Technical analysis of on-going projects

Contract ENER C2/2014-642 / S12.698798

"Support to R&D strategy in the area of SET Plan activities in smart grids and energy storage"

Deliverable D3.1

by

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Quality check: all

Due delivery date: 29th of June 2015 (M6)

European Commission

Table of contents

1 Publishable executive summary

The main goal of D3.1 is to support the topic selection and description processes of the integrated implementation plan 2016-2018 (cf. D2.1 and D2.2) by monitoring projects with European-added value, and show that *overlapping*, if any, is minimal.

The monitoring methodology is based on three sequential steps: 1) perform a State-of-the-Art for each topic and identify the main projects (i.e. projects with significant budget and knowledge coverage), 2) *quickly* analyse the coverage of each project and 3) show that overlapping if any is limited (overlapping has been measured by expert view).

Three types of data bases have been used to identify projects and feed the monitoring process: the EEGI database, the Cordis database and the databases of EASE, EDSO and ENTSO-E. Attention has been paid to RTD&D projects performed or on-going for the 2012 to 2015 time period at national (in the European Union) and EU level in connexion with the clusters of the existing EEGI roadmap. In some cases, when few projects were identified, the "2012 to 2015" criterion was extended and older projects were considered. The GRID+ data base on storage projects and the JRC database were used as a mean to cross check information gathered from the other databases and to check that no projects of importance were omitted.

The present monitoring exercise shows that, for all TSO, TSO/DSO, DSO and storage topics, there is a partial coverage of the research activities specified in the integrated implementation plan 2016-2018. For some storage topics (Topic ES04-2017 -Electricity storage for defence and restoration plans- and Topic ES05-2018 -Long-term network planning tools involving storage for capacity firming, active demand and investment deferral), there is no coverage at all.

2 Purpose and structure of this deliverable

2.1 Purpose of the monitoring process

The overarching goal of the monitoring work package (WP3) of the Grid+Storage service contract is to monitor the progress of R&D activities and market uptake annually[1] in order to better steer the R&D priorities at the SET plan level (i.e. the future H2020 calls will be written starting 2016, through the development of an integrated roadmap). More precisely, the specific objectives of WP3 are:

- To provide work package (WP) 1 with state-of-the-art (SoA) analyses and appraisal of projects' results[2] so as to support the selection of topics in the integrated implementation plans and the roadmap (cf. D2.1 to D2.6), based upon a set of validated criteria;
- To select projects for participation in the knowledge sharing workshops (these projects will be used to support knowledge transfer through articles in the knowledge sharing platform, cf. WP4);
- To appraise the EU added value of the on-going R&D activities at the EEGI team level (support to WP5 activities, i.e. EEGI meetings).

The main purpose of the present deliverable is related to the first objective: support the topic selection and description processes of the integrated implementation plan 2016-2018 (cf. D2.1 and D2.2) and show that *overlapping*, if any, is minimal. Overlapping means that some of the R&D activities identified in the topics of the integrated IP 16-18 have already been investigated or are under investigation in past or on-going projects, but the volume and the nature of such activities, in comparison to the overall scope of knowledge foreseen in the topic descriptions, is rather low. In such a case, more R&D activities are needed which calls for new research projects addressing the described topics.

2.2 Overview of the monitoring methodology

2.2.1 Framework of the present monitoring exercise

Monitoring as specified in the service contract means to collect and compile the information about R&D projects completed or on-going for 2012 to 2015 at national (in the EU) and EU level. It also means to link with the TSOs/DSOs active in the 28 Member states and the ministry representatives to identify specific information such as: budget and time to completion of the projects, TRL scale of the outputs indicating the maturity of the expected results and estimated time to reach successful system integration. For EASE, monitoring means to collect and compile information about the R&D projects performed or on-going between 2012 and 2015 in the EU28 at national and EU level, which address grid-connected storage (development, demonstration, business models and regulation). This list will be mapped into the eleven clusters of the integrated IP 16-18 (the same clusters as for the existing EEGI roadmap) with the same information as for the TSO/DSO projects' results.

As explained in D2.1 and D2.2, the topic selection for the integrated IP 16-18 is a constrained exercise:

- ENTSO-E has already published its own IP 16-18, which is a legal document;
- EDSO has already identified topics (cf. the draft IP 16-18 issued in the GRID+ project) which have been validated by its members;

[1] The exercise is performed at M6 for the integrated implementation plan 2016-2018 and one year later (M14) to support the writing process of both the integrated implementation plan 2017-2019 and the integrated roadmap.
[2] Results of national, EC-funded and international projects.

- EASE has identified promising R&D topics in its roadmap.

As a consequence, D2.1 and D2.2 have been written by scanning the above mentioned documents. The aim is to identify the possible use of storage solutions to enrich or complement the research and innovation topics pre-identified by ENTSO-E and EDSO and complemented by new topics identified by EASE. D2.1 is a draft version of the integrated IP 16-18 which has been submitted for public consultation (closed on May 19th 2015). The answers of 15 major players have been analysed and used to write the final version of the integrated implementation plan 16-18 (i.e. D2.2). D2.2 is therefore an amended version of D2.1 accounting for the feedback of the public consultation.

The present monitoring exercise aims at supporting the final selection of topics displayed in D2.2.

2.2.2 Monitoring methodology

The monitoring methodology is a three step process:

1. Step1: perform a SoA for each topic and identify the main projects (main projects are projects with significant budget[3] and knowledge coverage, cf. European projects and national projects with EU added value);
2. Step2: *quickly* analyse the coverage of each project;
3. Step3: show that overlapping if any is limited.

Steps 1 to 3 have been performed with the associations by answering the following questions:

- *What is the new knowledge of European added value to be generated by the proposed topic?*
- *What are the publicly accessible R&I or I[4] projects in the past five years which have addressed this type of new knowledge generation in EU28?*
- *What are amongst the above projects the ones which are finished, the ones which are still going on?*
- *What has been the supposed knowledge generated so far?*
- *What is lacking about new knowledge which is still to be gained at European level?* (a coherence check with first question has been performed)

Such questionnaires have been filled-in for each of the topics proposed by EDSO and EASE. For the topics proposed by ENTSO-E, the questionnaire has been filled in by resorting to the existing reports, cf. section 4.

The outputs of the questionnaires do not allow to list for each project, *the TRL scale of the outputs indicating the maturity of the expected results and the estimated time to reach successful system integration*, as foreseen in the service contract. Practical experience, gained during the present monitoring exercise, has shown that it is very difficult to obtain both ex-ante and ex-post accurate estimations of the TRL of the outputs, and consequently the time to successful system integration.

The consortium partners have decided to rely on expert views to obtain such information. In the present monitoring task, a first exercise has been carried out with the EASE experts: an expert view is provided on the percentage of coverage of the proposed topics, i.e. a

[3] Projects' budget is a good proxy of the volume of activities and ensures to some extent that the selected projects are representative of the current SoA. Attention has also been paid to national projects with significant budgets. Only projects dealing with activities having real European added value have been considered.

[4] R&I: research and development (TRL 3 to 5/6) and I: demonstration projects (TRL 5 to7/8).

measure of the coverage of the proposed topic by the identified projects (see Annex). Expert views will also be used in the next monitoring exercise (cf. D3.2) for the selection of topics in the integrated roadmap.

2.3 Structure

The present monitoring report is organized as follows. Section 3 provides a short analysis of the projects' data bases used. The monitoring exercise for the TSO topics is given in section 4. Similarly, the monitoring exercises for TSO/DSO topics, DSO topics and storage topics is displayed in sections 5 to 7.

In each of these sections, i.e. sections 4 to7, the present SoA is given (SoA of the projects and the current knowledge). This is followed by a description of the new knowledge to be generated (cf. *What is lacking about new knowledge which is still to be gained at European level* and *European added value to be generated by the proposed topic?*).

3 Available data bases

Several data bases have been used to carry out the monitoring process:

1. The EEGI data base, i.e. the list of smart grid national and EU-funded projects which were labelled (core and support labels) during the GRID+ project;
2. The Cordis data base, i.e. the list of selected H2020 smart grid and storage projects following the LCE-2014 calls;
3. The data bases of the associations (EASE, EDSO and ENTSO-E), i.e. all projects identified by the members, both at national and EU level;
4. The GRID+ data base on storage projects (data base with a European coverage: work performed in the mapping work package of GRID+);
5. The JRC data base.

The list of projects identified the first three data bases have been used to feed the monitoring process sketched in section 2.2.2. Attention has been paid to RTD&D projects performed or on-going for the 2012 to 2015 time period at national (in the European Union) and EU level in connexion with the clusters of the existing EEGI roadmap. In some cases, when few projects were identified, the "2012 to 2015" criterion was extended and older projects were considered.

The sub-sections hereafter, i.e. sections 3.1 to 3.5, describe each of these data bases and how they have been used.

3.1 The EEGI data base

The EEGI data base is populated with both national and EU-funded projects that have been awarded one of the two labels delivered by a team of experts[5]. This labelling process was carried out during the GRID+ project (work package 3). The labelling process ensures that the selected projects have reached a quality standard according to a list of criterion (budget, number of involved system operators, scaling-up and replication potential, etc.) and that they address some of the functional objectives listed in the cluster of the EEGI roadmap. Moreover, the labelling process guaranties that there is a significant European added-value generated by the projects, especially for the national projects.

[5] The list of labelled projects is available at http://gridplus.eu/eegi/eegi_projects.

The EEGI data base has been used for smart grid projects as a first proxy to appraise the coverage of the considered topics in the integrated IP 16-18. The analysis of the smart grid projects coverage has been completed with the Cordis data base (H2020 projects) and the inputs from EDSO and ENTSO-E, cf. sections 3.2 and 3.3.

3.2 The Cordis data base

The Cordis data base[6] has been used to list the recently funded H2020 projects, both for smart grids and storage topics, under the LCE-2014 calls. Sixteen projects[7] (7 storage projects and 9 smart grid projects) and one coordination and support action were found. For some of the projects which did not have a website at the time of writing this report, information has been gathered with the support of partners members of the associations (EASE, EDSO, ENTSO-E).

Special attention (when sufficient information was available) has been paid to these projects since they represent the latest possible knowledge coverage from EU-funded projects.

3.3 The data bases of the associations

The projects data base of TSOs has been constructed thanks to the ENTSO-E monitoring[8] and application[9] reports. The information available in these reports, supplemented the information at hand for the EU-funded TSO projects labelled in the EEGI data base.

The projects data base of DSOs has been constructed by the EDSO members when answering the questionnaire prepared by TECHNOFI, cf. section 2.2.2. As a consequence, the data base of DSO projects is a short list of projects that have been identified by EDSO's members as the best proxies for appraising the coverage of the topics listed in the integrated implementation plan 16-18. Some of these projects have been labelled, cf. EEGI data base.

The projects data base for storage has been constructed in a similar way as for EDSO. The EASE members carried out a supplementary exercise which was dedicated to both the monitoring process (work package 3) and the knowledge transfer process (work package 4). The EASE members provided more detailed information for each project, e. g.

- Challenge : key question addressed by the project towards the known SoA;
- Context (i.e. background) and assumptions;
- Description of the results;
- KPIs (if relevant: KPIs as defined in the project);
- Assessment on use : discussion about the use of the project outputs (including exploitation) and outcomes, and possible limits,

and more importantly, when possible, on project results:

- Challenge : key question addressed by the output in relation to the known SoA;
- Context (i.e. background) and assumptions;
- Description of the output;
- Assessment on use : discussion about the use of the output (including exploitation) and outcomes, and possible limits time to completion;
- TRL scale of the expected output indicating the maturity of the expected results;

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[6] http://cordis.europa.eu/search/simple_en
[7] with the following breakdown per topic: LCE-07-2014 (9); LCE-8-2014 (3); LCE-10-2014 (1); SCC-01-2014 (3))
[8] https://www.entsoe.eu/publications/research-and-development-reports/rd-monitoring-report/Pages/default.aspx
[9] https://www.entsoe.eu/publications/research-and-development-reports/rd-application-report/Pages/default.aspx

- KPIs (if relevant: KPIs as defined in the project);
- Estimated time to successfully reach system integration;
- Willingness by the players to share knowledge during the sharing workshops in the future.

This supplementary exercise showed that it is very difficult to obtain both ex-ante and ex-post accurate estimations of the TRL of the outputs, and consequently the time to successful system integration, as already mentioned in section 2.2.2, and therefore there is a need to resort to expert views.

The methodology to be implemented to gather expert views will be discussed by the partners after the first reporting period during a meeting to be held at the beginning of July 2015 so as to plan the coming activities for the drafting of the integrated roadmap and the associated monitoring process. The discussion will be based on the experience gained in the first exercise with EASE members.

