Strategic Energy Technology (SET) Plan

Towards an Integrated Roadmap: Research & Innovation Challenges and Needs of the EU Energy System

This document is an overview of the inputs from the stakeholders to the consultation in the framework of the development of the SET Plan Integrated Roadmap; it also includes comments and additional inputs from the SET Plan Steering Group, which endorsed it at its meeting of 13th November 2014.

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1. Introduction

1.1. Energy policy context

Energy has become one of the grand challenges that Europe is currently facing. The way that energy is produced and used has a major impact on our economy, environment and society as a whole; and, socially desirable and economic opportunities, which are emerging at an accelerating rate, can be harvested by integrating energy with other important enablers of our society such as ICT, the urban agenda, living and transport.

An evolving global and policy challenge

The EU energy bill for energy imports represents more than EUR 1 billion a day (around EUR 400 billion in 2013)[1]. Faced with volatile energy prices in the world market, European industries and consumers are spending an increasing share of their income on energy. In 2012, gas price for industrial consumers were about four times lower in the U.S. than in Europe[2]. At the same time, as recently confirmed by the International Panel on Climate Change (IPCC), global greenhouse gas (GHG) emissions have risen to unprecedented levels requiring rapid and major actions to keep global temperature change below 2°C relative to pre-industrial levels. This highlights the importance of decarbonisation of the energy system, which still relies by 80% on fossil fuels and produces 80% of all the Union's GHG emissions.

In addition, the recent geopolitical events remind us of the importance of security of energy supply as a key policy objective. Today, the EU imports 53% of the energy it consumes. Several Member States have a strong dependence on a single external supplier. This is particularly true for gas, but also applies to electricity for a small number of Member States. In this context, the exploitation of indigenous energy resource potential becomes increasingly important.

Moreover, the whole energy system needs to be better understood with the aim to improve its efficiency, by examining the interrelationships between its different parts as well as how different policy measures will work together, such as energy, environmental and climate policies; or measures implemented to reach climate targets and their implications on the energy markets. A greater understanding of the impact and consequences of energy policies, market developments and advancement of technologies is essential to ensure the transition towards a low-carbon and increasingly decentralised energy system.

The ambition of the Union to achieve a secure, competitive and sustainable energy system by the middle of the century has therefore become a matter of priority. Accordingly, the Commission put forward a proposal for an energy and climate policy framework up to 2030[3], in line with the objective of a competitive European economy and the long term GHG emission reduction of 80-95% by 2050 compared to 1990 levels. The European Council agreed on 23 October 2014 on a domestic greenhouse gas reduction target of at least 40% by 2030 compared to 1990 and set a target of at least 27% for renewable energy, binding at EU level, as well as an indicative target of energy savings by 2030, to be reviewed in 2020. The European Council underlined that a reformed, well-functioning ETS with an instrument to stabilise the market in line with the Commission's proposal will be the main instrument to achieve greenhouse gas emission reductions. A reliable and transparent governance system will be developed to help ensure that the EU meets its energy policy goals. This has been complemented by the recently adopted European Energy Security Strategy[4] to ensure that energy needs from households and companies are fulfilled at any location and time.

An energy revolution

The energy system in Europe is in a process of profound transformation: the growing share of renewable and decentralized generation, the progressive increase in energy efficiency along

[1] COM(2014) 330 final http://ec.europa.eu/energy/doc/20140528_energy_security_communication.pdf

[2] Energy challenges and policy - Commission contribution to the European Council of 22 May 2013

[3] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52014DC0015

[4] http://ec.europa.eu/energy/doc/20140528_energy_security_communication.pdf

the whole energy value chain, the increasing need for flexibility in the energy system, the emergence of the consumer as an active player in the energy system and the appearance of new network users are the main changes affecting the way in which energy producers, operators, regulators and consumers interact in an increasingly complex market.

