scientific domains

The key point here is not only that it can be difficult to clearly define the boundaries of *Energy Research Infrastructures*, but also that there will invariably be RIs considered here to be Energy RIs which have complementarities with other scientific domains, and also RIs outside the scope of this study which have major complementarities with RIs inside it.

Table 2. Examples of infrastructures with complementarities with Energy RIs

Examples of infrastructures	Relevance for Energy RIs
Spatial Data Infrastructures	Spatial data infrastructures play a key role in assessing and harvesting the potential of renewable technologies such as wind, solar, tidal and geothermal as well as the development of carbon capture, storage and reuse technologies.
Synchroton facilities, CERN	Large-scale facilities for experimental physics can have relevance for nuclear energy research and vice versa. For the RISCAPE-project most facilities will be considered to be in the domain of physics.

Marine and coastal facilities	There are often clear links between marine and coastal facilities and experimental facilities for research on marine energy and offshore wind.
Green chemistry and pharmacology infrastructures	Biotechnology can be used for energy purposes, as well as for a wide range of other purposes. Research facilities aimed at facilitating advanced biofuels can e.g. be very similar to green chemistry research facilities. Unless the facility is clearly geared towards energy purposes (e.g. biofuels), they will not be considered part of this RISCAPE-work package.
High Performance Computing-centers	Digitalisation is a major transformational driver for the energy system, and research in the utilisation of digital opportunities (Smart Grid, Smart Cities etc.) is in itself a major research focus. In addition, computing power (big data) is increasingly becoming the backbone of other research infrastructures, including in the energy research field.

2 Methodology and explanation of the tasks done

2.1 Methodology

2.1.1 Defining Research Infrastructures

We have followed in this report (1) the ERIC status research infrastructure definition and to some extent (2) the MERIL inventory principles. We are aware that there is the large variety of Research Infrastructures and the lack of common terminology. So called GSO framework proposed (Group of Senior Officials on Global Research Infrastructures 2017, 22-23) that Global Research Infrastructures are:

1. *Real single-sited global facilities* (RSSGFs), which are geographically localized unique facilities whose governance is fundamentally international in character.
2. *Globally distributed Research Infrastructures* (GDRIs), which are Research Infrastructures formed by national or institutional nodes, which are part of a global network and whose governance is fundamentally international in character. Ad-hoc distributed facilities, linked with time-limited campaigns of observations, might also be considered for possible inclusion in this category. For example, scientific information exchange, data preservation and distributed computing infrastructures relying on high-speed connectivity, provide new opportunities in terms of virtualization of resources, advanced simulation environments and improved and wide-access to RIs.
3. *National facilities of global interests* (NFGIs), which are national facilities with unique capabilities that attract wide interest from researchers outside of the host nation.

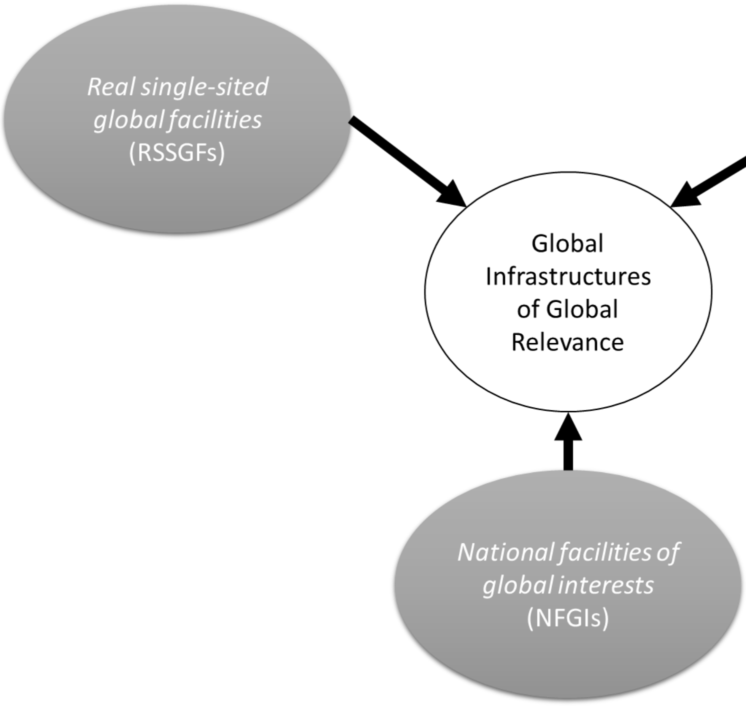

Figure 4. Global Research Infrastructures.

For the identification of Research Infrastructures of global relevance (RIGRs), these three definitions are useful. Common principles for the development and operation of Global RIs are (Group of Senior Officials on Global Research Infrastructures 2017, 23):

(1) Global Research Infrastructures may *constitute the basis for the national or regional development of comprehensive innovation clusters around the Global Research Infrastructures*, with the aim to coordinate other nationally or regionally important infrastructures, research labs, technology transfer and educational structures which need to be identified and supported along the lifecycle of the Research Infrastructure. Different RIs with complementary capabilities working in similar scientific areas should consider realizing collaborative Global Research Infrastructure.
(2) Second principle is: *the use of variable geometry schemes where only interested stakeholders should participate along the full lifecycle*.
(3) Third principle is: *the use of harmonized evaluation criteria to assess the benefits of a Global Research Infrastructure*.
(4) Fourth principle is: *there are clear rules for accepting additional partners*.

Such common principles of GSO Framework are good to keep in mind, when we analyze Global RIs. GSO Framework includes also recommendations for the framework criteria. In Table 1 we present a summary of these framework criteria (Group of Senior Officials on Global Research Infrastructures 2017, 24-25):

Table 3. Issues of Framework Criteria, Framework Criteria and the various contexts of Energy RIs.

Issues	Criteria	The context of Energy RIs
Core purpose of Global Research Infrastructures	Global RI initiatives should address the most pressing global research challenges, i.e. those frontiers of knowledge where a global-critical mass effort to achieve progress is required. Science, technology and innovation (STI) and addressed training goals should be fully integrated throughout the infrastructure plans from their early development.	The challenges of climate change New global framework of SDGs
Defining project partnerships for effective management	Global RIs initiatives should explicitly and clearly define, as early as possible, the roles and responsibilities of the partners throughout different phases of project´s full lifecycle, planning, construction, operation, upgrading and termination or decommissioning. Also rules for future participation should be defined to allow the inclusion of new partners	EU-Outside EU – partnerships and networks EU-USA EU-Japan EU-Australia EU-BRICS EU-Latin America EU-ASEAN EU-Africa
Defining scope, schedule and cost	Stakeholders should agree upon a shared understanding of the foreseen scope, schedule (timetables), and cost. This principle helps partners to address inherent uncertainties and external constraints and define processes to effectively address deviations.	Energy research fields
Project management	Appropriate management structures and professional top level management should be established consistent with best practices derived from existing recommendations and experience at the international level. Rigorous project management is needed.	Leaders and actor-networks of the energy RI projects
Funding management	The development of Global RIs should foresee a careful balance between the minimum acceptable percentage of in-cash contributions and appropriate in-kind contributions. The in-kind contributions should be evaluated regarding quality and schedule.	Funding instruments of energy RIs Public-Private partnerships of Energy RIs
Periodic reviews	Global RIs should be periodically evaluated to ensure consistent excellence of the scientific output.	Evaluation systems of Energy RIs

Termination of decommissioning	Planning for termination of decommissioning of Global RI initiative should be established early in the development of the facility. There should be criteria for the conclusion of operation and also exit criteria and procedures for closing down and recognizing future termination liabilities or encumbrances on the sponsors.	Life-cycles of Energy RIs
Access goal based on merit review	The GRI should reflect the global-Excellence-driven Access (gEA) paradigm through publication of a clear and transparent access goal.	The goals of Energy RIs
E-infrastructure	Global RI initiatives should recognize the utility of the integrated use of advanced e-infrastructures, services for accessing and processing and curating data, as well as remote participation (interaction) and access to scientific experiments.	The E-infrastructures of Energy RIs
Data exchange	Global scientific data infrastructure providers and users should recognize the utility of data exchange and interoperability of data across disciplines and national boundaries as a means to broadening the scientific reach of individual data sets.	The data-sharing strategies of Energy RIs
Clustering of Research Infrastructures	Where clustering of complementary research infrastructures appears to be consistent with the mission of the global research infrastructure, schemes for access to and mobility of researchers, engineers and technicians through the cluster should be actively encouraged.	Collaborations of Energy RIs.
International mobility	Measures to facilitate the international mobility of scientists and engineers to participate in global research infrastructures should be promoted.	Energy RIs' policies for access.
Technology transfer and intellectual property	In order to facilitate technology transfer activities and the most productive participation of industry, members of the GSO should regularly exchange information on best practices regarding intellectual property rights management, and on the sharing and exploitation or utilization of data and technology generated in global research infrastructures, by following internationally accepted regulations, in order to facilitate technology transfer activities and the participation of industry.	Energy RI's strategies for commercialisations, public-private partnerships etc.

Monitoring socio-economic impact	The socio-economic impact and knowledge transfer issues of global research infrastructures should be assessed not only in the beginning but during the life-cycle of the project. Reference may be made to relevant documents such as those published by the OECD Global Science Forum.	Evaluations systems of Energy RIs

On the basis of Table 3 we can also define an ideal life-cycle of an Energy RI (Fig. 5).