3.4 The GRID+ database on storage projects

This database developed in work package 1 of the GRID+ project encompasses all recent RTD&D projects dealing with storage in Europe, especially national projects[10]: in this data base, 391 projects in 14 different countries have been analysed with regard to several criteria (total project budget, specific storage-related budget, source of funding, position of the storage solution in the electricity value chain, technologies being used, main project objective, state of development of project). This data base was used by the Grid+Storage partners as a sanity check, i.e. a way to check that no projects of importance were omitted for the appraisal of the current knowledge coverage of the integrated IP 16-18 topics.

3.5 The JRC data base

A periodic review of smart grid projects across the European Union member states is carried out by the EC Joint Research Centre (JRC) in tight cooperation with the Directorate-General for Energy (DG ENER)[11]. The latest *Smart Grid Projects Outlook 2014* comprises a total of 459 smart grid projects over a period ranging from 2002 to 2014. Annex III of the *Smart Grid Projects Outlook 2014* includes an exhaustive project catalogue –a data base[12].

As for the GRID+ data base on storage projects, this database was used as a mean to cross check information gathered from the other databases and to check that no projects of importance were omitted.

3.6 Other data bases

The monitoring exercise carried out so far showed that it was difficult to have access to national projects. In agreement with the ERANet Smart Grids (SG) Plus[13] representatives and Henrik Dam, the Grid+Storage consortium plans to use the ERANet SG Plus network to have access to member states so as to reach a more in-depth data set regarding national projects. The GRID+ EEGI labelling process will be adapted in order to detect national projects with European added value. The strategy is to push member states to detect projects through the labelling process. This "ERANet SG Plus" data base will be used during the course of the monitoring process dedicated to the integrated roadmap and the integrated IP 17-19.

[10] http://gridplus.eu/publicationsandresults/public-deliverables, see deliverables 1.3 and 1.4.
[11] http://ses.jrc.ec.europa.eu/smart-grids-observatory
[12] Project name, period, stage of development, participants, participating countries, and a ranking according to 8 key functions: smart network management, integration of DER, integration of large scale RES, aggregation, smart customer and smart home, electric vehicles, smart metering, other.
[13] http://www.eranet-smartgridsplus.eu/

As for the *ERANet SG Plus* data base, the ENTSO-E data base will also be extended: projects financed by the TSOs without EU funding will be monitored if exhibiting a significant European added value.

The list of projects provided in the next sections is non-exhaustive. All projects with similar coverages and similar European added-value have not been listed: in such a case only one project has been chosen, most of the time the project which had the widest coverage (i.e. the best available proxy of the coverage of the topics listed for smart grids and storage projects).

4 Project monitoring for ENTSO-E's R&I topics

4.1 Topic 1-2016: fast storage needed by TSOs

4.1.1 State-of-the art

The need for fast large-scale storage facilities has been highlighted in several studies[14]. There are few technologies which can bring the needed services when reaching the GW scale, i.e. a ramp rate of several GW per hour: pumped-hydro storage (PHS) and yet to be demonstrated, compressed air energy storage (CAES) as well as power-to-gas if fast turbines (CCGT) are available. Large PHS units have not been designed to balance power variation generated by wind power plants, and their distance to the consumption sites often calls for the operation of HV overhead lines or cables. Both these issues have raise the following challenges: (i) to develop and install highly controllable hydro power plants (i.e. revamping existing units with variable speed machines)[15] and (ii) operating HV lines under real-time balancing power constraints with additional control mechanisms to stabilise the electrical system, cf. Topics 2-2016 and 3-2016. As far as CAES is concerned, there are currently two CAES units running in the world, Huntdorf in Germany operated since 1978 (290 MW and 2 hours discharge time) and McIntosh in the United States operated since 1991 (110 MW and 26 hours discharge time). CAES has two major limitations[16]: it relies on fossil fuels[17] and it is a diabatic process[18]. These two limitations can be simultaneously removed in a technology which is a variant of CAES, i.e. Adiabatic Air - CAES[19] (AA-CEAS). Additionally, there are major regulatory issues to be solved regarding the ownership and the exploitation of such storage installations, i.e. can regulated players (such as TSOs) operate such storage units?

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[14] See for instance http://www.agora-energiewende.org/topics/the-energiewende/detail-view/article/12-insights-on-the-energiewende/

[15] Which means rapid variations in flow and hydro reservoir levels, and therefore operation conditions of the hydropower system that may have adverse effects on the rotating machinery, the hydraulic structures, the dams and tunnels, and also rivers and reservoirs (these effects generate additional operational costs).

[16] Apart from the site limitation (caverns) as for PHS.

[17] Open Cycle or Combined Cycle Gas-Turbine (OCGT or CCGT) units, thus generating the emissions of greenhouse gases with a clear environmental impact during operation.

[18] Heat generated during the compression of air is lost in a heat-exchanger (cooler) whose function is to lower the storage temperature of the compressed air.

[19] In such a unit, compressed air as the working fluid is used to expand in an "air turbine" linked to a generator. Generated heat during compression is stored in a specific vessel and used during electricity production, i.e. air is heated before entering the turbine.

Some projects[20] have partially covered the above mentioned issues.

- **ADELE-ING** (Germany)[21]. Within the framework of the ADELE[22] project, researchers are further examining the techno-economic feasibility of the AA-CAES technology, focusing on three key components: turbo-machines (compressors operating at pressures over 100 bars with temperatures exceeding 600 °C), heat exchangers (heat accumulator operating at high internal pressures and temperatures and subject to stresses resulting from the cyclic pressure and temperature loads due to the storage and production cycles), and caverns. The ADELE-ING project aims at specifying a demonstration plant, so that an investment decision can be made at the end of the project (June 2016).
- STORE[23]. The stoRE project focused on storage technologies needed to facilitate the realization of the objectives for high penetration of variable and intermittent renewable energies in the European grid by 2020 and beyond, by unlocking the potential for (mainly) PHS and CAES technologies implementation. The consortium addressed environmental, regulatory and market issues at the European level and more specifically for six target countries (Ireland, Denmark, Germany, Austria, Spain and Greece). Recommendations for improving the regulatory and market frameworks were made, taking into account the input from a wide consultation process with all relevant stakeholders (these recommendations were discussed with decision makers helping to advance the on-going debate in Europe and the targeted member states about the future of the EU energy policy).
- **eStorage[24].** The eStorage project focusses on a full PHS variable speed technology (power regulation in both turbine and pumping modes): the eStorage consortium will demonstrate the feasibility of upgrading the variable speed technology, develop new IT systems for smarter grid management, put forward market and regulatory recommendations, and develop scenarios for the rollout across the EU. The full variable speed technology increases plant efficiency and flexibility; it also enables electric utilities to harness surplus power from intermittent sources to fill PHS plants' upper reservoirs faster, storing the surplus energy for later use when demand is high or when no wind energy is available. It is also expected that coupled with improved IT systems, variable speed technology would facilitate grid management for better real-time balancing of supply and demand.
- **Konvergenz Strom-Gasnetze KonStGas** (Germany)[25]. The coupling of the power system with the gas infrastructure, based on power-to-gas technologies, may offer great opportunities for an optimized overall energy system. This project examines the potential for RES integration when coupling electricity and gas grids. The optimization of the energy system is performed with and without coupling in order to appraise the influence of the coupling of the two networks and to assess the use of power-to-gas technology for the integration of the renewable energy sources (power-to-gas is also relevant for Topic ES08-2018, cf. section 7.8).

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[20] In the following, projects where the acronym is underlined are completed. On the contrary, projects for which the acronym is in bold text are on-going. When the project is not funded by the EC, the funding country is specified. H2020 projects have a "*" superscript.

[21] http://forschung-energiespeicher.info/projektschau/gesamtliste/projekt-einzelansicht//Druckluft_statt_Pumpspeicher/

[22] http://www.rwe.com/web/cms/mediablob/en/391748/data/364260/1/rwe-power-ag/innovations/Brochure-ADELE.pdf

[23] http://www.store-project.eu/en_GB/project-results

[24] http://www.estorage-project.eu/why-estorage/

[25] http://www.dbi-gruppe.de/konstgas.html

4.1.2 New knowledge to be generated

The analysis of the existing projects shows that there is a need for demonstrating the technical feasibility and the system integration of CAES and power-to-gas technologies (Topic ES08-2018, cf. section 7.8). There are also economic, regulatory, market and environmental aspects that must be addressed. When using highly responsive power and energy storage technologies at different voltage levels in the power system, novel solutions with ancillary services included in the storage facility must be provided (e.g. reactive power, voltage control, short circuit power and inertia). Finding the optimal size and location(s) of highly responsive power and energy storage devices for operation in transmission systems is still an issue, as well as regulatory aspects (who will own and/or operate storage facilities? What should be the investment incentives if any? Etc.)

New knowledge is therefore expected on the following sub-topics:

- Further feasibility studies of several technologies being able to support the power system with highly responsive power and energy storage;
- Pilot demonstration(s) of highly responsive power and energy storage integrated at transmission (HV) levels for balancing, congestion management and/or support with ancillary services;
- Analyses and recommendations for regulatory and economic impacts and opportunities for storage facility compared to other available flexibility solutions (for instance deferred investments for transmission grid reinforcements and lower social costs associated with high penetration of fluctuating renewable power generation);
- Address regulatory issues for assessing benefits/ costs of the ownership of storage devices by TSOs.

4.2 Topic 2-2016: control system of the future (real time tools for control centres)

4.2.1 State-of-the art

Pan-European transmission system security issues have become more challenging due to 1) the growing share of renewable electricity production (mainly at MV/LV level for wind and solar power), 2) the introduction of new controllable PE[26]-based devices (FACTS and DC components), 3) a partially controllable electricity demand 4) the increasing difficulty to build new overhead transmission lines and 5) the progressive construction of a single European electricity market (with the management of the associated cross-border links). This has resulted in more complex system operations and a grid working closer to its operational limits. Therefore, there is a need for a major revision of operational rules and procedures, which requires a new generation of tools allowing the different TSOs to operate efficiently in real-time and increase coordination at pan-European level. Several projects have partially addressed the issue of real-time tools for control centers.

- ANEMOS Plus[27]. A probabilistic approach to wind forecast was developed to deploy innovative tools to support the decision-making process for system operators. The ANEMOS Plus tool allowed TSOs to quantify their confidence in the forecast and the error size, resulting in a better assessment of additionally required reserves, and thus optimizing the reserves mobilized in the power market. The ANEMOS Plus tool was successfully tested by the Portuguese TSO (REN).
- PEGASE[28] New optimized algorithms for time-domain simulations of transmission networks were developed together with an improved state estimator. The results of

[26] PE: power electronics
[27] http://www.anemos-plus.eu/
[28] http://www.fp7-pegase.com/

the project were mainly used by the French TSO (RTE) to improve several tools and processes, for instance the EUROSTAG simulation software. The results of PEGASE have also been used in the iTesla project.

- **iTesla**[29] The iTESLA consortium is developing a toolbox to carry out operational dynamic simulations in the frame of a full probabilistic approach, thus optimizing the transit capacities of the grid at different spatial (national, regional, Pan-European) and time (two-day ahead, day-ahead, intra-day, real-time) scales, and going further that the current N-1 approach. The outputs of the iTesla toolbox will be relevant preventive and curative actions needed to keep the system in a secure state. These preventive or curative actions will include for instance generation redispatching, change in transformer tap position, topology of substations, set point values of HVDC lines or phase shift transformers, change in the maintenance scheduling, etc. The partners will deliver a validated prototype toolbox which could be industrialized after the end of the project (December 2015).
- **GARPUR**[30] The main objective of the project is to design, develop, assess and evaluate new system reliability criteria and management (beyond the current N-1 criterion) to be progressively implemented mainly in system operation over the next decades at a pan-European level, while maximizing social welfare. Different alternatives to improve reliability management of the pan-European power system are to be studied and validated by TSOs before being analysed with the help of a Quantification Platform. Pilot tests of the new proposed reliability criteria are to be performed by TSOs, using this quantification platform.