Moderating energy demand as the foundation of the energy transition

Energy efficiency is an effective way for increasing security of supply as it significantly reduces fossil fuels imports, in particular gas, to which heating heavily relies upon. Analysis shows that every additional 1% in energy savings leads to a reduction of about 2.6% in gas imports[5]. In terms of sustainability, several energy efficiency measures, including those addressing behaviour of energy users are among the least-costly options for GHG abatement. Further, in terms of affordability (for households) and competitiveness (for the EU economy), tapping the large energy efficiency potential and moderating our energy demand will support the economy in several ways: it will increase productivity and economic output; positively affect the trade balance of the EU; support employment growth in the current economic environment; give more visibility to markets given their exposure to the volatility of energy prices; and lead to increased public budget revenues. Therefore, moderating energy demand should be the starting point for reducing EU energy dependency.

The need for diverse, reliable and cost-effective energy supply technologies

The qualities of the energy system are strongly linked to its energy supply. The Union and its Member States have set as a matter of priority the development of a diverse, reliable and cost-effective portfolio of energy supply technologies to meet the EU Climate and Energy Policy goals for 2020 and beyond. This requires exploiting further the vast untapped indigenous renewable energy potential, ensuring the safe operation of nuclear systems, utilising clean coal technologies and carbon capture, CO_2 utilisation and storage, as well as of unconventional hydrocarbons while providing solutions to respect environmental and climate imperatives at an affordable energy price. It is also important to mention that the development of fusion energy, in particular through the construction of the International Thermonuclear Experimental Reactor (ITER), has high potential in terms of contribution to the low carbon technologies albeit in the long run. The development of such a portfolio of energy supply technologies should be accompanied by a more innovative and interconnected energy market which will allow new business models to be developed and hence trigger the necessary private investments. These investments must also encompass the whole technology supply chain to reduce the EU dependence on imported technologies and create, in conjunction with the appropriate international collaboration framework, new market opportunities for EU industry at the global level.

An imperative for innovation

Transforming these substantial changes to the energy system in the medium to long term into an economic and industrial opportunity for Europe will not happen without further development and rollout of new solutions. Innovation is needed to further reduce primary energy demand, diversify and consolidate supply options (both external and indigenous) compatible with Member States energy mix choices, and to develop a flexible and integrated energy system, from energy supply to energy networks and demand. In addition, technological progress should be accompanied by the appearance of innovative business models and schemes that guarantee a fair reward of the services ensuring the adequate functioning of the system.

Towards a reinforced EU Research and Innovation response

Accordingly, following the adoption of the Communication on Energy Technologies and Innovation[6], and the Conclusions of the European Council of 22 May 2013, the European Commission has initiated an update of its EU's

[5] Source: Impact assessment on the Energy Efficiency Directive Review, European Commission, 2014

[6] http://ec.europa.eu/energy/technology/strategy/doc/comm_2013_0253_en.pdf

energy research and innovation (R&I) policy, the Strategic Energy Technology (SET) Plan, with the aim to strengthen and make it more effective to meeting its objectives.

1.2. Concept and methodology

This document presents an overview of the research and innovation(R&I) challenges and needs, the latter as proposed by stakeholders. It has been reviewed and complemented with comments from the SET Plan Steering Group. More than 150 stakeholders[7] were involved, representing the entire energy system, coming from the European energy technology platforms, sector associations, the research community, market actors and investors.

Four key ***Energy System Challenges*** for the entire energy system have been identified to meet the three overarching energy and climate policy objectives: ***Security of supply, Competitiveness and Sustainability***. These challenges are consistent with the various scenarios of the evolution of the European energy system in the medium and long term, as described in the EU Energy Roadmap 2050[8], as well as in national roadmaps and in other major European roadmaps and outlooks:

- *Active consumer[9] at the centre of the energy system:* Engaging consumers through better understanding, information and market transformation; and activating them through innovative technologies, products and services.
- *Demand focus - increasing energy efficiency across the energy system:* Increasing energy efficiency in buildings, in heating and cooling, in industry (including in energy intensive sectors) and services. This challenge should result in the development and market uptake of innovative energy efficient systems, technologies, products and services.
- *Systems optimisation:* Modernising the European electricity grid and establishing synergies between the various energy carriers and networks; unlocking the potential of energy storage and conversion of electricity to other energy carriers; providing the energy system with flexibility, demand response, security and cost-effectiveness; and developing and demonstrating holistic system optimisation at local/urban level.
- *Secure, cost-effective, clean and competitive supply:* Making renewable electricity and heating/cooling technologies competitive; enabling the decarbonisation and increased efficiency of energy supply in the fossil fuel-based power sector and energy intensive industry sectors; supporting safe and efficient operation of nuclear systems and development of innovative reactor concepts and sustainable solutions for the management of fissile materials and radioactive waste (both from fission and fusion systems); and developing sustainable biofuels, fuel cells and hydrogen and alternative fuels for the European transport fuel mix.
- *Cross-cutting aspects:* Developing innovative financing for energy efficiency and for energy supply; investing in education; and promoting socio-economics in support of policymaking.

For each ***Energy System Challenge***, a portfolio of key technological and non-technological solutions have been formulated by the Stakeholders as specific ***R&I actions***[10]***.*** Through a bottom-up process that lasted about a year (Sept 2013 - Oct 2014) the experts from various sectors provided insights on the main challenges in different areas and proposed the key R&I responses that need to be carried out to address those challenges***.*** The ***R&I actions*** are organised at programme level according to the following structure:

- ***Advanced research programme*** that describes actions for developing next generation of solutions, i.e. proposing and moving solutions from TRL 1/2 to TRL 4/5;
- ***Industrial research and demonstration programme*** that describes actions for developing and demonstrating short to

[7] http://setis.ec.europa.eu/set-plan-implementation/integrated-roadmap

[8] http://ec.europa.eu/energy/energy2020/roadmap/index_en.htm

[9] The 'Consumer' term represents households as well as public authorities, large and small enterprises

[10] A detailed description of the R&I Actions and the expected impact from each of these as developed by the stakeholders is provided in the Annexes

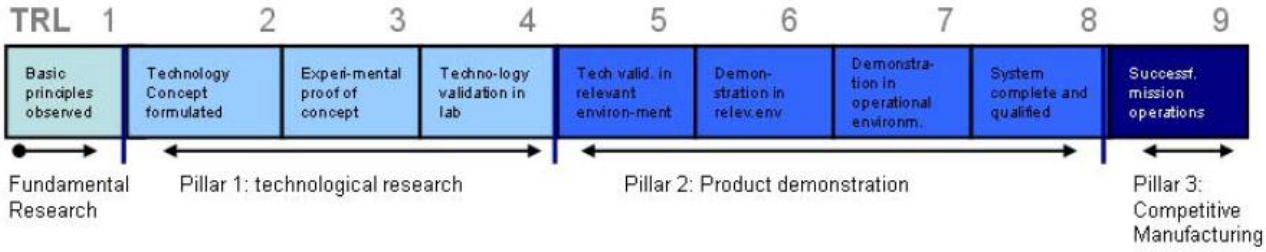
medium term solutions i.e. proposing and moving solutions from TRL 4/5 to TRL 6/7;

- ***Innovative and market uptake programme*** that describes actions for fostering the market roll-out of innovative solutions i.e. proposing and moving solutions from TRL 6/7 to TRL 8/9. It includes actions addressing the removal of regulatory, financial, market and behavioural barriers.

These actions have also been organised into ***Themes*** so as to correspond to the main challenges of the energy system identified above. Overall, 13 themes and 3 additional cross-cutting topics of different nature and scope, have been defined together with the Member States and stakeholders to cover the diversity of Member States' energy mix and national energy systems, as well as the variety of possible paths for the energy transition, taking into consideration associated uncertainties. Their combination allows the development of integrated solutions across the entire energy system, while allowing business initiatives to shape them according to evolving market conditions.

By design, the ***Themes*** enable synergies to take place between funding programmes at EU and national level while taking into account the regulatory framework such as the EU legislation in the field of energy and State Aid.

These themes and cross cutting topics provide the framework to develop an Action Plan promoting cooperation between Member States and the European Union in areas of common interest. The document can be regularly updated to adjust it to the evolution of the policy agenda, the energy system and technological advance.