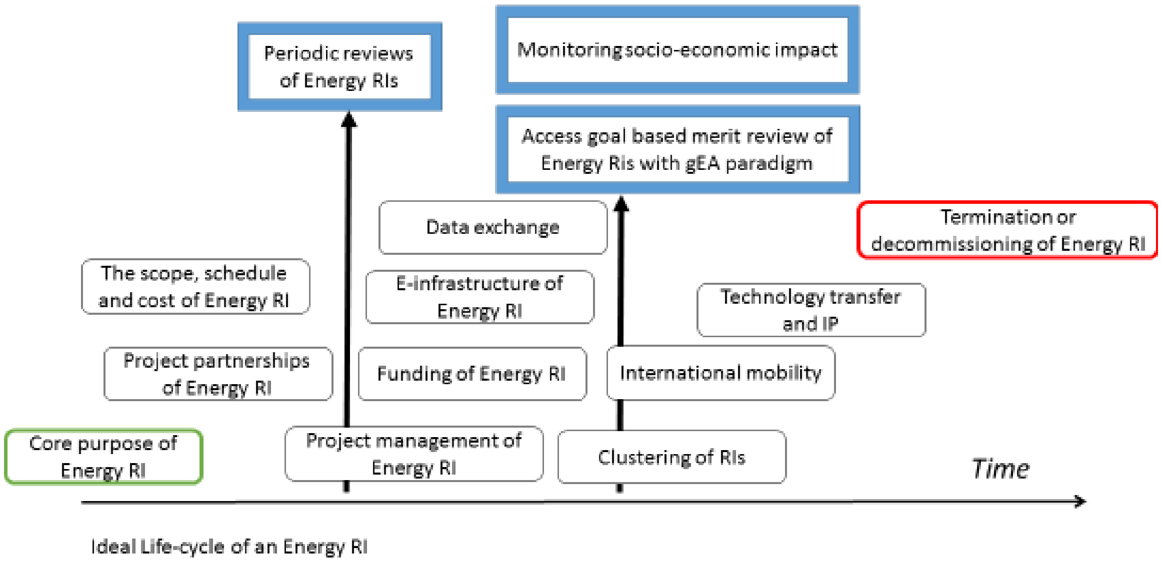

Figure 5. Ideal Life-cycle of Energy RIs and 14 Framework criteria of Energy RIs.

2.1.2 Using triangulation methodology

The use of triangulation methodology can make scientific studies more robust though using varied research methods, data sources, investigators and theories. The pillars of so-called super-triangulation are: (1) Methods triangulation, (2) data/source triangulation, (3) analyst/investigator triangulation and (4) theoretical triangulation (see e.g. Kaivo-Oja & Lauraues, 2017a).

The RISCAPE-project on energy research infrastructures will use methods triangulation, combining literature survey, desk research, workshops, and qualitative and quantitative information gathered by the use of questionnaires. For evaluating scientific relevance of RIs a mix of qualitative (peer assessment) and quantitative (bibliometrical analysis, patent data) methods will also be used. For this preliminary paper, the combined results of surveying key documents, desk research and a workshop with European Energy RIs are presented, thereby also making use of methods triangulation.

Following this we are also by definition making use of data/source triangulation, as we have gathered the information using a variety of different sources. The sources used are both official public documents, documents of the European Union, academic sources, and literature written in those countries surveyed.

With two primary researchers we are also scratching at the surface of analyst/investigator triangulation. This helps limit the risk of personal bias clouding the gathering, reporting and interpretation of data and information sources. For the general RISCAPE-project the involvement of a scientifically sound Stakeholder Panel is another method of strengthening the analyst/investigator triangulation.

2.2 European RIs interviewed / analysed

We have conducted thorough research of the European energy sector based on the following means of analysis (Kaivo-Oja & Knudsen, 2017):

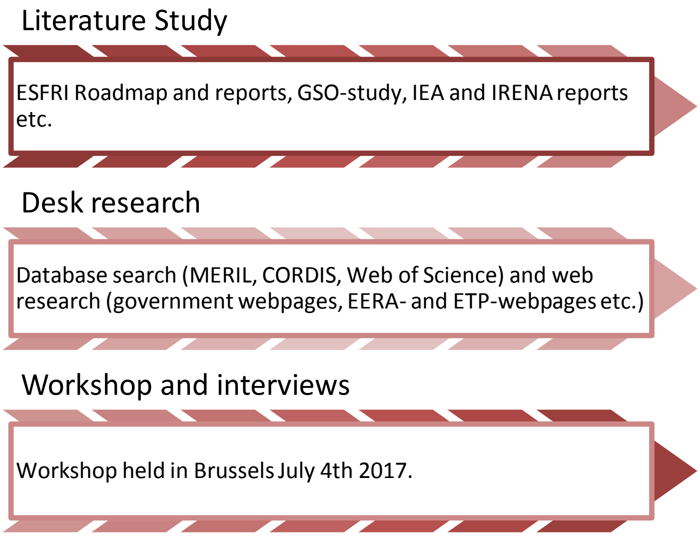

Figure 6. The analysis work of Energy RIs.

In order to get the best possible result of the workshop, and in order to provide the best possible starting point for the international landscape analysis, contact was made to a broader list than those projects represented in the ESFRI-roadmap. One reason for this is that the latest ESFRI-roadmap (2016) only cover *some* of the energy subsectors, while consortiums in several other fields are currently attempting to build projects for future ESFRI-roadmaps (and, eventually, mature research infrastructures). In order to increase both the value and the durability of RISCAPE's recommendations, it was considered relevant to also cover these, at least in the earlier stages of the project, and with a view to the landscape analysis also.

A list of the key European RI's (of varying maturities) identified and contacted can be seen below in table 4.

Table 4. European research infrastructures identified and contacted

Short name	Name	Details	Communication
JHR	Jules Horowitz Reactor	ESFRI Landmark (Roadmap 2016)	E-mail
ECCSEL	European Carbon Dioxide Capture and Storage Laboratory Infrastructure	ESFRI Project (Roadmap 2016) ERIC (status awarded 2017)	Participant at RISCAPE-workshop
EU-SOLARIS	European SOLAR Research Infrastructure for Concentrated Solar Grid	ESFRI Project (Roadmap 2016)	E-mail
MYRHHA	Multi-purpose hybrid Reactor for High-Tech Applications	ESFRI Project (Roadmap 2016)	E-mail
WindScanner	European WindScanner Facility	ESFRI Project (Roadmap 2016)	E-mail
MARINERG-I	Marine Renewable Energy Research Infrastructure	Funded by Horizon-2020.	Participant at RISCAPE-workshop
MaRINET2	Marine Renewables Infrastructure Network	MaRINET (2011-2015) was funded by 7th Framework Programme; MaRINET2 (2017-2021) is funded by Horizon 2020.	Participant at RISCAPE-workshop
ITER		ITER-agreement signed by EU, China, India, USA, Russia, South Korea and Japan.	E-mail
JET	Joint European Torus	RI in operation, supported by EU (EURATOM).	E-mail
DEMO	Demonstration Fusion Power Reactor		E-mail
ERIGrid	European Research Infrastructure supporting Smart Grid Systems Technology, Validation and Roll-Out.	Funded by Horizon 2020 as Integrating Activity.	Participant at RISCAPE-workshop
BRISK-2	Biofuels Research Infrastructure for Sharing Knowledge	Integrating activity, funded by 7th Framework Programme / Horizon 2020.	Participant at RISCAPE-workshop
H2FC		Project funded by Horizon 2020.	E-mail

In addition, the workshop included participants involved in key research projects within geothermal energy, fuel cells and hydrogen research, biofuels, bioeconomy research, and smart energy and transport solutions.

The experts involved have already been helpful in identifying and evaluating key international research infrastructures within their own fields. There is expected to be extensive additional communication with the contacts already made over the course of the project. This will also include the use of *questionnaires* which is expected to be finalized with results in the beginning of 2018.

3 Desk research of international RIs

3.1 GSO Progress Report

The *Group of Senior Officials on global Research Infrastructures* has provided not only a framework for assessing Global Research Infrastructures (GRIs), but also delivered a progress report with a list of research infrastructures of global interest (Group of Senior Officials on Global Research Infrastructures, 2017)[5].

The RIs identified in the report are of obvious interest for the RISCAPE-project.

3.2 Patent activity

International property (IP) statistics provide an important tool in understanding trends in technology developments worldwide (Kaivo-Oja & Lauraeus, 2017b). Patents are regarded as one of the most useful indicators of innovative activity.

Patent application data shows a dramatic change in the patent activity trend in the global innovation ecosystem, as the dominance of G7-countries have decreased substantially.

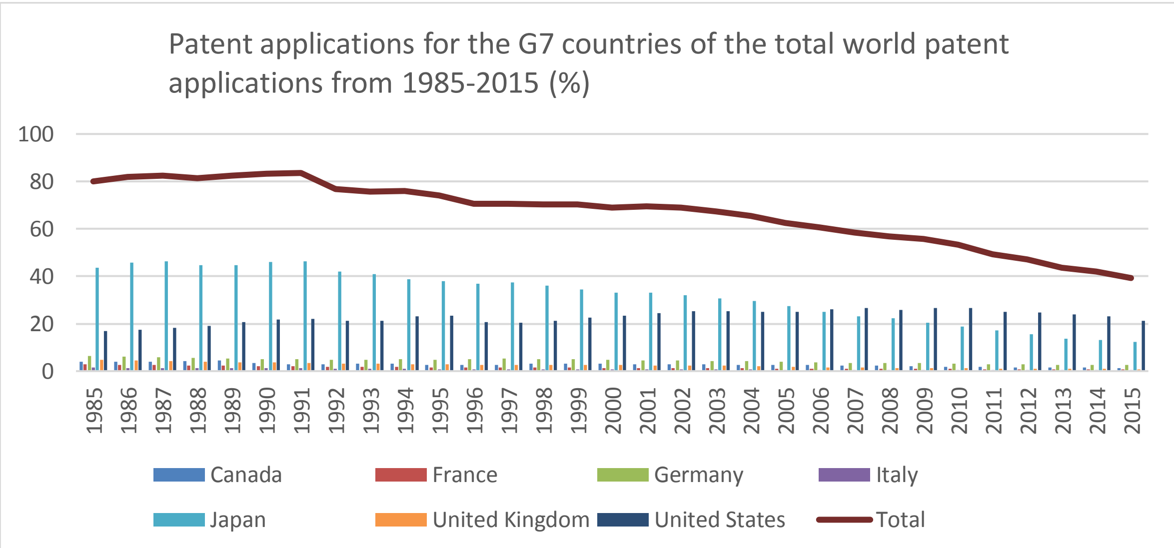

Figure 7. Patent applications for the G7 countries of the total world patent applications from 1985-2015 (Kaivo-Oja & Lauraeus, 2017b)

While the share of G7-patents have decreased, the share of patents applications from BRICS-countries (Brazil, Russia, India, China and South Africa) have increased, and in the case of China exploded. We expect this to be an indication of which regions might be most fruitful to analyse for this project.