4.2.2 New knowledge to be generated

The above mentioned tools, especially the iTesla toolbox and the GARPUR Quantification Platform, are a first step towards innovative tools and methods to observe and control the pan-European network. There is a need to assess these tools in operations, and particularly to demonstrate the added value for dispatchers when operating the network in real time. As a consequence, more research is needed on the following sub-topics:

- Optimized man-machine interface in control rooms to synthesize information for operators when they are facing close to real time decision-making issues. These interfaces should allow easy navigation through large quantities of data and accelerate the decision-making process;
- Beyond the dynamic simulations of the iTesla toolbox and the associated preventive and corrective actions, further R&D work should be carried out so as to be able to quantify the adaption of parameters and setting points of the transmission system controls;

4.3 Topic 3-2016: monitoring and observation tools for power network infrastructures

4.3.1 State-of-the art

Topic 3-2016 goes hand in hand with Topic 2-2016: real time tools for control centres must rely on real-time data to characterize the dynamic behaviour of the transmission network and to strengthen asset management policies based on risk evaluations. The growing number of components (mainly PE-based) already installed, and to be rolled out in the transmission network, requires new sensors able to provide reliable information for control and decision making tools, e.g. monitoring systems for substation equipment

[29] http://www.itesla-project.eu/project. See also http://www.e-umbrella.eu/.
[30] http://www.garpur-project.eu/

(transformers, converters, breakers, etc.). In addition to the sensors, the already existing IT infrastructure must be strengthened to ensure a reliable data flow (the system must be uninterruptible and must withstand external threats, e.g. cyber security must be dealt with). Some projects have partially addressed this topic:

- EWIS[31] The project allowed to validate the wider use (several types of assets) of Dynamic Line Rating (DLR) applications for a secure operation of the network. National Grid (the British TSO) which had already used DLR on a few selected assets, extended it to several other transmission assets after the conclusions of the EWIS project. Other TSOs started to exploit the outputs of EWIS: TenneT TSO B.V. (the Dutch TSO) has begun to apply DLR to a few 150 kV lines with the aim of lowering dispatching costs.
- TWENTIES[32] (demonstration project 5, NETwork-enhanced FLEXibility -NETFLEX-) The Ampacimon[33] technology was used to monitor the OHL[34] transmission capacity in real time with a good accuracy. The real-time monitoring was enriched with ampacity forecasts up to two days ahead for low wind speeds (this was performed with a number of extraneous factors as well as local weather conditions). Statistical models and learning algorithms were used based on real line measurements: this substantially improved the dependability of the forecasts (two day-ahead ampacity forecast with a 98% confidence were achieved) and yielded an average 10 to 15% gain over static, seasonal ratings.
- TWENTIES (demonstration project 6, Improving the FLEXibility of the GRID -FLEXGRID-) An OPPC[35] conductor was used to monitor with a 2°C accuracy the temperature profile (2 meter spatial resolution) over a 30 kilometre long line (time resolution: 10 minutes). Six weather stations were installed in several towers along the route of the line to record fast changing weather conditions and therefore increase accuracy. This real-time monitoring of the conductors´ temperature allowed to increase the capacity of the OHL (15% more wind-generated was brought onto the transmission grid). The demonstration showed that by using the combined effect of DLR and power flow controlling devices to control the flows in the grid, more wind in-feed could be integrated in the existing grid without jeopardizing system security.

4.3.2 New knowledge to be generated

Most of the projects at hand show that known techniques (e.g. DLR) have been further validated in operation by the European TSOs to improve ampacity forecasts and to host a greater share of renewable electricity such as wind power. Today, European TSOs also use PMUs[36] mostly for analysis purposes and monitoring (to support operations). For instance, PMUs have been adopted to provide a high-sampling rate voltage and current phasors for Wide-Area Monitoring Systems (WAMS). However PMU data is not used for control purposes. New R&D work is needed to know if existing infrastructures of PMUs can support for example the real life closed-loop control when encountering stability issues during operations.

Many other research activities are needed to help TSOs monitor the network status either in operation or for maintenance and planning activities. New sensing techniques are needed

[31] http://www.wind-integration.eu/
[32] http://www.twenties-project.eu/
[33] http://www.wsl.be/fr/p/ampacimon (uses vibrations to assess the critical sag of overhead lines).
[34] OHL: overhead lines.
[35] OPPC: Optical Phase Conductor. It is a conventional conductor into which a beam of fiber optics is integrated, so as to measure the thermal behaviour over the complete line using a Distributed Temperature Sensor (DTS).
[36] PMU: Phasor Measurement Unit.

(with the proper IT infrastructures), e.g.:

- DLR for underground an submarine cables,
- Presence detection around critical infrastructure (such as substations).

4.4 Topic 1-2017: advanced tools for new market models

4.4.1 State-of-the art

An EU-wide target model (TM) is under deployment for EU electricity market integration across regions and more especially for the harmonisation of Capacity Allocation and Congestion Management (CACM) at EU level. The main issues of implementation of the TM have so far dealt with a flow-based (FB) transmission capacity allocation method, a European platform for the allocation and nomination of long-term transmission rights, a single European market coupling mechanism for day-ahead capacity allocation, the design of cross-border continuous trading for intraday capacity allocation and the development of cross-border balancing. This unbundling and liberalization of electricity markets in Europe have highlighted the need for a better understanding of the dynamics of these new markets so as to reach the highest possible efficiency in terms of social welfare while maintaining the technical performance of the European transmission and regional distribution networks. There is therefore a need for market simulation tools able to take into account the technical constraints identified in the transmission systems.

Some projects have partially addressed this topic, i.e. tools for simulating the dynamics of new electricity markets:

- OPTIMATE[37]. The main output of the OPTIMATE project is a tool allowing the numerical simulation (and comparison) of different wholesale electricity market designs for the integration of large share of RES. With the OPTIMATE platform, various market studies can be performed for the Western European power markets by modelling many market players' configurations (generation/load incumbents, generation portfolios, etc.) so as to evaluate different design options based on economic efficiency (energy prices, generation costs, etc.), climate policy (RES share of overall generation, CO_2 emissions, etc.) and security of supply (amount of tendered reserves, load shedding, etc.). The dynamics between players and over different control zones can also be appraised in terms of social welfare, consumer/generator surplus, and congestion revenue so as to detect possible issues when envisaging a new market design. With the OPTIMATE tool, ENTSO-E TSOs have now a shared software to assess market design issues.
- **Market4RES[38]**. Market4RES is a follow-up to OPTIMATE which investigates the potential evolution of the Target Model for integrating EU electricity markets. With a focus on wholesale market design, Market4RES aims to recommend the required steps for implementing policy, legislation and regulation across the different timeframes of the energy markets. One of the key objectives of the project is to facilitate dialogue between stakeholders concerning which steps are required to achieve the most economically sustainable market design.

4.4.2 New knowledge to be generated

The above mentioned projects have and are addressing some of the issues relative to new market designs. However, due to the fast evolving stochastic behaviour of generation patterns (liberalized market with massive variable renewable energy integration) and as a consequence cross-border flows, innovative capacity calculation methods including short

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[37] http://www.optimate-platform.eu/.
[38] http://market4res.eu/.

term adequacy are still needed to allow accurate forecast of available capacities in transmission lines and cross-border interconnections so that they can be efficiently used (close to their physical limits) by the European market players. The modelling of market players' behaviour is also necessary to design adequate rules allowing for optimizing the overall system efficiency.

4.5 Topic 3-2017: market modelling and system adequacy assessment for long-term planning

4.5.1 State-of-the art

The rapid expansion of renewable electricity sources and demand-side management technologies is going to change the way transmission systems are designed and operated. Electricity should be transported over longer distances, across national borders, in order to connect renewable resources located far from the main European consumption areas. Active demand response services might also be controlled over large geographical areas, therefore involving many stakeholders under different regulatory regimes. A pan-European infrastructure is thus required to enable more power and data exchanges between the different stakeholders of the power system, in order to comply with these new constraints including the progressive construction of a single European electricity market. The deployment of such a pan-European infrastructure must be supported by innovative planning tools able to account for all technical, economic and social constraints when making long-term investment decisions.

One on-going project partially covers Topic 3-2017:

- **e-Highway2050**[39]. The project aims at developing a top-down methodology to support the planning of a pan-European Electricity Highways System (EHS) between 2020 and 2050. A new, multi-layered planning approach, including several steps has been introduced: scenarios (including power localization scenarios) and data base elaboration, simulation techniques to identify feasible and efficient pan-European grid architectures, and development of implementation routes from 2020 to 2050, proposed on the basis of extended cost/benefit analyses. These simulations and analyses have allowed identifying candidate grid architectures addressing the future challenges of power systems while maximizing European social welfare. The possibility to mathematically formalize such long-term planning methods is also investigated using enhanced optimization and advanced simulation tools.

4.5.2 New knowledge to be generated

The e-Highway2050 project has laid the foundations of new planning methods to help ENTSO-E TSOs carry out long-term studies, beyond the time horizon of the TYNDP exercise. Yet, many improvements remain to be performed so as to fully account for the technical, economic and social constraints governing planning decision-making:

- Interactions with other networks, i.e. gas and to some extent heat network, should be considered;
- Planning tools should be able to account for control issues, i.e. the possible grid architectures must be operated (with known control systems) and maintenance (asset management) must be ensured;
- Existing and future market constraints and the development of new services for the power system must be accounted for;
- The growing impact and the evolution of different technologies (PE-based devices,

[39] http://www.e-highway2050.eu/.

electric vehicles, storage, etc.) must also be accounted for;

- The use of enhanced optimization methods and advanced simulation tools must be further investigated following the preliminary work carried out in work package 8 of the e-Highway2050 project.

4.6 Concept 1-2018: data and information management for system operation and asset management

4.6.1 State-of-the art

The evolution of the electric system, i.e. from fully predictable centralized generation with stochastic load to some stochastic and dispersed generation (renewables) with some controllable consumption (active demand), requires a re-engineering of the power system. Novel ICT systems to be used by consumers, market players and regulated system operators are needed to support decision-making, for instance when TSOs are calling for balancing services or when aggregators are selling demand response services in the wholesale market. As a matter of fact, two distinctive types of ICT infrastructures will be needed: one allowing growing exchanges between market players (including consumers through aggregators) and another one dedicated to system operators with stringent requirements to ensure network security. The latter infrastructure must be built upon two ICT layers: one layer linking market players with system operators to ensure ancillary services and another layer linking the network components (hardware) with the control centres through sensors (cf. Topic 3-2016). This latter layer will also ensure TSO-DSO communications, cf. TSO/DSO Topic 1-2016.

As also highlighted in DSO Topic 1-2016, in order to manage the enormous volume of information generated throughout the above mentioned ICT infrastructures, novel data management methods will be needed. No TSO-driven big data processing projects have been found. There is however a newly funded (H2020 LCE-7-2014 call) CSA[40] that will partially addressed the topic:

- ***ENERGISE[41]**. The ENERGISE partners will conduct an analysis of different telecommunication infrastructure deployment options, as specified in the call, i.e. *whether to exploit as much as possible the telecommunication infrastructure and its future developments, or whether to develop specific telecommunication infrastructure to cover parts of the architecture.* The analysis will be based on a CBA with focus on both capital and operational costs (for all involved stakeholders), including business models.

4.6.2 New knowledge to be generated

TSOs are already managing a significant amount of data for operation purposes and the CIM[42] should help to standardize and accelerate data exchanges between TSOs. As explained above, this growing volume of information will require a new approach for data acquisition and data management (updates, storing/archiving and cleaning methodologies, data security).

Moreover, the data-mining techniques under development (cf. iTesla project) for dynamic simulations and security assessments will have to be extended to help system operators in decision-making processes for asset management purposes, both at the component and system level.

Further development of TSO/DSO interfaces are needed.

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[40] CSA : Coordination and Support Action

[41] www.project-energise.eu

[42] CIM: Common Information Model

4.7 Concept 2-2018: realisation of ultra-high voltage lines with partial underground cabling

4.7.1 State-of-the art

As outlined in Topic 3-2017, and in the recent TYNDP exercise released by ENTSO-E, new grid infrastructures are needed (both onshore and offshore) to connect renewable electricity sources with the main consumption centres over long distances. Due to the increasing public reluctance and stringent regulations (environmental impact studies for instance), building new OHL (new corridors) will be more and more difficult. As a consequence revamping techniques for existing corridors and improved cables technologies must be used. This is already the case in many countries, e.g. Germany where demonstrations have been implemented and in Denmark where most of the lines are build underground. Two dimensions are to be distinguished: (i) connecting offshore wind farms to the grid which will require the development of HV meshed DC networks (submarine cables and underground cables), (ii) connecting on shore renewable energy sources which will require revamping techniques and partial undergrounding solutions. Manufacturers are currently developing products, for instance AC and DC XLPE cables with higher capacities (voltage and intensities) but system integration remains to be demonstrated.