Technology Readiness levels[11] - COM(2012) 341

[11]TRL: Technology Readiness Level (http://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf)

2. Energy system challenges

2.1. Integrated Challenge 1: Active consumer at the centre of the energy system

Theme 1	***Engaging consumers through better understanding, information and market transformation***
Theme 2	***Activating consumers through innovative technologies, products and services***

Introduction

The energy transition will not only require the implementation of technological solutions but also a change in consumer behaviour with respect to the uptake of energy efficiency solutions and the increasing use of renewable energy sources. Energy consumers, such as households, public authorities, large or small enterprises, should therefore be considered at the heart of the energy system and become active market players. They should benefit from the innovative technologies, services and products offered by the market.

In the last decade, the European energy policy has made considerable progress towards creating an integrated and liberalised internal market for both electricity and gas. The liberalisation of the market across Europe is expected to lead to a number of benefits for the European consumers including price competition, high standards of consumer protection as well as a better control of their energy consumption and costs.

With the increased share of renewables, consumers have an increasingly active role to play in bringing more flexibility to the market and in becoming prosumers. For instance, changes in their energy consumption patterns coming from energy efficiency or demand response solutions could provide such flexibility as well as a new opportunity to produce renewable energy at local level.

In this context, there is a need to directly engage consumers in the energy system through better understanding, information and market transformation. Innovative technologies, products and services should also help consumers and prosumers to actively manage their energy demand and supply.

Theme 1: Engaging consumers through better understanding, information and market transformation

Rationale

Energy consumers have traditionally been considered passive users rather than an influential part of the energy system[12]. A wide range of measures can be used to provide information to consumers and support their active engagement in the energy system. For instance, consumers could better understand and be motivated to adapt their consumption and production behaviour based on direct feedback coming from smart meters or in-home displays, indirect feedback from enhanced billing, advice, public engagement campaigns, capacity building actions or labelling schemes. There is also a need to better explain to them their new role, rights, obligations and opportunities.

The aim

Research is necessary to achieve a deeper understanding of consumers' behaviour, energy consumption and benefits of energy efficiency. These activities should help consumers take advantage of their new role and make better informed choices and purchases.

R&I actions are also necessary to help energy consumers benefit from relevant consumption data and information. This information should be tailored to each consumer in order to trigger a change in consumer behaviour and practices. Information and data should also be made available in a transparent, safe, efficient, trustworthy and user-friendly manner.

In addition, this needs to be complemented by an exchange of information (e.g. data sharing, transfer of good practices, capacity building) among market actors and by supporting the current and forthcoming energy policy in order to facilitate consumers' empowerment.

[12]COM(2013) 7243 final on Delivering the internal electricity market

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Advanced research:

- Develop theories and models of energy consumption behaviour and behaviour change in order to better understand how to engage energy consumers. They should include the re-examination of the barrier concept (e.g. related to the purchase of energy related products and systems), and analysis of policy applications and strategies to address specific groups of consumers.
- Assess the macro-economic impact of large scale deployment of energy efficiency while taking into account its multiple benefits for consumers.

Industrial research and demonstration:

- Analyse and share energy related information by compare user's consumption across neighbourhoods, cities and countries to increase consumers' engagement.

Innovation and market uptake:

- Support, develop and evaluate innovative engagement actions to help consumers benefit from their new active role and change their behaviour in their everyday life (e.g. capacity building, campaigns, sharing of good practices).
- Facilitate transparency and build trust, especially concerning energy data security and privacy.
- Set-up an EU energy poverty observatory to establish EU indicators and transfer good practices in support of vulnerable consumers.
- Enhance public procurement and cooperative procurement techniques to help public authorities and group of buyers make informed decisions and stimulate market transformation.
- Collect and disseminate good practices on consumer and prosumer aggregation and support activities for the removal of the related regulatory barriers.
- Further develop EU standards to help consumers become "active" with a minimum learning curve; foster the development and implementation of efficient monitoring systems; create the market for innovation and support consumers' empowerment through the implementation of relevant EU legislation.