5 https://ec.europa.eu/research/infrastructures/pdf/gso_progress_report_2017.pdf#view=fit&pagemode=none

3.3 National research infrastructure roadmaps and EU partnerships

Using web research relevant information on research infrastructures have briefly been assessed for a number of selected countries and regions. The main method of collecting this information has been to:

- Conduct web searches for: i. “”research infrastructures” + [*country name*]”, ii. “”big science” + [*country name*]”, iii. “energy research facilities + [*country name*]” and follow the relevant information using the snowball sampling method (note: this has not been pursued exhaustively, but rather as a mean of quickly selecting the key relevant information).
- Assess relevant public and government websites for the various countries.
- Assess the information and documents in the ‘International Cooperation’ portal at the website of European Commission Research & Innovation[6].

This information gathering method provides a cursory overview rather than a comprehensive and exhaustive identification of research infrastructures, but using triangulation and the other ways of collecting data used in this paper, it does in our opinion provide a solid initial indicative focus for the more detailed landscape analysis to follow during the next stage of the RISCAPE-project.

3.3.1 United States

There are a total of 17 laboratories under the US DOE Office of Science[7]:

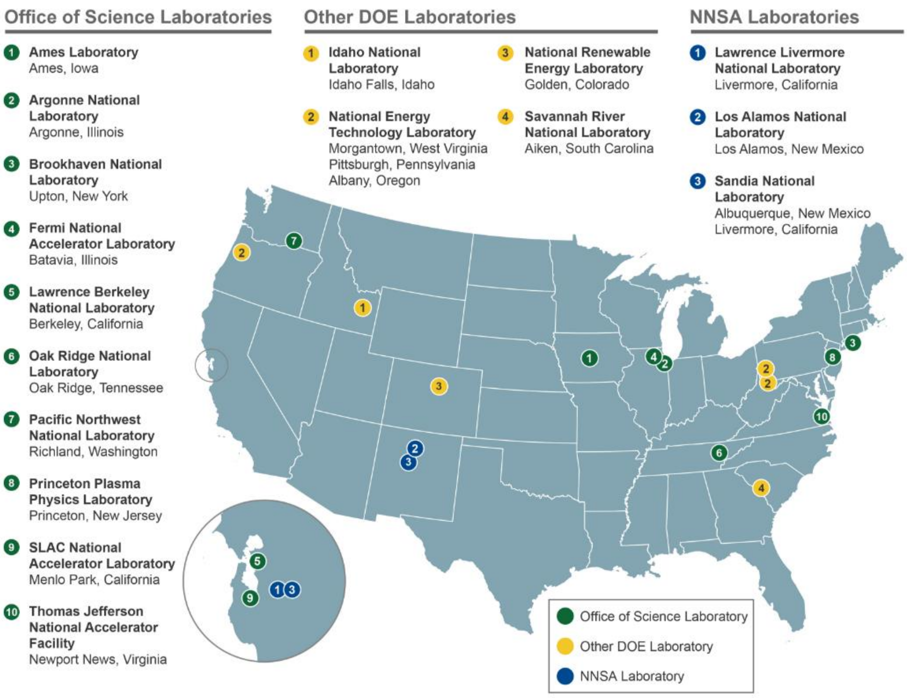

Figure 8. US DOE laboratories (from US DOE, 2017a)

[6] http://ec.europa.eu/research/iscp/index.cfm?pg=regions
[7] https://science.energy.gov/laboratories/

These 17 major research facilities of the US Department of Energy would all in principle be relevant to assess further within the RISCAPE-project. Several laboratories can more appropriately be considered to be within the physics domain, at least by the scope chosen for this paper. After a preliminary examination Ames Laboratory, Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Princeton Plasma Physics Laboratory, SLAC National Accelerator Laboratory, Thomas Jefferson National Accelerator Facility, and Los Alamos National Laboratory are all considered to be beyond the scope of the RISCAPE energy domain work package.

For the landscape analysis it can be relevant to focus further on more granular elements than laboratory level, e.g. the National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL).

The US DOE also provides a list of national scientific user facilities[8]. Most of these facilities are considered to be beyond the scope here; however, the user facilities related to fusion energy are relevant, as they complement European RIs in this field.

In addition to national laboratories and user facilities, the US DOE also provides an overview of 36 so-called Energy Frontier Research Centers (EFRCs) (US DOE, 2017a).

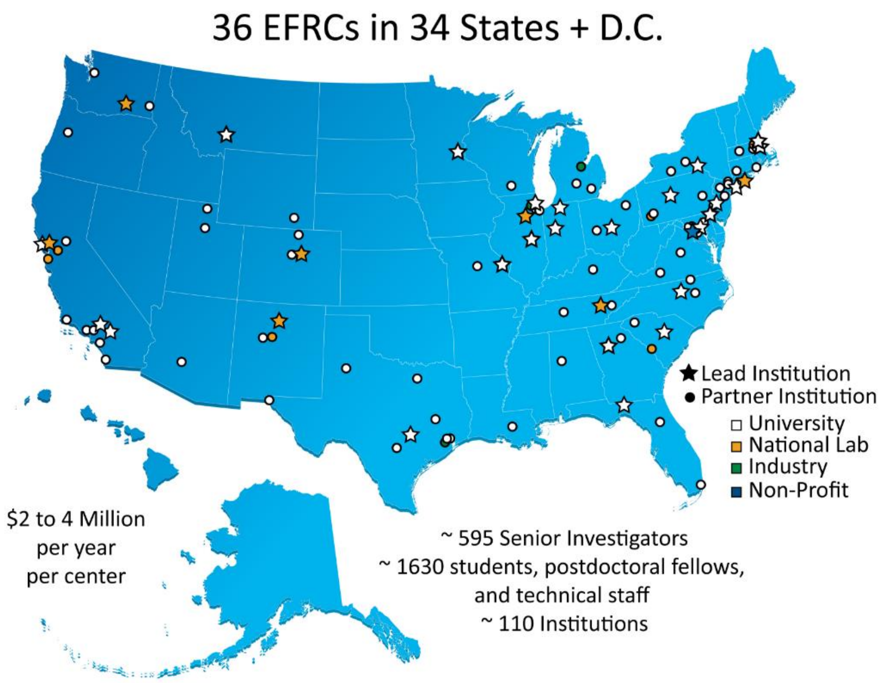

Figure 9. US DOE Energy Frontier Research Centres (from US DOE, 2017a)

The US DOE provides a technical summary of all 36 EFRCs, including both description of the research and of the *mission statement*, ie. the scientific questions the EFRCs attempt to solve (US DOE, 2017b)[9].

[8] https://science.energy.gov/user-facilities/user-facilities-at-a-glance/

[9] https://science.energy.gov/~/media/bes/efrc/pdf/technical-summaries/ALL_EFRC_technical_summaries.pdf

3.3.2 Canada

A comprehensive review of Canadian science was published in April 2017 (Canada's Fundamental Science Review (CFSR), 2017)[10]. The review also covers research infrastructures, and one recommendation is a more coordinated manner of investing in 'Big Science' and the formation of a standing committee on Major Research Facilities (MRFs). Nine MRFs are highlighted for selection, with **Ocean Networks Canada** being the only one of major energy research interest (as also listed in the GSO-reports as linked with energy).

Canada also has different forms of Networks of Centres of Excellence[11].

Table 5. Canadian Networks of Centres of Excellence

Network and Centres by Program	Energy RIs
Networks of Centres of Excellence (NCE)	BioFuelNet – BFN
Centres of Excellence for Commercialization and Research	Ocean Networks Canada Innovation Centre
Business-Led Networks of Centres of Excellence (BL-NCE)	Green Aviation Research and Development Network – GARDN Refined Manufacturing Acceleration Process - REMAP

In addition, The Research Facilities Navigator is a comprehensive online directory of public research facilities in Canada. The directory provides a total of 180 facilities for the search word "Energy" [12]. Furthermore National Research Council Canada provides its own research facilities[13].

Table 6. National Research Council Canada facilities

Energy, mining and environment	Research facilities
Oil and gas	Advanced, non-linear optimal imagining and microscopy (CARSLab) Marine performance evaluation and testing facilities
Renewable energy	Algal Biorefinery Biorefinery Pilot Plant Gas Turbine Research Facilities Hydraulics Laboratory Marine performance evaluation and testing facilities Nanotubes production facility
Utilities	Canadian Centre for Housing Technology

10 http://www.sciencereview.ca/eic/site/059.nsf/vwapj/ScienceReview_April2017.pdf/$file/ScienceReview_April2017.pdf
11 http://www.nce-rce.gc.ca/NetworksCentres-CentresReseaux/ByBrogram-ParProgramme_eng.asp
12 https://navigator.innovation.ca/en/search?search=Energy
13 https://www.nrc-cnrc.gc.ca/eng/solutions/facilities/index.html

	Civil infrastructure and related structures testing facility

3.3.3 Japan

Japan Science and Technology Agency (JST) provides an overview of the STI-field in Japan[14]. Several different programs and agencies are involved in energy research, including the National Institute of **Advanced Industrial Science and Technology** (AIST), the **Japanese Atomic Energy Agency** (JAEA) and the **Advanced Low Carbon Technology Research and Development Program** (ALCA)[15].

Japan is a global leader in STI, accounting for 10 % of global expenditures on R&D (European Commission, 2017a). The framework conditions for cooperation with Europe on R&D are also considered to be good. Current areas of particular strong cooperation includes nuclear energy research (European Commission, 2017a), while non-nuclear energy research is among the fields singled with potential for more cooperation in the future. Japan has a particular interest in floating offshore wind, and there is interest from the European Energy Research Alliance (EERA) in cooperating with Japanese research facilities in this field. There are also particular areas of energy storage research, biomass conversion, hydrogen fuel cells etc., where cooperation would be suitable.

In terms of Research Infrastructures, the EU-Japan roadmap explicitly expects the 2018 ESFRI Roadmap update and the International Conference of Research Infrastructures (ICRI) to foster further dialogue on research infrastructures (European Commission, 2017a).

3.3.4 Brazil

A bilateral cooperation agreement under the Euratom treaty in the area of Fusion Energy Research was signed in 2009 and entered into force in 2013[16]. The EU-Brazil roadmap notes that Brazil is an emerging global player in nuclear fusion with an ambitious fusion national programme supported by the **National Fusion Laboratory** in Sorocaba, Sao Paulo. There are presently 15 on-going collaborative activities in the field of fusion energy research, involving 17 European and 14 Brazilian entities.