Few projects have addressed/are addressing these issues:

- **BestPaths**[43] (demonstration 1, HVDC links in offshore wind farms and offshore interconnections). Interactions between the converters in wind turbines and HVDC substations (full-bridge and half-bridge in different configurations) will be studied first with simulation tools to be developed and validated, and then in a real environment with real measurements from converter equipment in the testing facilities owned by SINTEF Energy Research in Norway. The results and lessons learned during the tests will be applied in a simulation of the East Anglia project - an area of 7.2 GW of wind capacity in the UK.
- **BestPaths** (demonstration 4, Innovative repowering of AC corridors). Several issues regarding the revamping of AC corridors will be dealt with: (i) analyze and model the ageing behaviour of existing HTLS[44] conductors, and determine the benefits of insulated cross-arms, (ii) validate all potentials for innovative design and field working processes, including retrofit process and live line working, (iii) development of a prototype DLR system based on low cost sensors. These studies should help implement improvement options of existing overhead lines, including safety issues during construction and operation (monitoring) of the AC lines.
- **BestPaths** (demonstration 5, Superconductor cables power up for DC grids). A prototype scale validation of the technical feasibility of integrating DC superconducting cable links (MgB_2 technology[45]) within an AC meshed network will be performed (a monopole cable system operating between 5 to 10 kA / 200-320 kV for a transmitted power of 1 to 3.2 GW and operating in helium). These technologies could offer solutions for densely populated, high load areas, without resistive losses, for instance medium voltage feeds for load centres in dense urban areas where the grid is often saturated, and existing infrastructure is ageing.

4.7.2 New knowledge to be generated

The BestPaths project partially address all technological and system integration issues which will allow the realisation of ultra-high voltage lines with partial underground cabling

[43] http://www.bestpaths-project.eu/.
[44] HTLS: high-temperature low-sag.
[45] Magnesium diboride.

in Europe. For example, new additional demonstrations are needed for validation of:

- Ultra-high voltage AC OHL solutions (500 kV and possibly 750 kV) including new conductors and new tower designs;
- XLPE DC cables up to ±500 kV for partial undergrounding solutions, including reduction losses, reduction of trench width, etc.

5 Project monitoring for TSO/DSO's R&I topics

5.1 Topic 1- 2016: demonstration of demand side management mechanisms at DSO level into TSO operations

Main functional objective: **TD2**.

5.1.1 State-of-the art

Real-time DSO-TSO data exchanges are still quite scarce. Furthermore, distribution system states and conditions (i.e. load, capacity, and voltage) are often not monitored. The reversal of power flows due to the massive integration of DER into distribution grids pushes to develop tools and procedures for the observability of the distribution system for transmission network management, through DSO-TSO communication interfaces and distribution system status information. The challenge is to aggregate data at DSO level in an accurate manner from short-term up to long-term time horizons so that services provided by DSOs to TSOs can be developed, such as ancillary services though demand response, storage (including EV charging), active and reactive power control of DER. The integration of demand side management (DSM) leans on the concept of real-time pricing (which has a long history in literature): it needs to be revisited to complement the work done by some projects.

Few projects have directly addressed the enhanced coordination between DSOs and TSOs, i.e. how DSOs could offer new services (support to frequency control for instance) to TSOs. As a matter of fact, some projects have addressed the access by TSOs to demand response bids through market mechanisms.

The following projects partially addressing DSO-Topic-2016 have been identified:

- **evolvDSO**[46] deals with the development and validation of methods and tools for network integration of distributed renewable resources. The objective of the project is to define future roles of DSOs and develop new tools and methods including new market architectures addressing the role of DSOs versus markets players and TSOs. Field tests will be carried out as well as laboratory tests in facilities that can replicate a real network including flexible DER such as wind generation, solar PV, electric vehicles and stationary storage. In particular, two tools are developed with respect to the DSO-TSO coordination domain. The Interval Constrained Power Flow, with the aim to estimate the flexibility range of a primary substation node in a certain period of the day. This information enables a characterization of the distribution network flexibility in the boundary between transmission and distribution systems based on the availability of flexibility and controllable resources connected to distribution network. A sequential OPF[47] tool with objective to define a set of optimal control actions for the flexible resources will be also be developed in order to uphold a pre-agreed active and reactive power profile at primary substations.

[46] http://www.evolvdso.eu/

[47] OPF: Optimal Power Flow.

- The SuSTAINABLE[48] consortium proposed a new operation paradigm, leveraging information from smart meters and short-term localized predictions to manage distribution systems in a more efficient and cost-effective way (large-scale deployment of variable distributed resources including storage, controllable loads, electrical vehicles, etc.) through simulation-based studies. A multi-objective decision-making scheme maximizes, among other, the ancillary services (balancing) to be provided to TSOs through a TVPP (Technical Virtual Power Plant).
- The **EcoGrid[49]** project deals with a large-scale demonstration of a real-time market place for distributed energy resources (DER) where ICT systems and innovative market solutions enable small-scale consumers (with heat appliances, such as heat pumps and electric hot water systems) to offer TSOs additional and more efficient balancing services. A demonstration in a real power system, with more than 50 % renewable energy, has been carried on the island of Bornholm in Denmark[50].
- The **INCREASE** consortium focuses on how to manage renewable energy sources in LV and MV networks, to provide ancillary services towards DSOs, but also TSOs, in particular voltage control and the provision of reserves. INCREASE also investigates the regulatory framework, grid code structure and ancillary market mechanisms. The INCREASE solutions are validated by lab tests, as well as in three field trials under real-life operations in distribution networks in Austria, Slovenia and the Netherlands.

5.1.2 New knowledge to be generated

For TSOs, the main added value of demand response[51] is the provision of balancing services during a few hundreds of hours per year, in a way similar to peak generation. Demand response has some limitations compared to peaking units. The very wide scope of demand response services to be covered needs to meet quite different technical requirements since different demand response contracts require different technical features. Demand response services should match with direct load control contracts which should be fast and available at very short notice (ancillary services such as balancing).

New knowledge which is still to be gained at European level is:

- studies of an adequate range of contracts to reflect the different consumer categories, and the related technological infrastructures and demand-response technologies to support the commercial products,
- a detailed understanding and appraisal of the role of DSOs which must be incentivized to facilitate or take up some demand response services and their coexistence to increase competition,
- how to practically address TSO-DSO collaboration (services, uses, purposes of the interaction, etc.),
- detailed analysis of the information that needs to be shared among DSOs and TSOs (data specifications meeting privacy and cyber-security constraints),
- specifications of the best means to interchange data (system-wide communication infrastructures and information integration capabilities).

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48 http://www.sustainableproject.eu/

49 http://www.eu-ecogrid.net/

50 The final evaluation of the results of the EcoGrid demonstration has not been finalized yet (August 2015).

51 Aggregated demand response for small customers (demand response for large industrial customers is operational for most European TSOs).

5.2 Topic 2-2017: improved defence and restoration plans

Main functional objectives: **TD4** and **TD5**.

5.2.1 State-of-the art

As mentioned in TSO Topic 2-2016, the pan-European transmission network is becoming more sensitive to disturbances, because it operates closer to its stability limits. Europe has experienced several blackouts due to cascading events which are not tackled by the normal online security procedures, since the probability of such events is very low and normal security procedures are focused on higher probability events. Consequences of a pan-European blackout are so huge that mitigation (defence and restoration plans) must be addressed aside available tools for operations[52]. These defence and restoration plans must account for the high share of distributed and intermittent renewable energies, but also other degrees of freedom such as storage technologies and active demand response.

Some projects partially cover TSO/DSO Topic 2-2017, i.e. they mainly address the possible contribution of DER.

- **iTesla**. In work package 6 of the project, a comprehensive work is ongoing so as 1) to assess the impact and effectiveness of existing defence plans in the context of the pan-European interconnected system and propose new elements in a pan-European defence plan and 2) to define a coordination methodology among TSO's to efficiently mitigate the impact of "blackout situations" at a pan-European level. There is a specific focus on the detection of weak points of existing defence plans in the pan-European grid, and also on recommendations for the integration of renewables and the use of PMUs in future pan-European defence plans (coordination between control centres of different TSOs).

No projects considering the use of active demand or storage in defence and restoration plans have been found.

5.2.2 New knowledge to be generated

The current SoA of defence and restoration plans shows that many research activities are needed, e.g.:

- To investigate the contribution of storage solution and active demand in defence plans;
- To investigate the role of storage solution for system restoration and its contribution to immediate system reserves;
- To propose operational procedures to involve DSOs in control zones with high share of DER (including storage), e.g. by investigating the role that microgrids and islanding capabilities could play.

6 Project monitoring for EDSO's R&I topics

6.1 Topic 1-2016: smart metering data processing

Main functional objective: **D10**.

No real big data processing projects in the electricity sector have been found contrarily to the banking or telecommunication sectors where there is a significant experience. Some projects have partially addressed this topic:

[52] The low probability/high impact cases are not captured by the available online security assessment tools.

- **GRID4EU**[53] (demonstrator 2): the second demonstration will help to validate that the monitoring and control of LV distribution networks using Smart Grids and AMM[54] technology allow for anticipated future utilisation of distributed generation while improving customer power quality. The main objective is to utilise novel AMM technology in substations enabling (while relying on data from existing -and extended- AMR[55] technology), among other, network planning based on accurate power flow metering, high penetration of plug-in hybrid electric vehicles/electric vehicles (PHEV/EV), etc. The implementation/development of the AMM technology is integrated with advanced MDMS and SCADA/DMS[56] together with RTUs[57] in secondary substations.
- ***FLEXICIENCY**: the objective of the project is to accelerate the development of advanced monitoring, local control and flexibility services of aggregated consumers based on the availability of relevant metering data close to real time supported by standards for data exchange at EU level. DSO platforms will be further developed so as to provide smart metering data close to real time in a non-discriminatory way, together with advanced functionalities aimed at facilitating service provisions in the retail market. A virtual ICT environment, referred as EU Market Place, will be developed in the project to catalyze the interaction between relevant stakeholders at EU level. The architecture of the data exchanges, the formats as well as the communication protocols to be adopted, guaranteeing privacy, safety and security of data will be defined. The way data and information are exchanged will be specified in a standardized way in order to guarantee interoperability and service accessibility to all the players in the market and the entry of new players at EU level.

6.1.1 New knowledge to be generated

There is today a need to meet the challenge posed by the growing volume, velocity and variety of data in the electricity sector. Managing this large volume and velocity of data generated by short-interval reads of smart meter data can overwhelm existing IT infrastructures (for instance data storage costs could be very high due to increased data volumes and retention requirements if DSOs are using traditional database technologies). Additionally, report generation and analytics can become low due to high volumes since it may be difficult to load and analyse all of the information fast enough to support decision making.

As a consequence, scalable solutions to address large-scale data management issues in the electric distribution systems must be developed, which implies the standardisation of data models, methods and tools for data storage, data mining techniques, and data editing solutions. More Research is needed on:

- efficient systems to obtain information from different and disparate sources of data (standardization and interoperability, data privacy and cyber-security issues, etc.),
- novel data mining and data processing techniques (forecasting of generation and consumption -aggregation of consumer profiles-, availability of data for market players and customers),
- analysis of potential applications based on available data to improve the quality of electrical service or reliability of the electrical system.

[53] http://www.grid4eu.eu/
[54] Advanced Meter Management.
[55] Automatic Meter Reading.
[56] Meter Data Management System (MDMS) and Distribution Management System (DMS).
[57] Remote Terminal Units.

6.2 Topic 2-2017: network management tools

Main functional objective: **D9**.

6.2.1 State-of-the-art

Medium Voltage (MV) monitoring and control equipment as well as appropriated dispatching control software are becoming available. Recently, some efforts towards autonomous intelligence to manage locally the grid have been done in several projects[58]:

- The DG DemoNet Smart Grid (Austria)[59] project dealt with the control concepts for active network operation with a high share of distributed energy resources. In the rural medium voltage distribution network structures, typical for Austria, the increase of voltage through the feeding-in of distributed electricity generation plants is the most significant system limitation when integrating generation units. Voltage control concepts were developed in numerical simulation environments based on real network data (three different typical Austrian medium voltage networks). Two different solutions for voltage control in MV networks have been validated and successfully demonstrated (coordinated voltage control and distributed voltage control) on a test platform in two different medium voltage networks (Lungau in Salzburg and Großes Walsertal in Vorarlberg).
- **DISCERN**[60]: the target of DISCERN is to assess the optimal level of intelligence in the distribution MV/LV networks and to determine the replicable technological options (based on KPIs) that will allow a cost-effective and reliable enhancement of observability and controllability of the future distribution networks in Europe. These optimal technological solutions are tested and validated by means of real time simulations (e.g. Real Time Digital Simulator) and small-scale field tests. Recommendations for the cost-effective application of advanced distributed sensors, monitoring and control systems to increase the intelligence of electricity distribution networks based on KPIs will be formulated. Relevant standards will be mapped and a contribution to standardization activities will be ensured.
- **GRID4EU** (demonstrator 1): the first demonstration of GRID4EU deals with the better utilization of MV networks through the implementation of autonomous multi-agent systems for surveillance and automated control (autonomous working agents will be installed in a distributed way at critical locations in the grid). The agents communicate amongst each other as well as with sensors which can be e.g. smart meters, to figure out the current state of the MV network (the agents make their own decisions from available data, e.g. switch or adjust transformers or DER to operate the MV network in an optimized way). Decisions and commands of the agents are sent to a control center which fulfils surveillance purposes and which can overrule the agents' commands for safety reasons. The added value of the proposed agent system in comparison to a conventional system is their robustness and low need for maintenance since a central approach needs greater maintenance in case of system modifications.