Theme 2: Activating consumers through innovative technologies, products and services

Rationale

Important market changes have occurred in the past years with the emergence of smart meters, wireless sensors, small scale renewable energy systems, smart functions in appliances and their integration with Internet, home networks, smart energy infrastructures or local energy storage systems, setting the path towards smart systems. All these new technologies, products and services should help consumers better manage their energy demand (e.g. by detecting malfunctions or optimising intelligent control and automation) and energy supply.

The aim

R&I actions are needed to develop and deploy more intelligent and interoperable control systems and services (e.g. user friendly energy management systems, smart appliances) to enable consumers and prosumers becoming more energy efficient and active.

R&I actions are also needed to develop new business models putting customers at the core of value creation while using new and emerging technologies. Both demand side and supply side need to take the on-going market changes into account and adapt their business operations so to give a higher value to decentralisation of energy production, energy efficiency and energy efficient behaviour. The quality of the services provided needs to be ensured and be subject to minimum requirements, towards easy switching between contracts, services and service providers.

Furthermore, there is a need for social innovation so that the end-users themselves are stimulated to propose new solutions (e.g. services, products) to better manage their energy demand and supply.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Advanced research:

- Study how different technologies interact within networks of other technologies and practices.

Industrial research and demonstration:

- Study the disaggregation of energy consumption data and effective users' interfaces for e.g. smart meters, energy management systems while using relevant ICT solutions (web, mobile applications, etc.).
- Develop appropriate links between smart meters, in-home central energy management systems and/or smart appliances, including internet and data-sharing platforms.
- Complement on-going standardisation activities to support interoperability (open standardisation) across all interfaces between the smart grid and the end device that triggers energy consumption behavioural change.
- Develop and demonstrate solutions for effectively and sustainably integrating renewable solutions in the energy system and in the built environment at reasonable cost. These solutions should use new small-scale cost-effective renewable energy (electricity and gas) and heating and cooling systems, as well as smart management interfaces and operational approaches.
- Develop new technologies and systems tested and compared in real life situations to assess their performances (e.g. impact on energy efficiency behaviours), taking advantage of the data provided through ICT environment, smart meters, plugs, appliances or grids.

Innovation and market uptake:

- Develop new business models and contractual arrangements (e.g. integrating supply, demand flexibility and energy efficiency) that give a higher value to energy efficient and flexible behaviour, and recognize the role of smart energy-related appliances and systems. These activities should enable the market penetration of new services and innovative demand response solutions that are easy to install (plug and play), user-friendly and low cost.
- Encourage entrepreneurship within local communities for the development of specific new collective services and products based on local community needs.

2.2. Integrated Challenge 2: Demand focus – increasing energy efficiency across the energy system

Theme 3 ***Increasing energy efficiency in buildings***

Theme 4 ***Increasing energy efficiency in heating and cooling sector***

Theme 5 ***Increasing energy efficiency in industry and services***

Introduction

Meeting the EU energy efficiency target of 20% will result in 370 Mtoe primary energy savings per year in 2020 compared to business-as-usual projections (PRIMES 2007), while bringing multiple benefits[13] to the society and the economy. Furthermore an indicative target for 2030 at the EU level of at least 27% is set (with an option to review it having 30% in mind) for improving energy efficiency compared to projections of future energy consumption based on the current criteria.[14]

The EU has put in place a comprehensive regulatory framework on energy efficiency, based on the Eco-design (2009/125/EC) and Energy-labelling (2010/30/EU) directives inducing innovation in the area of energy-related products[15], the Energy performance of buildings directive (EPBD) (2010/31/EU) mandating buildings certification and the setting of requirements for nearly-zero energy buildings, and the Energy Efficiency directive (EED) (2012/27/EU) putting forward binding energy efficiency measures across the energy value chain including measures related to demand response. The implementation of this regulatory framework has to be strongly underpinned by research and innovation actions enabling faster penetration of innovative energy saving technologies and solutions to the market, as well as removal of persistent barriers to energy efficiency (mainly those of non-technological nature) and demand side flexibility.