Renewable energy is another top priority for EU-Brazil cooperation, with a particular emphasis on the development of advanced biofuels. Brazil is the world's second largest producer of liquid biofuels and have conducted successful strategic R&D in the field since the 1970s.

3.3.5 Russia

Russia is considered the scientifically most important non associated neighbour country to the EU (European Commission, 2017c)[17]. The EU has had agreement on scientific cooperation with Russia

[14] http://www.jst.go.jp/EN/index.html
[15] See e.g. http://www.jst.go.jp/alca/en/pdf/ALCA_Brochure_2016.pdf
[16] http://ec.europa.eu/research/iscp/pdf/policy/br_roadmap_2017.pdf#view=fit&pagemode=none
[17] http://ec.europa.eu/research/iscp/pdf/policy/ru_roadmap_2017.pdf#view=fit&pagemode=none

since 1997, and coordination includes a Joint S&T Cooperation Committee and 13 thematic working groups, of which one concerns energy research. Russia also cooperates with the in the area of research infrastructures, as Russia collaborates in a number of large European projects like ITER, CERN etc., and in return Russia has opened access for Europeans for its 'future megascience physics facilities' (European Commission, 2017c). This includes access to the IGNITOR-facility mentioned in the GSO Progress Report.

A list of 54 Russian Research Infrastructures is available at the R&I IC-portal[18], and while the list is undated and the criteria for selection not specified, the information is useful (European Commission (EC), undated). Below is a list of the RIs in which 'energy' is mentioned as part of the description:

Table 7. Russian research infrastructures adapted from EC (undated)

Founding organization	Location	Name of research infrastructures	Description	Relevant RISCAPE WP 6
All-Russian Research Institute for Optical and Physical Measurements (VNIIOFI)	Moscow		Among other things: Development of new energy-saving light sources	No
National Research Center Kurchatov Institute	Moscow	The Kurchatov complex for synchroton – neutron researchers	Accelerator complex of the Kurchatov synchroton radiation source.	Yes (in GSO report)
Tver State Technical University	Tver	Institute of Nano- and Biotechnologies	Research in the field of energy (among other subjects)	Unlikely
P.G. Demidov Yaroslavl State University	Yaroslavl	Diagnostics of Micro- and Nanostructures	Development of nanocomposite and nanostructured materials for solar energy and chemical power sources.	Unlikely
Southern Federal University	Rostov-on-Don	CUC Molecular Spectroscopy	Investigation of electronic excitation energy	No
Southern Federal University	Rostov-on-Don	CUC Nanotechnologies	New and renewable energy sources technologies	Unlikely
Southern Federal University	Rostov-on-Don	CUC "High Technology"	New and renewable energy sources technologies	Unlikely
Ioffe University	St. Petersburg	Joint Research Centre "Material science and characterization in advanced technology"	High-energy physics	No
Immanuel Kant Baltic Federal University	St. Petersburg	Science and Technology Park "Factory"	Development of methods for the creation of nanostructures for energy-saving systems of monitoring and control of technological processes and	No

18 http://ec.europa.eu/research/iscp/pdf/policy/russian_research_infrastructures.pdf#view=fit&pagemode=none

			equipment and elf-contained power supply	
National Research Tomsk Polytechnic University	Tomsk	"Research Nuclear Reactor" Centre	Energy efficiency, energy conservation, nuclear power, in the area of research for the development of advanced fuel compositions, as well as the study of the properties of materials, working in extreme conditions.	Yes
Novosibirsk State University	Novosibirsk	Center for collaboration in usage of devices and equipment "High Technologies and Analytics of Nanosystems" (CCU HTAN)	Experimental implanter with the energy of the particles up to 150 keV	No
Lomonosov Moscow State University	Moscow	Astrophysical complex MSU-ISU for the study of cosmic rays of ultrahigh energies	Energy measurement, energy accuracy	No
Institute for Nuclear Research	Moscow	Unique scientific installation "Baikal deep water neutrino telescope" – Baikal GVD	High energy moon detection	
National Research Nuclear University MEPhI	Moscow	Experimental complex NEVOD	Facility can measure energy deposit of charged particles	No
State Research Center of Russian Federation – Institute for High Energy Physics	Protvino	Accelerator Complex U-70of SRC IHEP, beam transfer lines and experimental facilities included (U-70)	High energy physics	No
Budker Institute Nuclear Physics of Siberian Branch Russian Academy of Sciences	Novosibirsk	Complex of Electron positron collider VEPP-4-VEPP-2000 for high energy physics experiments	High energy physics	No
Budker Institute Nuclear Physics of Siberian Branch Russian Academy of Sciences	Novosibirsk	Complex of Long Open Traps	The results obtained are applied to material science, energy environment etc.	No
Moscow State University of Civil Engineering	Moscow	Head Regional Collective Research Centre of Moscow State University of Civil Engineering	Improving the energy efficiency and automation of engineering systems in buildings and structures	Unlikely

As can be seen by table 6 most of the Russian research infrastructures nominally related to energy works in the domain of high energy physics. Certain RIs with a nuclear focus will be relevant for the RISCAPE-study, however, as they complement European nuclear energy RIs.

3.3.6 India

The EU is India's biggest trading partner, and India and the EU has had an agreement on scientific cooperation since 2001 (European Commission, 2017d), and a specific agreement on cooperation within the field of nuclear energy research since 2010. India has very few researchers and generates very few patents per capita, but the country does host several world-class facilities, particularly at the Indian Institute of Technology, and the country's share of the world's high-quality scientific publications is surging (European Commission, 2017d).

A certain degree of collaboration between European and Indian Research Infrastructures is ongoing, with India being part of several European RI's and also an active part in the Group of Senior Officials (GSO). India has here sought partners for its underground laboratory (INO, the India-based Neutrino Observatory) (European Commission, 2017d).

In terms of future S&T cooperation, energy research is one of the key areas, in particular renewables and smart grid capacity in the framework of Mission Innovation (European Commission, 2017x). There is also an explicit partnership regarding fusion cooperation with the main area of cooperation being potential Indian membership in the Joint European Torus (JET)-programme.

Finally, the EU-India roadmap suggests bioeconomy as a potentially new area for S&T-cooperation, and India as a region primed for Concentrated Solar Power (CSP). There is already an Indian collaboration with the Unites States on solar energy in the **Solar Energy Research Institute for India and the United States** (SERIUUS).

3.3.7 China

China is the world's third largest economy after the EU and the US, EU is China's biggest trading power and China is the EU's second biggest trading power after the US (European Commission, 2017f). China is in other words a key economic region of the world.

China plays an increasing role in global research and innovation, as can be seen by the fast rising number of annual patent applications, cf. figure 5. More annual patent applications are now coming from China than from all OECD-members combined.

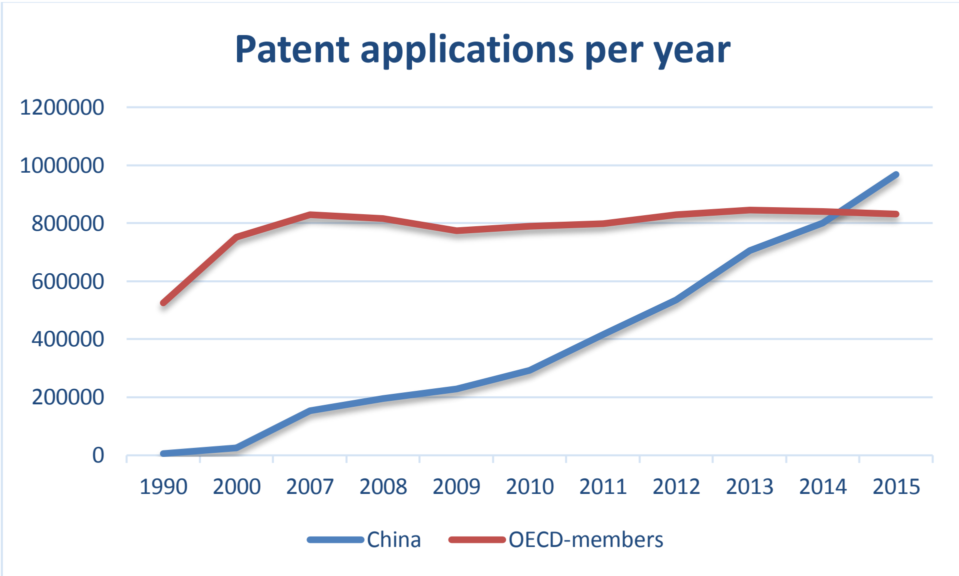

Figure 10. World patent applications data (adapted from World Bank, 2017)

The EU and China also cooperates within research and development, having in 2017 signed both a joint statement on two flagship initiatives (on food, agriculture and biotechnologies (FAB) and aviation) and a framework research arrangement between the European Commission's Joint Research Centre and the Chinese Academy of Science (European Commission, 2017f).

Chinese entities have also cooperated in a large amount of Horizon 2020-projects (255 projects in total), although with very little impact within energy research.