6.2.2 New knowledge to be generated

The increasing share of renewables connected to distribution networks and energy efficient applications varying with real-time price signals has led to increased volatility in electricity generation and consumption, thus potentially stressing the distribution networks. To cope with these difficulties, specific DER and grid interfaces have to be developed. An ICT

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[58] This topic has also been partially covered in other projects such as **VENTEEA** (France), **evolvDSO**, Open Node, REServices, InovGrid (Portugal).
[59] http://www.ait.ac.at/departments/energy/smart-grids/smart-grids-projects/dg-demonet-smart-lv-grid/?L=1
[60] http://www.discern.eu/

infrastructure for monitoring and controlling DER will allow for instance the active control of DER. New functionalities for a more accurate grid control, enhancement of fault isolation time, automatic management of outages and special operations like transition to islanding or anti-islanding procedures should also be developed. An additional challenge is to prove through large-scale demonstrations and under real life condition, the potential of electricity storage (focusing on power and/or energy). Different small-scale storage technologies should be tested. Regulatory recommendations should be proposed so that network operators are given incentives to implement such technological solutions when appropriate, together with adapted communication infrastructure.

More research is needed on the following sub-topics:

- new optimal load flow calculation algorithms for distribution grids with distributed RES, storage and other new uses like EV,
- new methods for generation and consumption forecast
- new tools and methodologies for voltage regulation including the interface with RES generators together with suitable technologies (storage, SVCs[61], auto-transformers, etc.),
- active management and control using communication infrastructures at MV and LV level restricted in bandwidth and availability (resulting in new and cost-effective active low voltage network control solution approach enabling higher DER densities).

6.3 Topic 3-2017: integration of DER at MV/HV using novel technologies

Main functional objective: **D4**.

6.3.1 State-of-the-art

In rural medium voltage distribution network structures, the increase of voltage through the feeding-in of distributed electricity generation plants has turned out to be the most significant system limitation when integrating generation units. This is of paramount importance in distribution network operations since network operators are responsible for keeping the voltage within defined limits without having direct access to energy production units (due to the legal unbundling of electricity generation, trading and distribution).

More globally, the impacts of DER on distribution networks are mainly due to the possible reversal of power flows due to small DER units feeding in at medium voltage (MV) and low voltage (LV) levels of the network: maintaining power quality (e.g. by avoiding or mitigating harmonic distortion and power oscillations) has become a major challenge. Since the existing distribution grid was designed for unidirectional power flows, there is a limited capacity to integrate intermittent generation sources. The increased distribution grid hosting capacity for intermittent renewable energy sources requires active, real-time, large scale integrated management of distributed generation using novel technologies (including standards) allowing the implementation of active control. The following projects have partially addressed this topic[62]:

- The DG DemoNet Smart Grid (Austria) project dealing with active operation of medium voltage distribution networks with a high share of distributed generation has addressed the integration of already existing standards: IEC 60870-5-104 and IEC 60870-5-101 for telecontrol,; IEC 61968 for information exchanges (remote control commands based on XML-based messaging protocol defined by the CIM).

[61] Static Var Compensators.
[62] This topic has also been partially covered in other projects such as META-PV, INERTIA, eTelligence, **SINGULAR**, **SuSTAINABLE**

The implemented solutions are based on enhanced network monitoring and algorithms for active control of OLTC[63] at substation level as well as reactive power management at selected generation units based on the network monitoring.

- **IGREENGrid[64]** The main output will be a set of guidelines, consisting in a portfolio of accurate methodologies and tools for an appropriate integration of small and medium size variable renewable resources in distribution grids (both in MV and LV networks). Knowledge sharing as well as promotion of best of practices and initiatives will be implemented by identifying potential solutions for integration of distributed RES brought about in the individual demo projects and then validating them via a specific set of KPI developed within the project to evaluate the rest of network environments to assess the replicability and scalability at EU level. The following topics will be taken into consideration (non-exhaustive list): communication and control signals, intensive usage of ICT and impact of other technologies (storage, active demand, etc.).
- **GRID4EU** (demonstration 4): the fourth demonstration of GRID4EU, addressing MV networks, aims at realizing an advanced control system communicating with all the network relevant nodes (MV generators, HV/MV and MV/LV substations, and a storage facility), through an IP standard-based communication solution. The new system will allow, among other, to develop new procedures for managing efficiently and reliably generation units disconnection in the event of unwanted islanding, to test and assess the use of a storage facility for optimized network operations and energy management, and to enable the dispatching of the renewable generation on the MV network;
- **VENTEEA[65]** (France). Located in Champagne-Ardenne, and more precisely in Aube where there is the highest density of medium and high power wind farms in France, the project aims to study and test new solutions and products designed to adapt the distribution grid to wind production. For instance, in order to stabilize customer voltage levels, a 20kV/ 400-230V MV-LV transformer which automatically adapts low voltages in line with medium voltage variations has been installed. This transformer uses an innovative technology, patented by Schneider Electric, where real-time voltage adjustment, in accordance with the different generation sources is enabled. Moreover, a local voltage regulation enabling reactive power to be absorbed only when there is an actual constraint on the network has been developed and tested.

6.3.2 New knowledge to be generated

Specific DER and grid interfaces have to be developed in order to cope with the growing share of wind and solar generation. A dedicated ICT infrastructure for monitoring and control of RES will allow for the active control of DER. Cost effective solutions to increase the hosting capacity of existing grids, deferring reinforcements should be studied. The potential contribution and economical effectiveness of storage systems to distributed RES integration and grid reliability should be also addressed.

Up to now, there is little capacity to manage active elements connected to the distribution networks. In order to maximise the use of distributed generation units, these active components should be really integrated in the electricity distribution process through ICT. More research is needed on the following sub-topics:

- Market mechanisms for DER: new business opportunities should be explored in

[63] OLTC: on-load tap changer.
[64] http://www.igreengrid-fp7.eu/
[65] http://www.venteea.fr/

order to stimulate the participation of DER into power markets. New renewable energy support schemes based on market rules should also be further explored, to contribute to distribution grid reliability.

- Services provided by DER to the grid: different services could be further explored, such as ancillary services provided by DER.
- In addition to demand response and forecasting tools, energy storage can provide profitable solutions to balancing issues, as well as new options to address power quality and network losses management

6.4 Topic 4-2017: novel approach to asset management

Main functional objective: **D12.**

6.4.1 State-of-the-art

Few projects have directly addressed asset management issues relative to the new working conditions of equipment (which were not initially designed to withstand over several decades such operating conditions): intermittent generation (mainly wind power), mobile loads, distributed low power sources (PV power) do change the working conditions of existing assets. The following projects have partially addressed this topic:

- MBI (Italy). The MBI system implemented by TERNA on the *transmission network* processes the decision-making parameters and the technical conditions data (indicators of degradation) of critical components. Such parameters automatically come from the network remote control system, from on-line local sensors installed on the critical power HV equipment and as an outcome of the controls locally carried out on the components. The MBI system specifies the appropriate actions to be carried out by technicians at the right time, by highlighting their priority based on techno-economic risk analysis (the MBI system allows to switch from a time-based maintenance policy to a condition-based maintenance and at the same time to standardize the maintenance routines of the technicians). *As matters stand, distribution grids are less automated and the amount of installed sensors is much lower than on transmission grids. This why it has been difficult so far to design and roll-out MBI-like tools in distribution grids.*
- **evolvDSO** deals with the development and validation of methods and tools for network integration of distributed renewable resources. In work package three of the project (development of new methods and tools including simulations), a tool addressing asset renewal analysis is developed, i.e. new approaches for the maintenance of smart grids.
- **STAR** (Spain). Iberdrola is going to roll-out and upgrade smart meters after its initial pilot that began in 2010. The meters will be interoperable with the PRIME telecommunications protocol[66]. Asset management tools for maintenance, inventory, logbook of incidents, etc., of smart meters will also be developed for both MV and LV distribution grids (monitoring, automation and smart metering assets). Along with meters, transformers and automation assets will be upgraded in several regions of Spain.

6.4.2 New knowledge to be generated

Asset management is a major issue for DSOs which have the opportunity to completely review maintenance procedures when upgrading the distribution networks. New knowledge must be generated dealing with critical parameters that impact ageing of equipment and

[66] Iberdrola's power line communications open standard.

inspection methods relying on ICT techniques (completing the in-field inspection visits). More precisely the following sub-topics should be investigated:

- Observation of the real behaviour of equipment in the distribution network, combining new simulation techniques and new observation approaches (e.g. drones), with an on-site monitoring (sensors and robots for in-situ observation);
- Understanding equipment ageing by improving the feedback from existing pieces of equipment (cf. previous point), specifying and performing laboratory tests to qualify their real-life reliability, modelling and simulating ageing laws (including forecasting equipment ageing due to extreme events which cannot be reproduced experimentally);
- Developing decision making tools to optimise asset management for three time scales:
  - operation, to take into account the probability of failure of an equipment, and perform on-line the related risk analysis,
  - maintenance, to optimize maintenance and intervention plans relying on new IT systems,
  - network planning, to increase the life time of new pieces of equipment, without impacting the electric system safety, but also to prepare their replacement without impacting network operation.
- Optimise the electric system by proposing evolutions for maintenance policies of equipment (hardware and software), using new doctrines that reinforce the coherence between system operation, asset management and network planning (cf. point above).

6.5 Topic 5-2018: monitoring and control of LV networks

Main functional objective: **D7**.

6.5.1 State-of-the-art

Large European DSOs (e.g. Iberdrola in Spain, ERDF in France, ENEL in Italy and Vattenfall in Sweden) are developing and rolling out advanced monitoring and automation technologies in order to better monitor and operate their distribution networks. From the DSOs' point of view, the monitoring of the low voltage (LV) network is key regarding load-flow optimization at local level, faults detection, power quality and optimization of maintenance operations within a fast evolving environment (growing share of distributed generation). Some projects[67] have partially addressed this topics:

- **GRID4EU** (demonstrator 2, cf. Topic 2-2016): LV supervision systems for secondary substations able to provide transformer and LV feeders' status, automatic localization of smart meters have been developed. Reconfiguration possibilities in LV grid have also been tested;
- **GRID4EU** (demonstrator 3, cf. STAR project in Topic 5-2017 as well). Several monitoring and control solutions will be developed and tested at the LV level in this demonstrator: (i) automatic outage detection to sort alarms in order to support the dispatchers (control room) and the maintenance service, (ii) monitoring and automation of secondary substations in order to have remotely configurable, automatically accessible, and self-healing equipment;
- **GRID4EU** (demonstrator 5). The fifth demonstration is dealing with automation of LV grids within interconnected secondary substation configuration (simple mesh

[67] Topic 6-2018 is also partially addressed at national level (cf. for instance **GreenLys**, **NiceGrid** and **SoGrid** projects in France; DG DemoNet and **SGMS** projects in Austria, PRICE in Spain).

between two distribution substations), remote controlled circuit breakers located in secondary substations and in LV street cabinets. All these devices are controlled via a set of RTUs. Automatic balance during island operation will be implemented so as to test the capability to ensure sufficient power supply to the islanded area with the required quality of supply.

- ***UPGRID** (project starting at the time of writing) is dedicated to the improvement of power system observability, system tools to support LV/MV grid operations and advancements in Advanced Metering Infrastructures (AMI) and in-home systems, with focus on power quality and outage management.
- **DISCERN** (cf. Topic 3-2017).

6.5.2 New knowledge to be generated

As mentioned above, the modernization of the distribution grid is an ongoing process that currently requires further development such as cost effective new management methodologies and control methods. European LV networks are still often managed with a coarse-grained monitoring of power and voltage in MV/LV transformers, a rather poor knowledge of topology, and few tools for decision-making support, even though some major DSOs have started to equip their distribution network with TSO-like monitoring and control equipment (cf. projects above). As a consequence, further research is need in order to:

- Use AMM as an operational component in the LV automation architecture for instance in islanded zones;
- Find the most cost-effective automation level (semi-automated versus fully automated LV network) with data protection and cyber security approaches, adapted protection schemes and use of decentralize storage (prosumer storage).

These developments will lead to full distribution network flexibility to integrate distributed RES (supported by new actors such as storage operators or others) and will allow risk reduction when managing distribution grids.

6.6 Topic 6-2018: novel approaches for market design addressing new grid operations

Main functional objective: **D13**.

6.6.1 State-of-the-art

The fast evolving environment of distribution networks, both in terms of technical and regulatory challenges, calls for new market design(s), for instance for the management of active demand by DSOs and ancillary services provided by DSOs to TSOs, both including the possible use of storage devices. Some projects have partially addressed the market design topic for new distribution grid operations, e.g.:

- <u>ADDRESS</u>: the main goal of the project was to enable the active participation (i.e. active demand, AD) of domestic and small commercial consumers to electricity system markets and the provision of services to the different market players. A comprehensive technical and commercial architecture has been tested (for instance interfaces between customers and the aggregator, i.e. an aggregator toolbox linked with energy boxes installed in the customers' premises). Several functionalities were implemented in the aggregator toolbox such as consumer's consumption and flexibility forecasting, market forecasting, market and consumer portfolio management, operational optimisation as well as settlement and billing.
- <u>LINEAR</u> (Belgium). The LINEAR project dealt with the design of a demand response architecture supporting multiple aggregators and multiple energy management

system providers as well as the development and integration of smart grid ready appliances. The field trails covered 240 families, 460 remote controlled appliances and four business cases: day ahead portfolio management, intraday wind balancing, decrease transformer ageing and line voltage control. Two remuneration models were tested as well as the impact from retailer business cases on the local grid and the impact from local grid control on the retailers' portfolio.

- **evolvDSO**. By means of a role model, the potential (evolving and new) future roles envisioned at distribution system level have been identified by the project. This set of roles allows for an optimal management of flexibilities connected at distribution system level. By adopting these roles the DSO will facilitate and support current and potential new energy markets in the smart grid environment. Moreover, this model opens the way for the DSOs towards the possibility to contract and activate flexibilities at different timeframes to solve specific network constraints and improve network planning and operational processes.

6.6.2 New knowledge to be generated

Many other projects have touched the issue of market design(s) when addressing new grid operations, many of them through simulations or limited (in terms of involved customers) field tests. As a consequence, new knowledge is still needed, including:

• a categorization method to take into account both the technical potential and the willingness of consumers to participate in the electricity market(s) (demand response) so as to allow DSOs to better control ancillary services from DER, island operation, etc.,

• studies of an adequate range of contracts to involve the above consumer categories, and of the related technological infrastructures and demand-response technologies to support the commercial products,

• a detailed understanding and appraisal of the role of intermediaries (market players such as aggregators) which must be incentivized to facilitate or take up some but not all demand response services and their coexistence to increase competition,

• new business models that demonstrate the profitability of demand response,

• and proposals to address non-technological barriers which still slow down demand response expansion (economic, regulatory and social barriers).

The focus for these new R&D sub-topics should be put on:

- new market models for demand response to make customers willing to accept alternative consumption schemes which allow different delivery patterns according to actual grid condition,
- new and different electricity generation schemes, including aggregators and storage systems, should be studied in order to allow DSOs to provide ancillary services to TSOs,
- business strategies and economical evaluation should be analysed to determine the viability of island operation in different countries and under different conditions throughout Europe.

6.7 Topic 7-2018: integration of infrastructure to host electrical vehicle

Main functional objective: **D6**.

6.7.1 State-of-the-art

Up to now, electro-mobility for private end-users has remained very limited. In case of massive roll-out of electrical vehicles, impacts on both the distribution and transmission networks must be carefully evaluated. For DSOs, the mitigation of impacts generated by the different charging options at LV (slow charge, boost charge, etc.) will be key when experiencing possible overloads and power quality problems. For EV-owners, the main issue is the availability of a pan-European network of charging points with standardized solutions (plugs, billing, etc.). Some projects have partially covered these sub-topics[68]:

- **COTEVOS[69]** - COTEVOS verifies the functionalities that different systems require to manage EV charging including the associated smart grid infrastructure. The consortium will address key issues such as the interactions between grid infrastructures and vehicles, and the operational reliability, while reducing the time-to-market of equipment, so that they will be available in line with the arrival of electric vehicles. For that purpose, a number of on-going demo projects will be used as a reference. In order to improve the electro-mobility adoption and the sustainability of the EV market segment, the long-term, overall goals of COTEVOS are: (i) to assess and improve the degree of interoperability of the pan-European charging services, (ii) to improve the conformance assessment cost and time, through the design of procedures and facilities, in agreement with standardization and industrial working groups, (iii) to facilitate a potential growth of customer acceptance of EVs, by reducing some known adoption barriers: availability of charging infrastructure, charging time, safety risk concerns and cost (beyond incentives policies) and (iv) to assess new systems and applications for the electricity grid in order to allow grid operators to host a larger penetration of EVs within their management procedures;
- Green eMotion[70]. Standardised, interoperable electro-mobility solutions have been proposed to allow convenient travel with electric vehicles (EV) throughout Europe. The Green eMotion consortium has specified a pan-European ICT architecture which ensures the involvement of all market participants and which allows open and convenient access for EV drivers to the charging infrastructure. The ICT systems of all participating companies are networked on a so-called marketplace. Value-added services like reserving a charging point or easy payment systems have been also proposed.
- MERGE[71]. The MERGE consortium has evaluated the impacts that EVs may have on the European electric grids from the perspective of planning, operation and market design. Concepts such as EV control and aggregation as VPP (virtual power plants) have been addressed, i.e. EV batteries as decentralized storage devices (V2G applications). Tools needed to assess the steady state and dynamic impact of a large roll-out of EVs on the grid have been specified, developed and applied. Economic impacts have also been quantified for the distribution grids. Recommendations regarding the best planning practices combined with the most efficient strategies for charging EV to be followed by the DSO have been put forward. Identification of regulatory issues regarding market design and network regulation to efficiently integrate electric vehicles in electricity grids has been performed.

6.7.2 New knowledge to be generated

As shown above, a lot of work has already been carried for the needed infrastructures and standards to roll-out electric vehicles. Further R&D activities are needed to quantify the EV-grid interactions, viz:

- Charging points and battery replacing stations have already been developed and

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[68] Some national projects have addressed specific topcs
[69] http://cotevos.eu/the-project/
[70] http://www.greenemotion-project.eu/
[71] http://www.ev-merge.eu/

tested. Novel control techniques in charging technologies (smart EV charging management) must also be developed and tested in order to optimise the integration of volatile power from renewable sources (solar and wind) by aggregating the EV power demand;

- As a consequence, smart load management approaches should be proposed since the intelligent integration of electric vehicles into the electricity network is strongly dependent on the individual patterns of mobility for each user, specific vehicle characteristics and the communication infrastructure that is used;
- The development of smart EV charging solutions, such as the centralized management of electric vehicle recharge stations from grid secondary substations, should be explored. Positive consequences of massive integration of EV could rely on several services provided by EV charging to the grid, such as a potential for load shaping and ancillary services. Adequate market mechanisms for V2G (vehicle-to-grid) could provide incentives to promote optimized EV charging. Developing and implementing tools and methods to analyse the consequences of the massive charging of electrical vehicles on operations, asset management and planning, should also be developed.
- The impact of the foreseen deployment of Electric Vehicles (EV) in Europe on distribution grids (possible overloads and power quality issues like harmonics, voltage profiles) could become an opportunity with appropriate rules and incentives promoting the possible services provided by EV charging to the grid. Short-, medium- and long-term plans for implementation of the adequate infrastructures are needed for the assessment, validation and certification of electro-mobility systems.

7 Project monitoring for EASE’s R&I topics

7.1 Topic ES01-2016: active demand at TSO level using centralized control –at DSO level) of small scale storage units for cross-border exchanges

7.1.1 State-of-the-art

The proposed topic addresses small scale storage devices which have reached TRL 8-9 and are already found widely in private households. Such devices are not only storage devices, but provide the owners with important services related to comfort and convenience. The projects mentioned below focus on batteries (and super capacitors) at relatively low TRL and include battery technology development. The goal of these projects is to allow more intermittent energy input to the electricity system – particularly when studying problems related to islands and microgrids.

The following projects that partially address Topic ES01-2016 have been identified:

- **GREEN2STORE**[72] (Germany) - Integrative usage of storage capacity in the ‘cloud’ for developing renewable energies (11/2012 – 10/2016). The project aims to ensure that a greater proportion of renewable energy generation can be integrated into the distribution networks by the integrative usage of local storage units centrally managed. Various stakeholders along the electricity value chain are involved so as to address technical, industrial, economic and regulatory issues. Demonstrations are taking place in Lower Saxony and Baden-Württemberg with a network of batteries managed through the cloud and used by different players.

[72] www.green2store.de

- ***NETFFICIENT**[73] - Energy and economic efficiency for today's smart communities through integrated multi-storage technologies (1/2015-12/2018). The project will deploy and demonstrate local storage technologies which have reached TRL 5-6 in a real grid, and will develop ICT tools to exploit the synergies between the storage units, the smart grid and the consumers. The real-life demonstrations will be implemented for different use cases (homes, buildings, and public lighting) in low voltage and medium voltage networks, and for a wide range of applications and functionalities. Viable business models will be defined for the use cases, and recommendations for possible changes in regulations will be made. The expected outcomes of the project are:
  - An energy management system to be used by the DSOs and the aggregators to manage the storage devices;
  - Control systems (renewable generation and storage systems) to integrate management and decision support tools (forecasting);
  - Innovative storage solutions, for instance HESS[74].
- ***TILOS**[75]: Technology Innovation for the Local Scale Optimum Integration of Battery Energy Storage (2/2015-1/2019). TILOS aims to demonstrate the optimal integration of local scale battery energy storage devices in small grids (islands) when performing multiple services. The main objective of the project is the development and operation of a prototype battery system based on the FIAMM[76] $NaNiCl_2$ technology, supplied with a real-environment smart grid control system and ensuring multiple tasks including micro grid energy management, maximization of RES penetration, grid stability, export of guaranteed energy, ancillary services to the main grid of Kos. The battery system will support both stand-alone and grid-connected operation, while proving its interoperability with the rest of the grid components, including demand side management aspects and distributed, residential heat storage in the form of domestic hot water.
- ***RealValue:** Realising Value from Local Electricity Markets with Smart Electric Thermal Storage Technology. The project deals with the development of SETS[77] Systems for demand side management. A cloud hosted aggregation platform will be developed to allow consumer engagement through development of aps and Internet of Things (IOT). The demonstrations, with more than 1250 homes in Germany, Ireland and Latvia (representing 8 MW of installed capacity) will show how local small-scale energy storage, optimised across the EU energy system with advanced ICT, could bring benefits to all market participants.

7.1.2 New knowledge to be generated

The above mentioned projects show a rather good coverage of Topic ES01-2016. However, new knowledge is still required:

- about intelligent control and operation of thousands of small-scale storage devices for use as ancillary services. RealValue should help understanding how consumers who own SETS will engage in business with grid operators/aggregators/BRPs[78] (i.e. which business models could be attractive for all parties?). Other small-scale storage devices could also be used with efficient ICT technologies to be developed accordingly;

[73] http://cordis.europa.eu/project/rcn/194443_en.html
[74] HESS: Hybrid Energy Storage System, for instance the hybrid use of Li-ion batteries and super capacitors. Second Life Electric Vehicle Batteries will also be considered.
[75] www.tiloshorizon.eu
[76] www.fiamm.com
[77] SETS: Smart Electric Thermal Storage.
[78] BRP: Balance Responsible Party.

- On a more general standpoint, new knowledge about consumer acceptance to engage in new business models is needed.

7.2 Topic ES02-2016: Role of storage system to optimally integrate RES in short-term markets

7.2.1 State-of-the art

Energy storage systems are very often considered for facilitating better integration of renewable energy sources from a technical point of view. The solutions include storage to enable more predictable, stable and reliable supply of energy, provide ancillary services and balancing capacity. However, the corresponding and required market designs as well as the corresponding regulations are far from being in place in Europe: today, market mechanisms and regulations are adapted to conventional power generation. Activities under the present topic will generate knowledge and point out challenges for designing market terms and regulating codes to allow a fair participation of energy storage systems in services for the future sustainable power system.