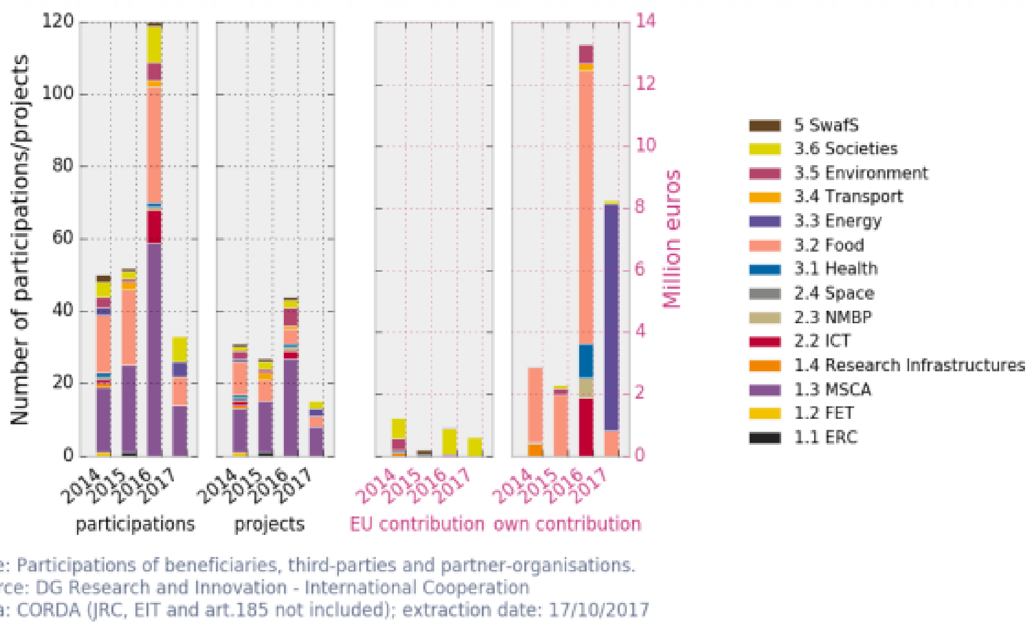

Figure 11. Participation of China in Horizon 2020 (European Commission, 2017f)

China has become one of the principal nuclear research interlocutors for Euratom since the signing of the RD-PUNE agreement in 2008 (European Commission, 2017f). China is a leading actor in fusion energy, a full member party of ITER, and the only country with plans to build a new fusion machine complementary to ITER during the next decade (Ibid.). This, the so-called **Chinese Fusion Engineering Testing Reactor (CFETR)**, will presumably be a major research infrastructure for European researchers to follow during the next decade, and it will naturally be included in the RISCAPE-project.

In total, there are no less than 108 on-going activites related to common fusion research projects, involving 15 European and 15 Chinese entities. On fission research bilateral cooperation has focused on supercritical water reactors (European Commission, 2017f). Specific EU-CN cooperation activities are also set out in the EUROfusion 2018 Work Plan.

The EU-China roadmap also notes that China is a strategic partner for the EU in non-nuclear energy research and innovation, and that there has been 'reasonable momentum' in cooperation in the field of clean energy research. The roadmap also notes Mission Innovation as a key enabler for further cooperation in this field.

China has invested a significant amount of money in large scale research infrastructures following the 15 years-plan for science & technology devised in 2006 (Xin & Yidong, 2006; Serger & Breidne, 2007). The 2006-plan identified energy as one of eleven priority areas. However, energy research is not part of the four major basic research projects which were also singled out in the plan.

The 13th Five-Year Plan released in 2016 strenghtened investments in research infrastructures further (Cyranoski, 2016). 15 new big science-facilities are planned for the period towards 2030.

The website of Chinese Academy of Science lists current 'Big Science-facilities'[19], althoug again none of the fall into consideration for this RISCAPE-work package.

Table 8. Big Science Facilities in China (Chinese Academy of Science, 2017)

	Relevant for RISCAPE WP6
Meridian Space Weather Monitoring Project	No
Shanghai Synchroton Radiation Facility	No
BEPC & BEPC-II *(Beijing Electron Positron Collider)*	No
HIRFL *(Heavy Ion Research Facility)*	No
Shenguang-II High Power Laser	No
FAST Telescope *(Five-Hundred-Meter Aperture Spherical Telescope)*	No
LAMOST Telescope	No

[19] http://english.cas.cn/research/facilities/

Yangbajing Int'l Cosmic Ray Observatory	No
Daya Bay Reactor Neutrino Experiment	No
Hefei Synchroton Radiation Facility	No
Soft X-reay FEL	No
China Spallation Neutron Source	No
Steady High Magnetic Field	No
China Remote Sensing Satellite Ground Station	No
Airborne Remote Sensing Aircraft	No
BPM & BPL Time Service	No
Research Vessels	No
China Germplasm Bank of Wild Species	No

3.3.8 South Africa

The South African government published the first South Africa Research Infrastructure Roadmap in October 2016 (Department of Science and Technology, 2016)[20]. The roadmap explicitly identies both large-scale research infrastructures (such as those in the ESFRI roadmap) end medium-sized research infrastructures, cf. figure 1.

Table 9. Information on Energy RIs in South Africa Research Infrastructure Roadmap (Department of Science and Technology, 2016)

Types of research infrastructures needed to advance scientific knowledge	• Solar cells development capabilities • Pilot plants for thermos-solar (concen-trated solar power) or photovoltaic systems, with or without solar concentration (concen-trated photovoltaics) • Pilot plants for wind turbine testing • Smart grid testing facilities • Nuclear reactors for fission energy research and for materials testing • Participation in fusion RIs
Research infrastructure identified in South Africa	• **SAFARI-1**. A fission research reactor as a source of neutrons • **Distributed energy research laboratories** focusing on generation, transmission and distribution, as well as energy efficiency and smart grids.
	• Plataforma Solar de Almeria (for research, development and testing of concentrating solar technologies) in Spain • Institute Laue Langevin in France

[20] https://www.gov.za/sites/default/files/sa%20research%20infrastructure%20road%20mapa.pdf

Relevant research infrastructure in other countries	• Fusion Research Reactors (JET, ITER, The National Ignition Facility at Lawrence Livermore National Laboratory in the USA etc.) • Experimental fission reactors and nuclear waste treatment plants in several countries.
Constraints	Fission research is mainly linked with evolution of nuclear plants, while South Africa is not active in fusion research.

We have purposefully adapted the full information on Energy RIs to the table above, as it gives an indication of what is considered important from the South African point of view.

The identification of non-South African RIs will be useful for the analysis of complementarities.

The roadmap also suggests a number of priorities for future research infrastructures in South Africa:

- **Nano-micro manufacturing facility**, which among other things will be able to focus on *Fabrication of thin films for solar cells and energy applications using film deposition techniques*.
- **Solar research facility,** consisting of a *solar tower rated up to* MW_{th}, a *heliostat field of approximately 60,000 m*^{2} *aperture area, space for testing other heliostat designs and concepts with optical and thermal targets on the tower*, *parabolic trough test loops with oil and molten salt as heat transfer fluids*, *space for dedicated testing of CSP components*, *demonstration systems of various photovoltaic types*, *accelerated photovoltaic lifetime testing equipment*, and *advance photovoltaic material and device characterisation.*
- **Material characterisation facility**

It should be noted that an original list of 17 RIs included two proposed energy RIs – a Solar research facility, and a SAFARI-2 materials research facility – of which only one (the former) was selected among the 13 RIs proposed in the final list.

3.3.9 South Korea

South Korea spends a higher percentage of its GDP on research and development than any other OECD-member and has more than doubled its academic publication output since 2005 (Zastrow, 2016). More than 75% of the R&D spending is funded by business, and nearly two-thirds is directly targeted at developing or improving specific applications (European Commission, 2017g). Basic research represents about 20% of total R&D spending.

South Korea has relatively low global research linkage, but EU and South Korea has had an Agreement on Scientific and Technological Cooperation in force since 2007, and an agreement on cooperation between Euratom and South Korea on fusion energy research entered into force in 2006 (European Commission, 2017g). South Korea is party to ITER, and the country is "*set to become a major world nuclear energy player*" (European Commission, 2017x). The country has with international help built the most recent and large world tokamak, **KSTAR**, which is also listed in the GSO-report.

The EU-South Korea roadmap lists energy as a priority, and the most recent EU-South Korea meeting confirmed acceleration of clean energy innovation through the Mission Innovation-initiative as a shared commitment. In nuclear energy research, there is also an explicit Bilateral Work Program between the two parties.

	Scientific Area	Share in world output	Share of international co-publications	Citation Impact: Difference with EU28	Citation Impact: 8-year trend
High publication output	Chemical Engineering: Catalysis	3,9%	37%	+0.44	↑
	Materials Science: Biomaterials	5,0%	33%	+0.4	–
	Engineering: Building and Construction	2,9%	29%	+0.33	–
	Materials Science: Metals and Alloys	4,9%	26%	+0.27	↑
	Energy: Renewable Energy, Sustainability and the Environment	4,1%	27%	+0.19	↑
	Materials Science: General Materials Science	5,5%	29%	+0.19	↑
	Engineering: Mechanics of Materials	4,3%	33%	+0.18	↑
	Physics and Astronomy: Surfaces and Interfaces	5,1%	26%	+0.17	↑
	Chemistry: Physical and Theoretical Chemistry	2,7%	37%	+0.17	↑
	Chemical Engineering: Bioengineering	8,1%	25%	+0.16	↑
Low publication output	Pharmacology, Toxicology and Pharmaceutics: Miscellaneous	1,9%	10%	+1.07	–
	Nursing: Emergency Nursing	1,2%	17%	+1.06	–
	Business, Management and Accounting: Management Information Systems	1,6%	58%	+0.93	–
	Social Sciences: Library and Information Sciences	1,4%	39%	+0.87	↑
	Social Sciences: Law	0,6%	37%	+0.62	↑
	Chemical Engineering: Process Chemistry and Technology	3,8%	24%	+0.58	↑
	Decision Sciences: Information Systems and Management	1,5%	50%	+0.58	↑
	Biochemistry, Genetics and Molecular Biology: Miscellaneous	6,8%	11%	+0.5	–
	Engineering: Miscellaneous	3,3%	35%	+0.44	↑
	Chemical Engineering: Filtration and Separation	4,6%	39%	+0.43	↑

Figure 12. Republic of Korea – Top scientific areas compared to EU28 in terms of citation impacts of publications (European Commission, 2017g)

3.3.10 Taiwan

Taiwan has grown to be a major factor in several global research fields, and Taiwan hosts or take part in a number of large-scale research facilities (Feder, 2014). As an example the Taiwan Photon Source (TPS) is designed as a state-of-the-art synchroton light source.

National Taiwan University also hosts a number of 'International Research Centers'[21] (National Taiwan University, 2017).

With complementarity to the energy research domain, Taiwan in particular is at the forefront at both high-energy research, research on robotics and automation, and research in the field of Internet of Things. All these fields have major overlaps with energy research, but at this stage no clear Taiwanese Energy Research Infrastructure has been identified.

[21] http://www.ntu.edu.tw/english/research/research.html

There is currently no specific science and technology cooperation agreement between the EU and Taiwan.

3.3.11 Australia

The 2016 National Research Infrastructure Roadmap was officially published in May 2017 (Australia, 2017)[22]. The roadmap recommends nine National Research Infrastructure Focus Areas, where each focus area can have relevance for a number of different scientific fields. Energy research can therefore be relevant across a number of RI focus areas, even if they are not dedicated to the energy domain.

Within the field of nuclear research, the roadmap notes Australia's linkages to ITER and the Australian facilities of the multi-purpose **OPAL Research Reactor** and the **National Deuteration Facility (NDF).** Enhancing Australia's nuclear capability is among the suggested priority areas for national research infrastructure.

For renewable energy research the roadmap singles out the **ARC Centre of Excellence in Exciton Science** as developing next-generation energy and security technologies by manipulating light in unique ways. In addition, the **CSIRO Manufacturing Flagship** utilises t**he ANFF Micro and Nano Devices Laboratory** to undertake research to support renewable energy developments.

3.3.12 New Zealand

New Zealand is currently developing its own research infrastructure roadmap which will be developed with the consultation of Australia, according to the Australia-New Zealand February 2017 agreement on Science, Research and Innovation Cooperation (Australia & New Zealand, 2017)[23].

The Roadmap for EU-New Zealand S&T Cooperation (European Commission, 2017h) notes that R&F intensity in New Zealand has increased over the past 20 years, that the New Zealand government is currently making major investments through the Innovative New Zealand-package, and that New Zealand benefits from a very high R&D intensive employment market.

Furthermore, the EU is the most significant regional science and innovation partner of New Zealand with more than half of New Zealand's researchers having an active collaboration with a European partner. However, European collaboration with New Zealand within energy research was previously assessed by an official review to be very low (Khan-Malek & Windsor, 2013: 44), despite areas of particular interest and relevance e.g. bioenergy and biofuels[24].

For future S&T cooperation the EU-New Zealand roadmap highlights two areas of interest for energy research (European Commission, 2017h). One is related to geothermal energy, where New Zealand major interests, having also joined the Global Geothermal Alliance in 2015, the other is related to

[22] https://docs.education.gov.au/system/files/doc/other/ed16-0269_national_research_infrastructure_roadmap_report_internals_acc.pdf
[23] http://www.mbie.govt.nz/info-services/science-innovation/pdf-library/summary-document.pdf
[24] http://ec.europa.eu/research/iscp/pdf/policy/eu-nz_report2013.pdf#view=fit&pagemode=none

closer cooperation on developing the bioeconomy. This is also a topic where New Zealand provides world-class research, although perhaps the link with agriculture, food production and climate change are stronger than the links with energy research. On this note, the roadmap connects potential cooperation with the EU Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI).

3.3.13 Africa (non-South Africa)

The EU has an agreement with the African Union on S&T cooperation, in addition to bilateral Science and Technology Cooperation Agreements with South Africa, Egypt, Morocco and Algeria. The 2017 *Roadmap for EU – African Union S&T Cooperation* (European Commission, 2017i) describes both state of play of EU-African Union S&T Cooperation and future opportunities[25].

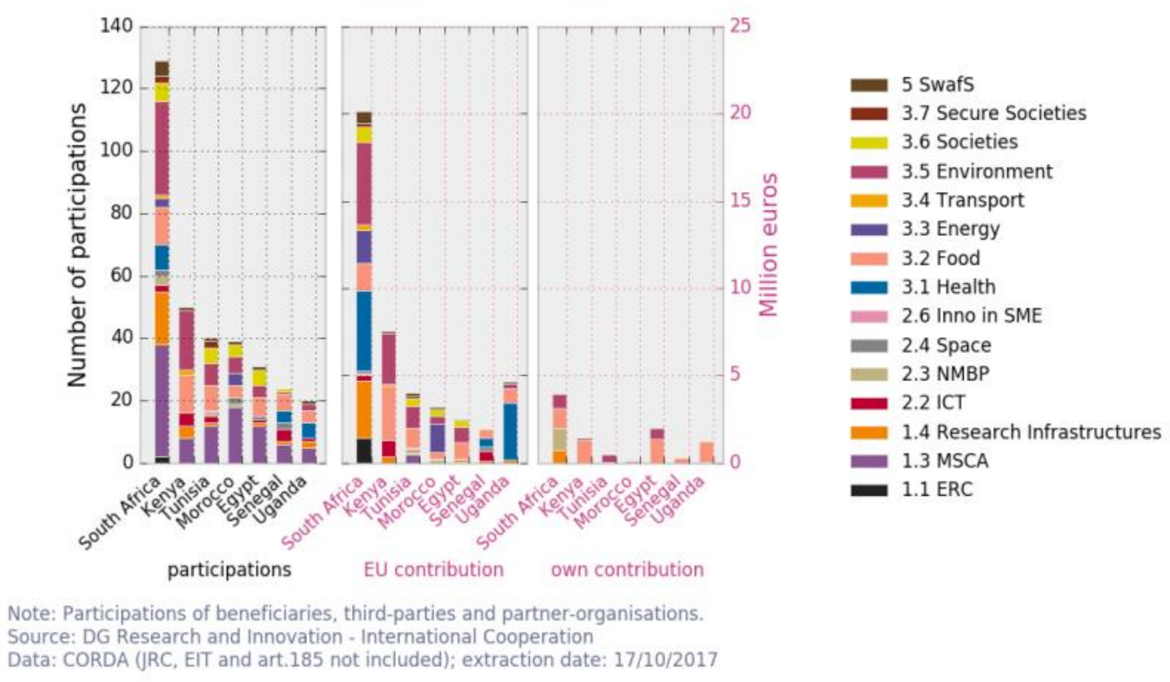

Figure 13. Participation of the most active African Union countries in Horizon 2020 (European Commission, 2017i)

South Africa in particular, but also Kenya, Tunisia, Morocco and others have been active participants in the Horizon 2020-program. Energy research appears to have played only a minor part in the overall research however.

[25] http://ec.europa.eu/research/iscp/pdf/policy/africanunion_roadmap_2017.pdf#view=fit&pagemode=none

A new EU-AU and Innovation Partnership on Climate Change and Sustainable Energy might increase cooperation in years to come. A roadmap[26] towards the dedicated R&I partnership was i officially launched November 2017. There is also an official strategy for further cooperation[27].

3.3.14 ASEAN

The 2017 EU-ASEAN Roadmap shows the areas of existing S&T cooperation[28] (European Commission, 2017j). ASEAN-countries have been active partners in Horizon2020-projects, although on a rather small scale. No ASEAN-countries have participated in Horizon 2020 energy research, cf. figure 6, nor is energy research among those thematic areas highlighted as potential new areas of future S&T cooperation.

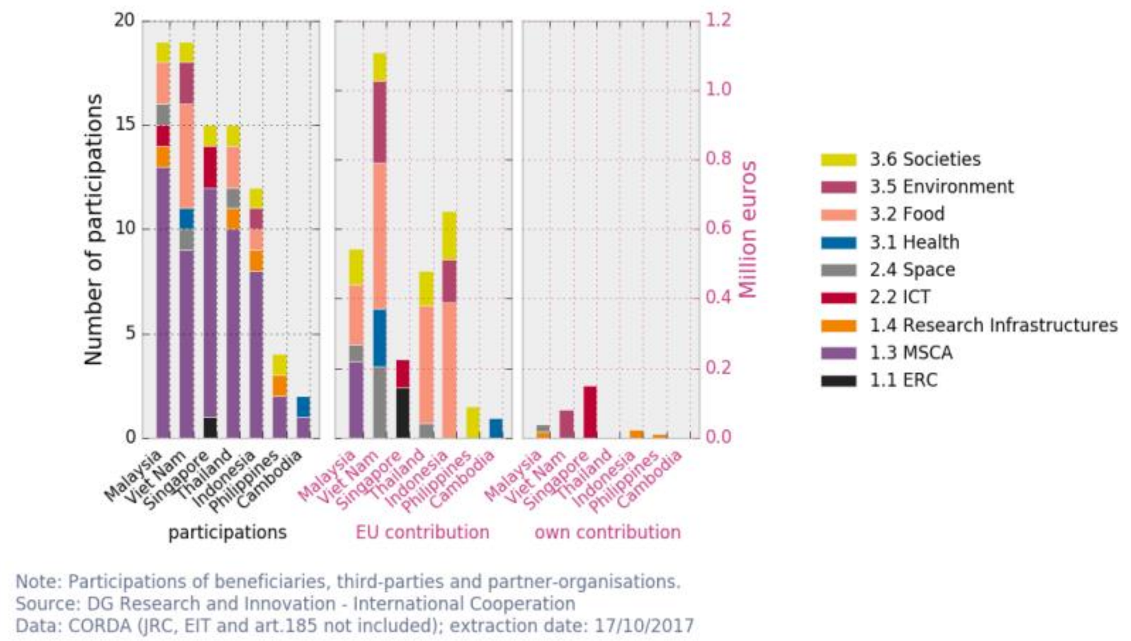

Figure 14. Participation of ASEAN countries in Horizon 2020 (European Commission, 2017j)

This is somewhat in contrast with earlier statements in the 2007 *Plan of Action to Implement the Nuremberg Declaration of an EU-ASEAN Enhanced Partnership*[29] in which Energy Security plays an important role. It is here suggested to build on the results of the EC-ASEAN Energy Facility Program.

[26] http://ec.europa.eu/research/iscp/pdf/policy/ccse_roadmap_2017.pdf#view=fit&pagemode=none
[27] http://ec.europa.eu/research/iscp/pdf/policy/rec-17-003-b5_1-africa_web.pdf#view=fit&pagemode=none
[28] http://ec.europa.eu/research/iscp/pdf/policy/asean_roadmap_2017.pdf#view=fit&pagemode=none
[29] http://ec.europa.eu/research/iscp/pdf/policy/action_plan_07.pdf#view=fit&pagemode=none

3.3.15 Central Asia

A Strategy for a New Partnership was made between EU and Central Asia (Kazakhstan, the Kyrgyz Republic, Tadjikistan, Turkmenistan and Uzbekistan) in 2009[30]. Energy plays a major role in the strategy, although not so much from a research and innovation perspective. It is also unclear whether the intensions of the strategy has fully been realized given the political turmoil in the period since.

This region is not expected to feature much during the landscape analysis.

3.3.16 Latin America and the Caribbean

In the area of energy, despite substantial bilateral cooperation with Brazil (biofuels) and Mexico (geothermal) the potential for cooperation is currently underexploited. Bioeconomy is another topic in which there is potential for further cooperation[31].