The following projects that partially address Topic ES02-2016 have been identified:

- **SOPRIS**[79] - Stochastic Optimal Planning for Renewable energy sources Integration in power Systems (5/2015–5/2018). The SOPRIS project aims to provide algorithms and tools for optimal scheduling decision in power systems in the presence of uncertainty while ensuring system reliability: stochastic and optimization based techniques to address the problem of unit commitment, reserve provision and energy scheduling both on the generation and the demand side will be developed, while taking the network and reliability constraints into account.
- ***ELSA**[80] - Energy Local Storage Advanced system (4/2015 – 4/2018). ELSA will implement and demonstrate an innovative solution integrating low-cost second-life EV Li-ion batteries and other direct and indirect storage options, including heat storage, demand-side management, as well as use of intermittent RES. The core idea is to consider Storage as a Service towards building and district managers for local energy management optimization, and towards DSO for enhanced network operations. ELSA will adapt, build upon, and integrate close-to-mature (TRL>=5) storage technologies and related ICT-based energy management systems for the management and control of local loads, generation and single or aggregated real or virtual storage resources, including demand response in buildings, districts and distribution grids.

7.2.2 New knowledge to be generated

Hardly any knowledge has been gathered about how energy storage systems can take part in e.g. ancillary and balancing service markets. Market conditions and frames must acknowledge the special features of storage technologies, for instance when considering remuneration schemes.

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[79] http://cordis.europa.eu/project/rcn/189926_en.html. FP7-PEOPLE-2013-IOF. Marie Curie Action: International Outgoing Fellowships for Career Development.

[80] http://cordis.europa.eu/project/rcn/194415_en.html

7.3 Topic ES03-2016: technology and market conditions allowing electricity storage units to provide ancillary services including in cross-border modes

7.3.1 State-of-the art

This topic focuses on (i) the identification and characterization of new technologies (assets) capable of providing energy services including cross-border issues and (ii) new energy market schemes to be developed in order to demonstrate the benefits of the new technologies at a pan-European level. Only few projects of the EASE data base (less than 10 out of 40+ European projects) address some aspects of Topic ES3-2016.

Some projects are devoted to H_2 technologies and Renewables integration for energy balancing services such as:

- **INGRID**[81] - High-capacity hydrogen-based green-energy storage solutions for grid balancing (7/201 – 6/2016) The INGRID project aims at demonstrating the effective usage of safe, high-density, solid-state hydrogen storage systems for power supply and demand balancing within active power distribution grids with high penetration of intermittent distributed generation (RES in particular). The INGRID project will be demonstrated through the design, deployment and the operation of a 39 MWh energy storage real life demonstrator located in Puglia, the Italian region with the largest RES portfolio. The hydrogen solid-storage systems with cutting-edge ICT-based active network control technologies will be used for balancing highly variable power supply and demand. This will also allow a seamless integration among different energy carriers (electricity, gas, heating systems).

- **DON QUICHOTE**[82] - Demonstration of new qualitative innovative concept of hydrogen out of wind turbine electricity (10/2012 – 09/2017). The project aims at the long-term demonstration of the readiness of combining renewable electricity and hydrogen. Emphasis will be put on analysis of regulations, standards, LCA, total cost of ownership and implementation ways all over Europe. The project objectives are to demonstrate 1) the technical and economic viability of hydrogen as large scale renewable energy storage solution 2) the commercial opportunity of connecting intermittent renewable electricity to transport applications (H_2 refuelling station), 3) grid balancing services using a fuel cell, 4) generate sufficient data for the exploitation of RE to H_2.

Other projects focus on small-scale storage for distribution network applications some related to the Smart Grid and microgrid concepts or for use in islands and remote communities:

- **Resilient**[83] - REnewable, Storage and ICTs, for Low carbon Intelligent Energy maNagemenT at district level (09/2012 – 08/2016). The RESILIENT project aims to design, develop, install and assess the energy and environmental benefits of a new integrated concept of interconnectivity between buildings, DER, grids and other networks at a district level. The RESILIENT approach combines different innovative technologies including smart ICT components, optimized energy generation (including RES) and storage technologies, all integrated to provide real-time accounts of energy demand and supply at a district level and assist in decision-making process. The proposed integrated concept has been first modelled and simulated for different typologies of buildings and different climates and then installed, monitored and evaluated in three pilot projects (including residential and non-residential buildings) in the UK, Belgium and Italy. These demonstrators are

[81] http://www.ingridproject.eu/
[82] http://www.don-quichote.eu
[83] www.resilient-project.eu/home

used to assess the energy and environmental benefits of the new integrated concept and also to validate models and technologies in order for the concept to be easily replicable throughout different climatic areas.

- **iLAND** (Belgium) - (2014/2021). Belgian officials are considering the construction of a massive new offshore hydroelectric energy storage project to help the country wean itself off nuclear power by 2025. iLand is an offshore island for energy storage, to be built on a sand bank off the Flemish coast in order to balance fluctuations on the electricity network which are caused, amongst others, by the wind parks. It will be used primarily to reconcile differences between forecasted and actual production and consumption. In the case of a power shortage, electricity is generated by letting water flow from the North Sea into the reservoir (a lock would be opened to let the sea water in), passing at the same through hydraulic turbines to generate electricity.
- **STORY** - Added value of STORage in distribution sYstems (5/2015 – 4/2020). The main objective of STORY is to show the added value storage in the low and medium voltage grid can bring for a flexible, secure and sustainable energy system. STORY presents eight different demonstration cases each with different local / small-scale storage concepts and technologies, covering industrial and residential environments to feed knowledge into the further analysis on large scale impact assessment and on market models, policy & regulation.
- **Life Factory Microgrid**[84]. Electric vehicles to grid, renewable generation and Zn-Br flow battery to storage in industry (07/2014 – 06/2017). Factory Microgrid is a demonstration project of the LIFE+ 2013 program, whose main objective is to demonstrate with the implementation of a full-scale industrial smartgrid that microgrids can become one of the most appropriate solutions for energy generation and management in factories willing to minimize their environmental impact. A novel technology of ZnBr flow batteries to store 500KWh of electricity is going to be tested at the Jofemar's industrial facilities in Peralta (Spain)[85].
- ***SENSIBLE**[86]**-**Storage ENabled SustaInable Energy for BuiLdings and communitiEs (01/2015 – 06-2018). The project SENSIBLE will demonstrate that the EU 2030 targets can be achieved on a local level by the intelligent integration of existing small-scale storage technologies (of TRL >= 5) into the local power distribution grid as well as into houses and commercial or industrial buildings. A wide range of available small-scale storage technologies, i.e. electro-chemical storage devices (batteries, supercaps); electro-mechanical storage devices (flywheels), and thermal storage devices (heat and cold storage devices; heating, ventilation and air-conditioning (HVAC) systems which, together with the building structure, form a thermal storage device), will be tested.

7.3.2 New knowledge to be generated

The main outcomes of the above mentioned projects are mainly demonstrations of the technical capabilities of energy storage technologies to provide energy balancing and power quality services locally. The extrapolation analysis at (transmission) grid level is not included and even though business models are to be developed in many cases, the impact analysis at national or trans-national (cross-border) level is not taken into account. More research should be carried out on the massive use of small-scale local energy storage devices (in micro and smart grids) to provide ancillary services at larger scale, i.e. in primary and secondary reserve markets.

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[84] www.factorymicrogrid.com/en/index.aspx
[85] http://www.jofemar.com/
[86] www.h2020-project-sensible.eu

7.4 Topic ES04-2017: Long-term network planning tools involving storage for capacity firming, active demand and investment deferral

7.4.1 State-of-the art

Existing network planning tools do not include the added value brought by energy storage (apart from existing PHS units or hydro generators) when studying new grid infrastructures. New knowledge is needed to include storage as an additional parameter in grid planning studies.

No projects have been identified by screening energy storage projects. For example, in the **e-Highway2050** project (cf. section 4), storage technologies have not been considered as a mean to envisage other grid architectures, i.e. how to spatially distribute storage devices so as to avoid for instance reinforcements and/or new corridors.

7.4.2 New knowledge to be generated

The future electricity networks are planned by use of system adequacy software and for the SoA studies by dynamic analyses able to simulate transient behaviour in detailed network areas (every node). To the best of our knowledge, cf. above, no planning tool is able to adequately include energy storage technologies as a component of flexibility. Planning simulation tools and planning methodologies must be provided to include storage options.

7.5 Topic ES05-2018: Electricity storage for defence and restoration plans

7.5.1 State-of-the art

Blackouts are extremely serious incidents in the electricity grid and can lead to incalculable damages and losses to society and the grid itself. Grid operators develop defence and restoration plans for in the first place preventing incidents from emerging and spreading to major parts of the grid and in the second place for restoring the system after the event. Activities under the proposed topic will provide new knowledge about the role of energy storage in the future grid defence and restoration plans.

No related ongoing projects have been identified by screening energy storage projects. The SoA today is to develop automatic tools accounting for the integration of renewables and distributed energy resources, and the use of time-synchronized measurements from PMUs (cf. **iTesla** project in section 4).

7.5.2 New knowledge to be generated

Electricity storage and defence plans include the application of a multitude of measures and actions to be taken depending on the type of collapse (e.g. voltage or frequency collapse and loss of synchronism): fast activation of active and reactive power, start of production units, load shedding, etc. Energy storage technologies can provide such important services, but are not currently included in simulation tools used for defence and restoration planning. Projects under the topic proposal will yield the lacking knowledge in terms of performance data, black start potential, cost effectiveness and regulatory as well as technical challenges, thus providing a sound basis for assessing the use of energy storage in defence and restoration plans.

7.6 Topic ES06-2017 Market design allowing storage system to join cross-border capacity markets

7.6.1 State-of-the art

Generation capacity sufficient to cover all demand in electricity peak demand situations is an issue of concern for the future supply security of Europe. Because of the ever increasing penetration of renewable energy sources in the generation mix, the operation time of traditional generation capacity (e.g. large CHPs or CCGTs) has dramatically decreased, leading to significant loss of revenues for such plants, which in turn results in a lack of investment in new dispatchable generation capacity required by the market in peak situations.

Energy storage systems are able to provide such capacity services and should be eligible to participate in upcoming capacity markets providing peak generation backup in critical cases. Activities under the present topic will generate new knowledge and propose mechanisms for the participation of storage systems in future capacity markets.

No related ongoing projects have been identified by screening energy storage projects.

7.6.2 New knowledge to be generated

New knowledge about how energy storage systems can take part in capacity markets is required. Market designs should take into account the specific features of storage technologies and a set of fair market mechanisms (remuneration schemes) should be studied accordingly.

7.7 Topic ES07-2016 P2X Storage involving the carbon intensive industrial sector (power, combined heat and power, process industries)

7.7.1 State-of-the art

The high shares of variable renewable energy sources fed into the European power system entail the need for large-scale energy storage to balance the production and consumption of large quantities of electricity during longer time periods. "P2X" concepts ("Power to X", where "X" is used for heat, fuel or gas) have been identified in the recent years as promising solutions for alternative large-scale energy storage solutions. Pilot scale demonstration projects on several "P2X" technologies are currently in development in the framework of European and national projects:

- **E-gas project**[87] (Germany). Audi intends to develop and test a pilot prototype for the production of methane as substitution of natural gas utilising electricity for hydrogen production and CO_2 from a biogas plant. With the Audi e-gas plant, car manufacturers could take a decisive step towards CO_2-neutral mobility because this power-to-gas technology links the electricity grid with the natural gas network.
- **MefCO$_2$ project -** Methanol fuel from CO_2[88] (12/2014–11/2018). The main aim of MefCO$_2$ is to develop an innovative green chemical production technology which contributes significantly to the European objectives of decreasing CO_2 emissions and increasing renewable energy usage. The overall concept underpinning the project lies in the utilisation of ordinarily emitted CO_2 and hydrogen, produced from redundant electrical energy, into a widely-useable chemical platform producing methanol. The technology is being designed in a modular intermediate-scale, with the aim of being able to adapt it to varying plant sizes and gas composition. The objective is the production of methanol from the utilisation of CO_2 captured from coal power plants and hydrogen produced from electricity. The key technology for the methanol production is also demonstrated in a small industrial scale in a methanol production plant in Iceland[89], while an upscale towards large industrial scale facilities has not been realised yet. In this framework the experience gained from these pilot projects is necessary for the proof of concept and the identification of the further development needs towards upscale of the technology and the

[87] http://www.audi.com/com/brand/en/vorsprung_durch_technik/content/2013/10/energy-turnaround-in-the-tank.html
[88] http://www.spire2030.eu/mefco2/
[89] www.carbonrecycling.is

realisation of the first of its kind industrial scale prototype.