The area does provide major opportunities for international research infrastructures. For example, Chile has become a scientific hub within Astronomy, housing nearly all major European telescopes and an increasing share of the observation capacity of countries such as USA, Canada and Japan (Garcia-Huidobro, 2017).

3.4 Mission Innovation

Beyond other traditional literature sources participants in the RISCAPE Energy Research Infrastructures-workshop in Brussels 4.7.17 suggested *Mission Innovation* (MI) as a key source of information on energy research infrastructures. Mission Innovation is a global initiative of 22 countries and the European Union to dramatically accelerate global clean energy innovation[32], announced November 30, 2015 during the COP21 in Paris.

It must be expected that this forum will have a major role in coordinating and strengthening high-level energy research in the coming years. The MI-website already functions as a valuable source of information provided by the organization’s member countries. At the time of writing (November 2017) the website’s library features a total of 206 roadmaps and reports[33].

Table 10. Country behind roadmaps and reports listed by Mission Innovation-website

Country	No. of reports/roadmaps
Australia	14
Brazil	2
Canada	22
Chile	3

[30] http://ec.europa.eu/research/iscp/pdf/policy/2010_strategy_eu_centralasia_en.pdf#view=fit&pagemode=none
[31] http://ec.europa.eu/research/iscp/pdf/policy/celac_roadmap_2017.pdf#view=fit&pagemode=none
[32] http://mission-innovation.net/about/
[33] http://mission-innovation.net/view/roadmap-and-reports-library/

China	6
Denmark	4
European Union	2
France	21
Germany	3
India	7
Indonesia	10
Italy	2
Japan	7
Mexico	2
Multiple[34]	70
Norway	4
Republic of Korea	2
Saudi Arabia	1
Sweden	3
United Arab Emirates	6
United Kingdom	1
United States	15

Of these 206 reports, 97 specifically concerns countries outside Europe, while many of the 70 reports by 'multiple' countries also concern global energy and global energy research questions. For the purpose of identifying non-European Research Initiatives, the Mission Innovation portal is therefore an essential library of information.

Annex A.1 provides an overview of selected key documents from the Mission Innovation portal.

[34] Primarily IEA, but also organisations like Asian Development Bank, Oxfam and Worldwatch.

4 Current list of the research infrastructures outside of Europe to be analysed

Below is a draft list of international RI's to be analysed. This is not a final version, and it is expected that the final list will include both additions and subtractions compared to the list below.

4.1 Current list of RI's identified for further analysis

4.1.1 G7-countries outside the EU

Table 11. Energy research infrastructures in non-EU G7-countries

Infrastructure name	Country	Subdiscipline	Complementary to European RI	Comments
Oak Ridge National Laboratory	USA	Nuclear Energy, Energy efficient materials		https://www.ornl.gov/
Sandia National Laboratories	USA	Concentrated Solar Power (CSP), Photovoltaics,		http://energy.sandia.gov/energy/#.T4yjrI5qujF
National Renewable Energy Laboratory (NREL)	USA	Bioenergy		https://www.nrel.gov/bioenergy/
National Wind Technology Center (NWTC)	USA	Wind Energy		https://www.nrel.gov/news/features/2017/americas-wind-energy-future-looks-seaward.html
Argonne National Laboratory	USA			https://www.anl.gov/
Lawrence Berkeley National Laboratory	USA	Materials Science		http://www.lbl.gov/research-areas/energy-sciences/
National Spherical Torus eXperiment Upgrade	USA	Fusion Energy		http://nstx-u.pppl.gov/
DIII-D Research Program	USA	Fusion Energy		https://fusion.gat.com/global/diii-d/home?redirect=1
Pacific Northwest National Laboratory	USA	Various		http://www.pnnl.gov/
National Energy Technology Laboratory	USA	Coal, oil & gas, renewables		https://www.netl.doe.gov/
Idaho National Laboratory	USA	Nuclear energy		https://www.inl.gov/
Savannah River National Laboratory	USA	Nuclear energy, hydrogen		https://srnl.doe.gov/

The Future of Geothermal Energy, MIT Initiative	USA	Geothermal energy		http://energy.mit.edu/landing-page/research/
MIT Energy Initiative	USA	All renewables		http://energy.mit.edu/landing-page/research/
Stanford Energy Research	USA	All renewables		https://energy.stanford.edu/people/faculty
NRU, Chalk River	Canada	Nuclear Energy, Energy efficient materials		http://nuclearsafety.gc.ca/eng/reactors/research-reactors/nuclear-facilities/chalk-river/index.cfm
NRC Energy, Mining and Environment Research Centre	Canada	Renewable energy, Bioenergy, Energy storage		https://www.nrc-cnrc.gc.ca/eng/rd/eme/index.html
Ocean Networks Canada	Canada	Marine Energy		GSO-report 2017; www.oceannetworks.ca
The Wind Engineering Energy and Environment (WindEEE)	Canada	Wind Energy		GSO-report 2017; www.windeee.ca
Oarai Research & Development Center	Japan	Nuclear Energy, Energy efficient materials		http://snsr.jaea.go.jp/en/research/ordc.html
The National Institute of Advanced Industrial Science and Tehcnology (AIST)	Japan	Energy research, all		http://www.aist.go.jp/aist_e/dept/en_denvene.html
Fukushima Renewable Energy Institute, AIST	Japan	Renewable energy		http://www.aist.go.jp/fukushima/en/
The New Energy and Industrial Technology Development Organisation (NEDO)	Japan	Energy research, all		http://www.nedo.go.jp/english/
The Japan Atomic Energy Agency	Japan	Nuclear energy		https://www.jaea.go.jp/english/
Global Research Center for Environment and Energy Based on Nanomaterials Science (GREEN)	Japan	Materials		http://www.nims.go.jp/eng/research/green/index.html
Advanced Low Carbon Technology Research and Development Programme (ALCA)	Japan	Renewable energy		http://www.jst.go.jp/alca/en/

4.1.2 BRICS-countries

Table 12. Energy research infrastructures in BRICS-countries

Infrastructure name	Country	Subdiscipline	Complementary to European RI	Comments
IPR-R1 Research Reactor	Brazil	Nuclear Energy, Energy efficient materials		http://www.cdtn.br/en/instalacoes-de-grande-porte/reator-triga-ipr-r1
Brazilian Centre for Research in Energy and Materials (CNPEM)	Brazil	Bioenergy, Materials		GSO-report 2017; http://cnpem.br/
Brazilian Bioethanol Sci&Tech Laboratory (CTBE)	Brazil	Biofuels, Bioenergy		GSO-report 2017; http://ctbe.cnpem.br/en/
Research Institute of Atomic Reactors (RIAR)	Russia	Nuclear energy, energy efficient materials		http://www.niiar.ru/eng/about
Tokamak IGNITOR	Russia	Nuclear Energy		GSO-report, 2017;
Bhabha Atomic Research Centre (BARC)	India	Nuclear energy, energy efficient materials		http://www.barc.gov.in/
Solar Energy Research Cente for India and the United States (SERIIUS)	India	Solar Energy		http://www.seriius.org/
DTB-ICGEB Centre for Advanced Bioenergy	India	Bioenergy		http://www.dbtindia.nic.in/dbt-icgeb-centre-for-advanced-bioenergy-research/
Nuclear Power Institute of China (NPIC)	China	Nuclear Energy, Energy efficient materials		http://en.npic.ac.cn/service/capability/reactor/
Experimental Advanced Superconducting Tokamak (EAST)	China	Nuclear Energy, Energy efficient materials		GSO-report 2017; http://english.ipp.cas.cn/rh/east/ /
Shanghai Synchroton Radiation Facility	China	Nuclear Energy, Energy efficient materials		http://www.ssrf.ac.cn/
China Agricultural University (CAU)	China	Bioenergy		http://admissions.cau.edu.cn/en/pages?cid=149&pid=145
Chinese Fusion Engineering Testing Reactor (CFETR)	China	Nuclear energy		
Safari-1, Pelindaba Site	South Africa	Nuclear Energy, Energy efficient materials		http://www.ntp.co.za/safari-1/ l

4.1.3 Other countries/regions

Table 13. Energy research infrastructures in other countries and regions

Infrastructure name	Country	Subdiscipline	Complementary to European RI	Comments
National Fusion Energy Institute, NFRI, The Korean Superconducting Tokamak Advanced Research (KSTAR)	South Korea	Fusion energy		https://www.nfri.re.kr/eng/index
OPAL Research Reactor	Australia	Nuclear energy		http://www.ansto.gov.au/AboutANSTO/OPAL/
National Deuteration Facility (NDF)	Australia	Nuclear energy		http://www.ansto.gov.au/ResearchHub/OurInfrastructure/ACNS/Facilities/NationalDeuterationFacility/
ARC Centre of Excellence in Exciton Science	Australia	Next-generation energy		http://www.excitonscience.com/
ANFF Micro and Nano Devices Laboratory	Australia	Materials for renewable energy		http://www.anff.org.au/

4.2 Countries and regions identified for further analysis

Based on the research hitherto conducted, including the highlights of previous reports (e.g. the GSO-report) and interviews with European RIs, the regions of the world listed in table 6 will be given special importance during the international landscape analysis.

Table 14. Most relevant countries/regions to pursue further

Region/country	
USA	G7 outside EU
Canada	G7 outside EU
Japan	G7 outside EU
Brazil	BRICS
Russia	BRICS
India	BRICS
China	BRICS
South Africa	BRICS
South Korea	
Taiwan	

Australia	
New Zealand	
ASEAN region	
Latin America (not Brazil)	
Africa (not South Africa)	

4.3 Next steps: Mapping international RIs in more detail

The next step in WP6 will be more detailed identification and mapping of international research infrastructures. This will happen through combining three strands of research:

- Direct contact with key European Energy Research Infrastructures
- Desktop research
- Questionnaire for European and International stakeholders

4.3.1 Direct contact with key European Energy Research Infrastructures

A RISCAPE Energy Research Infrastructures-workshop was held in Brussels 4th of July 2017 with the participation of representatives of key European Energy RI's. The inputs of this workshop, along with continued dialogue with European representatives, informs and focuses the international landscape analysis.

4.3.2 Desktop Research

The desktop research will include internet searches, examinations of scholarly papers and more.

Since RISCAPE aims to analyse *world class* facilities, we will need to measure some form of academic impact. How to measure the academic impact of research infrastructures is a difficult question in itself, as the infrastructures may or may not show up in the scientific output as metrics possible to analyse (cf. Mayernik et al, 2017). The attempt to solve this will be done in close contact with the other RISCAPE-work packages, in particularly Work Package 2.

Finally, as noted in Section 3.3 the information available through Mission Innovation is expected to be very helpful in this exercise.

4.3.3 Questionnaires for European and International stakeholders

We are in the process of developing short questionnaires which can be send to relevant experts.

Tentatively, the questionnaire will be send for:

- Contacts at key research infrastructures in Europe[35].

[35] Who have already been contacted as part of the RISCAPE-project.

- Members of the Horizon2020 Advisory Group on Energy
- Members of the ESFRI Working Group on Energy
- Members of the Executive Committees of the International Energy Agency's Technological Collaboration Programmes.

We are purposely aiming at recipients who have already been formally recognized as experts in their field, and who can easily be identified through desktop work. This ensures both greater transparency in the selection and it makes it possible to cover very wide ground, ensuring a large spread both geographically and in terms of technologies, without drowning in workload.

Participants at the RISCAPE Energy RI workshop in Brussels 4.7.17 also identified IEA's networks as important contacts. IEA has a total of 39 TCP's, of which not all are relevant for the purpose of RISCAPE. In total, the questionnaires will be send out for 100+ recipients. This should hopefully ensure a large number of respondents, covering all technologies and countries extensively.

The questionnaire is expected to consist of two individual parts:

1) Self-measurement along dimensions of the developed maturity model.
2) Identification of other key research infrastructures (EU and global) within the respondent's expertise.

Separate questionnaires will be send for recipients in Europe vs. outside-Europe.

The questionnaire will be brief and simple. This will hopefully help secure a sufficient level of responses. This might also result in a significant workload of selecting and sorting information after the responses come in, but at present this risk is considered manageable.

4.4 Complementarities with European RIs

The main target of the international landscape analysis is to analyse the complementariness of international research infrastructures with European research infrastructures. For this reason the work will be structured around identifying complementarities along *geographical* dimensions, *technical* dimensions and the *challenges* which the research infrastructures work to solve.

The methodology for analysing complementarities will be developed in close cooperation with the other partners in the RISCAPE-consortium.

5 Discussion

Ideal Life-cycle of Energy RIs and 14 Framework criteria of Energy RIs is a promising platform for European and international evaluation of Global Research Infrastructures (GRIs).

In this report we have presented current understanding of European and international RIs in the energy research. The role of global Research Infrastructures is changing in many ways. In recent decades the RIs of G7 countries have dominated intellectual property in the global arena, but now the role of BRICS countries and other developing countries is increasing (see e.g. Kaivo-oja & Lauraeus 2017b).

This is an issue, which requires special attention in the European STI policy arenas. We can expect that there is new global value chains, building blocks and network dynamics, where European RIs play a special and important role (see e.g. Kaivo-oja 2017). The increasing complexity of global value chains (GVCs) does not make it easier to identify emerging new Global Research Infrastructures – especially in the field of energy research. This is a reason, why there is need to discuss more about the nature of Global Research Infrastructures.

Typically, Global Research Infrastructures are so large, complex or expensive that they require international cooperation to construct and run them. Other challenges are naturally global in scope as they respond to global sustainability challenges and/or require the combined skills, data and efforts of the world's best scientists. For example, strong investment in research and innovation is needed to address pressing societal challenges such as climate change, health, an ageing population, and the move towards a resource and energy efficient society.

The next to step is to study more potentials of international cooperation between European and global RIs.

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Appendix I. Relevant documents

Table A.1: Selected relevant Roadmaps and Reports from Mission Innovation-website

Country	Publication	Year	Link
Australia	Science and Research Priorities: Energy – Capability Statement	2015	http://www.science.gov.au/scienceGov/ScienceAndResearchPriorities/Documents/Science-Research-Priorities-Energy.pdf
Australia	Australia's Innovation Catalyst	2015	http://www.innovationcafe.com.au/wp-content/uploads/2015/07/CSIRO_Strategy_2020-PDF.pdf
Australia	Towards development of an Australian scientific roadmap for the hydrogen economy	2008	https://www.science.org.au/files/userfiles/support/reports-and-plans/2008/roadmap-development-for-hydrogen-economy.pdf
Australia	Australian Energy Storage Roadmap	2015	https://www.cleanenergycouncil.org.au/dam/cec/policy-and-advocacy/reports/2015/150429-Australia-storage-industry-roadmap-FINAL/150429%20Australia%20energy%20storage%20roadmap%20FINAL.pdf
Australia	Australian Renewable Energy Mapping Infrastructure (AREMI)	2014	http://nationalmap.gov.au/renewables/
Brazil	Visao Brasil 2050 – A nova agenda para as empresas	2012	http://cebds.org/wp-content/uploads/2014/02/Vis%C3%A3o-Brasil-2050-2012_pt.pdf
Canada	Clean Energy Fund: Summary Report – Federal R&D	2014	http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/files/pdf/CLEAN-ENERGY-FUND-ENG-FINAL-may-29.pdf
Canada	Charting the Course: Canada's Marine Renewable Energy Technology Roadmap	2011	http://publications.gc.ca/collections/collection_2012/rncan-nrcan/M154-56-2011-eng.pdf
Canada	Energy Innovation Roundtables Report	2014	http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/files/pdf/14-0309%20Energy%20Innovation%20Roundtable_e.pdf
Canada	Moving forward together on energy research, technology and innovation	2015	https://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/www/pdf/publications/emmc/15-0163%20EMMC-Taking%20Action_access_e.pdf
Canada	Opportunities for Canadian energy technologies in global markets	2012	http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/energy/files/pdf/2013/McK-Report-eng.pdf
Canada	Carbon Sequestration Technology Roadmap	2013	http://hub.globalccsinstitute.com/sites/default/files/publications/115713/cslf-technology-roadmap-2013.pdf
Canada	Renewable Natural Gas Technology Roadmap for Canada	2014	http://www.cga.ca/wp-content/uploads/2015/04/The-Renewable-Natural-Gas-Technology-Roadmap.pdf

Chile	Hoja de Ruta 2050	2015	http://www.energia.gob.cl/sites/default/files/hoja_de_ruta_cc_e2050.pdf
Chile	Energia 2050 – Politica Energetica de Chile	2016	http://www.energia.gob.cl/sites/default/files/energia_2050_-_politica_energetica_de_chile.pdf
China	China's Thirteenth Five-Year Plan	2016	http://www.china-un.org/eng/zt/China123456/
China	Roadmap for Carbon Capture and Storage Demonstration and Deployment in the People's Republic of China	2015	https://www.adb.org/sites/default/files/publication/175347/roadmap-ccs-prc.pdf
India	India Energy Outlook	2015	http://www.worldenergyoutlook.org/media/weowebsite/2015/IndiaEnergyOutlook_WEO2015.pdf
India	Strategy on R&D activities for Thermo-Chemical conversion and promotion of biomass energy in the country	2011	http://mnre.gov.in/file-manager/UserFiles/national_rdbiomass.pdf
India	Cleantech Handbook – India	2014	http://team.finland.fi/en/article/-/asset_publisher/cleantech-handbook-india-published
India	Renewable Energy prospects for India	2017	http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_India_paper_2017.pdf
Indonesia	Energy Policies Beyond IEA Countries – Indonesia 2015	2015	https://www.iea.org/publications/freepublications/publication/Indonesia_IDR.pdf
Indonesia	Using Private Finance to Accelerate Geothermal Deployment: Sarulla Geothermal Power Plant, Indonesia	2015	http://climatepolicyinitiative.org/wp-content/uploads/2015/06/Using-Private-Finance-to-Accelerate-Geothermal-Deployment-Sarulla-Geothermal-Power-Plant-in-Indonesia.pdf
Indonesia	Renewable Energy Prospects: Indonesia	2017	http://www.irena.org/DocumentDownloads/Publications/IRENA_REmap_Indonesia_report_2017.pdf
Japan	Strategic Technology Roadmap in Energy field – Energy Technology Vision 2100	2006	http://www.iae.or.jp/wp/wp-content/uploads/2014/09/ene_vision_2100/overview.pdf
Japan	Energy Technology Strategy	2007	http://www.iae.or.jp/wp/wp-content/uploads/2014/09/ene_vision_2100/ETSofJPN_2007_082115.pdf
Japan	Cool Earth: Innovation Energy Technology Program	2008	http://www.iae.or.jp/wp/wp-content/uploads/2014/09/Cool_Earth08_e/CoolEarth_RM.pdf
Japan	New Low Carbon Technology Plan	2013	http://www8.cao.go.jp/cstp/english/doc/new_low_carbon_tec_plan/index.html
Japan	Roadmap and Other Items Pertaining to Each Item of Technology	2013	http://www8.cao.go.jp/cstp/english/doc/new_low_carbon_tec_plan/attach3-1.pdf

Japan	Strategic Road Map for Hydrogen and Fuel Cells	2016	http://www.meti.go.jp/english/press/2014/0624_04.html
Mexico	Cleantech Mexico 2015: Outlook and Policies for Unlocking Ecoinnovation	2015	http://d2ouvy59p0dg6k.cloudfront.net/downloads/cleantech_mexico_2015___exec_summary.pdf
Multiple/IEA	Energy Investments and Technology Transfer Across Emerging Economies – The case of Brazil and China	2013	https://www.iea.org/publications/freepublications/publication/PCS_ChinaBrazil_FINAL_WEB.pdf
Multiple/IRENA	RD&D for Renewable Energy Technologies: Cooperation in Latin America and the Caribbean	2015	http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=615
Multiple/IRENA	Renewable Energy Outlook: Advanced Liquid Biofuels	2015	http://www.irena.org/DocumentDownloads/Publications/IRENA_Innovation_Outlook_Advanced_Liquid_Biofuels_2016.pdf
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United States	DOE Technology Roadmaps & Research Needs	2016	http://mission-innovation.net/wp-content/uploads/2017/01/DOE-TechnologyRoadmapsResearchNeeds-Draft-April-2016.pdf
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