7.7.2 New knowledge to be generated

Considerable development work incorporating technical and non-technical (regulatory, environmental, social) aspects has to be carried out for every future project foreseen as a first of its kind industrial scale demonstration. The industrial integration of the "P2X" technologies in power plants, chemical plants or steel mills is an extremely challenging task, requiring innovative approaches for the re-designing of processes and plants, which usually operate under constrained conditions.

7.8 Topic ES08-2018: System integration of seasonal/large scale storage of energy involving cross-border exchanges

7.8.1 State-of-the art

In principle, large-scale storage of energy could be ensured by any kind of storage technology, but attractive properties and costs make PHS the only large-scale storage technology commercially available today. Storage of energy in chemical form and large scale thermal energy storage are new technologies with large-scale energy storage potential, over long time periods, but both technologies require considerable developments to reach economic feasibility. Topic ES08-2018 aims to maintain a European leading position in large scale storage technologies and allow export of high-value advanced technology as well as sale of knowledge and licenses while at the same time securing creation of jobs in the EU member states.

Some above mentioned projects already address storage of electricity in chemical form (H_2, cf. **MefCO2**; **INGRID**; **DON QUICHOTE**) or by conversion into thermal energy (cf. electric thermal storage, cf. ***RealValue**, ***SENSIBLE**) which could potentially be used for large scale storage applications. There are other projects which partially cover Topic ES08-2018:

- **ANGUS+**[90] (Germany)- *Auswirkungen der Nutzung des Geologischen Untergrundes als thermischer, elektrischer oder stofflicher Speicher im Kontext der Energiewende - Dimensionierung, Risikoanalysen und Auswirkungsprognosen als Grundlagen einer zukünftigen Raumplanung des Untergrundes* (07/2012 – 06/2016). The purpose of the project is to map the potential of subsurface storage of gas (salt caverns, porous rocks, etc.) and heat (aquifers, etc.), in terms physical and chemical properties. Frist, data gathering from both literature surveys and experimental work is performed (thermal, hydraulic, mechanical and chemical properties in caverns including groundwater). Second, the data base is used to carry out numerical simulations (with tools developed by the project's partners) to map and quantify the storage potential. Then, for each identified site, energy storage options are further investigated. Suitable methods for the monitoring of environmental impacts will be derived from simulations.
- **Energiepark Mainz**[91] (Germany) - *Grid scale hydrogen energy storage* (10/2012-12/2016). The primary objective is the development, testing and application of innovative technologies for the large scale production of hydrogen by means of electrolysis powered by renewable energies. As for other projects, the Power2gas concept will be tested (refilling stations, connection to the natural gas network, etc.). The project should provide feedback on the techno-economic potential of such solutions.

[90] http://angusplus.de/de
[91] http://www.energiepark-mainz.de/

- **HELMETH**[92]- Integrated High-Temperature ELectrolysis and METHanation for Effective Power to Gas Conversion (4/2014 – 3/2017). The objective of the HELMETH project is the proof of concept of a highly efficient Power-to-Gas (P2G) technology with methane as a chemical storage and by thermally integrating high-temperature electrolysis (SOEC technology) with methanation. The HELMETH project will demonstrate that 1) the conversion of renewable electricity into a storable hydrocarbon by high-temperature electrolysis is a feasible option, and that 2) high temperature electrolysis and methanation can be coupled and thermally integrated towards highest conversion efficiencies by utilizing the process heat of the exothermal methanation reaction in the high temperature electrolysis process. The demonstration work will be supplemented by LCA, market and socioeconomic studies.
- **BioCat**[93] (Denmark) - Power to gas via biological catalysis. The overall objective of the project is to design, engineer, and construct a commercial-scale P2G facility and demonstrate its capabilities to provide energy storage services to the Danish energy system. The facility uses an advanced alkaline electrolyser and a biological methanation system to produce pipeline-grade renewable gas (CH_4) for injection and storage in a local gas distribution grid.
- **Power-to-gas (P2G) unit Falkenhagen**[94] (8/2013 -12/2015). The unit uses wind power to run electrolysis equipment that transforms water into by means of electrolysis hydrogen which is injected into the regional gas transmission system. The hydrogen becomes part of the natural gas mix and can be used in a variety of applications, including space heating, industrial processes, mobility, and power generation. For private households, the “WindGas” product can be obtained from the pilot plant as a mix of 90 % natural gas and 10 % regenerative hydrogen. The unit, which has a capacity of two megawatts, can produce 360 cubic meters of hydrogen per hour. Alkaline electrolysis is a tried-and-tested method and, in the first year of operation, more than 2 million kWh of hydrogen (“WindGas”) were fed into the grid. The unit uses proven technology. This makes the project well suited to serve as a platform for gathering technical and regulatory experience in the construction and operation of P2G storage units. This experience will represent an important step toward making P2G technology ready for the mass market.

There are other national projects (mainly in Germany) dealing with H_2-based P2G applications, e.g. **Konvergenz Strom-Gasnetze KonStGas**[95]**, Power-to-gas unit Falkenhagen**[96] and **WOMBAT**[97].

7.8.2 New knowledge to be generated

Many of the above mentioned P2G projects are still ongoing: there is a need for further research to assess the potential of the investigated P2G technologies for power-to-power applications for instance through the injection and storage of methane in gas distribution networks, to be used when needed in CHPs or CCGTs. Moreover, large-scale thermal storage (heating and cooling) should be investigated so as to provide seasonal thermal storage.

[92] http://www.helmeth.eu
[93] http://biocat-project.com/
[94] http://www.eon.com/en/media/news/press-releases/2014/9/1/eon-power-to-gas-pilot-unit-falkenhagen.html
[95] http://www.dbi-gruppe.de/konstgas.html
[96] http://www.eon.com/en/media/news/press-releases/2014/9/1/eon-power-to-gas-pilot-unit-falkenhagen.html
[97] http://www.energiesystemtechnik.iwes.fraunhofer.de/de/projekte/suche/laufende/wombat.html

8 Conclusions

The present monitoring exercise has shown that, for all TSO, TSO/DSO, DSO and storage topics, there is a partial coverage of the research activities specified in the integrated IP 16-18. For some storage topics (Topic ES04-2017 -Electricity storage for defence and restoration plans- and Topic ES05-2018 -Long-term network planning tools involving storage for capacity firming, active demand and investment deferral), there is no coverage at all.

Moreover, there are two main lessons learnt from the present monitoring exercise:

- It was difficult to have access to precise data regarding national projects, except for a few projects labelled in the EEGI data base or for projects where some members of the associations could provide detailed information;
- It was also difficult to obtain for each project both ex-ante and ex-post accurate estimations of the TRL of the outputs, and consequently the time to successful system integration.

Therefore, it was proposed to adopt the following strategy for the next monitoring exercise (integrated roadmap and integrated IP 17-19):

- Use the ERANet Smart Grids Plus network to have access to member states so as to reach a more in-depth data set regarding national projects with European added value. This will be performed by adapting the GRID+ EEGI labelling process;
- Use the ENTSO-E data base to identify projects financed by the TSOs without EU funding and exhibiting a significant European added value;
- Rely on expert views to use a proxy for estimations of the TRL of the outputs, and the time to successful system integration, i.e. an expert view on the percentage of coverage of the proposed topics (a measure of the coverage of the proposed topic by the identified projects).

9 Annex

Topic ES01-2016	Active demand at TSO level using centralised control (at DSO level) of small scale storage units for cross-border exchange										**Comments**
Coverage ratio		**0-10%**	**11-20%**	**21-30%**	**31-40%**	**41-50%**	**51-60%**	**61-70%**	**71-80%**	**81-90%**	**91-100%**	
GREEN2STORE[98] NETFFICIENT[99] TILOS[100] RealValue[101]							**X**					• RealValue is very close to the topic but it does not address the transmission level and cross-border issues. • Demonstrations of aggregated control systems on smart grid level/local • The projects do indeed study the control of decentralised units, but never the cross border exchanges.
Topic ES02-2016	Role of storage system to optimally integrate RES in short-term markets										**Comments**
Coverage ratio	**0-10%**	**11-20%**	**21-30%**	**31-40%**	**41-50%**	**51-60%**	**61-70%**	**71-80%**	**81-90%**	**91-100%**	
SOPRIS[102] ELSA[103]		**X**									• None of the projects include cross-border modes or the transmission grid issues • Focus on ancillary services on smart grid level (ESCO). Some specific advanced tools: SOPRIS will provide algorithms and tools for optimal decision making in power systems and, corrective control schemes. ELSA uses ICT-based energy management systems for the management and control of local loads, generation and single or aggregated real or virtual storage resources, including demand response. ELSA would rather fit in the previous category (ES01-2016).

98 www.green2store.de
99 http://cordis.europa.eu/project/rcn/194443_en.html
100 www.tiloshorizon.eu
101 http://cordis.europa.eu/project/rcn/196841_en.html
102 http://cordis.europa.eu/project/rcn/189926_en.html. FP7-PEOPLE-2013-IOF. Marie Curie Action: International Outgoing Fellowships for Career Development.
103 http://cordis.europa.eu/project/rcn/194415_en.html

Topic ES3-2016	Technology and market conditions allowing electricity storage units to provide ancillary services including in cross-border modes										**Comments**
Coverage ratio	***0-10%***	***11-20%***	***21-30%***	***31-40%***	***41-50%***	***51-60%***	***61-70%***	***71-80%***	***81-90%***	***91-100%***	
INGRID[104]		**X**									• Ingrid: cutting edge ICT based network control for balancing in high RES scenario (30-50%). • Don Quichote: regulation, codes and standards for wind to hydro (in D, B, G, I, Iceland) • Resilient: Virtual Power Plant demo's in 3 countries. • Story: local & small scale storage & ICT demos in 9 countries plus simulations to analyse the impact of large penetration of storage plus effect of policies and regulations to the business opportunities • Life factory microgrid will test and validate different management strategies depending on the application, generating 160,000 kWh/year free of greenhouse gases, • SENSIBLE: 3 demonstrators show how to connect the local storage capacity with the energy markets in a way that results in sustainable business models for small scale storage deployment, especially in buildings and communities. • Lots of valuable input but no integrated picture and no specific attention to cross border modes • "including in cross border modes" = None of the projects actually focus on ancillary services through storage.
DON QUICHOTE[105]											
Resilient[106]											
iLAND											
STORY[107]											
Life Factory Microgrid[108]											
SENSIBLE[109]											

[104] http://www.ingridproject.eu/
[105] http://www.don-quichote.eu
[106] www.resilient-project.eu/home
[107] http://cordis.europa.eu/project/rcn/194425_en.html
[108] www.factorymicrogrid.com/en/index.aspx
[109] www.h2020-project-sensible.eu

Topic ES07-2016	P2X Storage involving the carbon intensive industrial sector (power, combined heat and power, process industries)										**Comments**
Coverage ratio	**0-10%**	**11-20%**	**21-30%**	**31-40%**	**41-50%**	**51-60%**	**61-70%**	**71-80%**	**81-90%**	**91-100%**	
E-gas project[110]		**X**									• We included only 2 projects here, INGRID is also very related to this topic and some aspects are analysed too • Power to H2 is partly covered, not power to heat or power to cold.
$MefCO_2$ project[111]											
Topic ES8-2018	System integration of seasonal/large scale storage of energy involving cross-border exchanges										**Comments**
Coverage ratio	**0-10%**	**11-20%**	**21-30%**	**31-40%**	**41-50%**	**51-60%**	**61-70%**	**71-80%**	**81-90%**	**91-100%**	
ANGUS+[112]		**X**									• Only some Technical P2G routes (hydro, methanisation to SNG). Some attention to local business models/local grid bottle necks (more spin offs, no core element of research). Energiepark Mainz although rather small scale will develop an optimized trading strategy for the local net. Seems also possible they will do some modelling on national level. • Most of the projects only deal with the technological aspects, not the integration in the system.
Energiepark Mainz[113]											
HELMETH[114]											
BioCat[115]											
Power-to-gas (P2G) unit Falkenhagen[116]											

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110 http://www.audi.com/com/brand/en/vorsprung_durch_technik/content/2013/10/energy-turnaround-in-the-tank.html
111 http://www.spire2030.eu/mefco2/
112 http://angusplus.de/de
113 http://www.energiepark-mainz.de/
114 http://www.helmeth.eu
115 http://biocat-project.com/
116 http://www.eon.com/en/media/news/press-releases/2014/9/1/eon-power-to-gas-pilot-unit-falkenhagen.html