Energy efficiency in transport has an important role to play to achieve the EU policy objectives of reducing energy consumption. This topic is not covered under this Integrated Challenge as it is already addressed in the self-standing transport research plan at European level[16]. Synergies between the SET Plan and the Transport Technology Plan will be promoted, in particular on those aspects relating to energy efficiency of vehicles (e.g. engine, fuels) and to refuelling/recharging infrastructures.

The scale of investment opportunity in the EU towards 2020 energy efficiency target is estimated to be around EUR 100 billion per year[17]. Therefore, R&I actions are needed to develop, demonstrate and roll-out innovative financing solutions and mechanisms, unlocking the stronger private capital participation. R&I actions on innovative energy efficiency financing are presented in the cross-cutting section.

Theme 3: Increasing energy efficiency in buildings

Rationale

Improving the energy performance of Europe's building stock is crucial. Buildings account for 40% of EU final energy demand and a third of the EU natural gas consumption, mainly for space heating and the supply of domestic hot water. The building sector, including both residential and non-residential buildings, provides the second largest untapped and cost-effective potential for energy savings after the energy sector itself[18]. Although energy consumption in existing buildings can be reduced by half or three quarters[19] using existing techniques and solutions, the renovation rate remains too low[20] (currently only at 1.2%/year[21]). Energy used in the manufacture of construction products and during the construction process also plays a major role in the overall environmental impact of a building. Finally, there are important co-

[13]Detailed analysis is provided in "The Multiple Benefits of Energy Efficiency: A guide to quantifying the value-added", IEA, 2014
[14]http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/145397.pdf
[15]Energy efficiency of products and systems, as promoted by the ecodesign and energy labelling Directives, and Energy Star, is also a key driver for innovation and competitiveness of European industry. The setting of minimum efficiency and labelling requirements is widely recognised as one of the most effective policy tools in the area of energy efficiency and is supported by industry as a cost-effective approach, safeguarding the internal market, spurring technological development and creating markets for top-class European products.
[16]*Strategic Transport Technology Plan, White paper 2011*http://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.htm
[17]Estimation based on the energy efficiency communication Impact Assessment, SWD (2014) 255 final.
[18]Eichhammer, W. et al.: Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries. 2009
[19]Energy Efficiency Plan 2011, COM(2011) 109
[20]EU Energy security strategy, 28/05/2014, COM(2014) 330 final
[21]Renovate Europe Campaign

benefits from making buildings more energy efficient, including job creation and retention, health improvements[22], better energy security, industrial competitiveness and fuel poverty alleviation.

The aim

Increasing the rate of existing buildings' renovation to at least 2-3% (the higher figure for the public sector) per year until 2030 is the key objective of this R&I agenda. To do this, it is necessary to reduce renovation costs, minimise disturbance for occupants and address specific barriers including socio-economic barriers and those linked to the building ownership structure. The degree of renovation should also be increased with (staged) deep renovations[23] aiming to achieve Nearly Zero Energy Buildings (NZEB) performance (minimum energy consumption reductions of 50-60% compared to pre-renovation levels).

Regarding new buildings, comprehensive R&I actions are needed to reduce the cost of high quality NZEB and broaden their applicability and market penetration while including non-price attributes which, building owners' value.

In addition, the existing qualification schemes, accreditation structures and training activities for professionals of the buildings sector will drive towards a more sustainable built environment (combining features of energy efficiency and on-site renewables). This objective needs to be fulfilled in conjunction with the entire supply chain from design to deployment of highly energy efficient buildings.

R&I actions also need to focus on coherent monitoring of the EU building stock, its renovation rate, energy performance, quality, impact of energy performance to real estate value, and other benefits from buildings renovation, such as externalities, reduced generation and system costs, impacts on health of inhabitants and job creation.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Advanced research:

- Develop new materials, products and processes for new and existing buildings enabling the integration of multi-functionality, energy efficiency and on-site renewables while taking into account their life cycle sustainability (e.g. cost-effective thermal energy storage materials, systems with intelligent control).
- Develop innovative building design concepts taking into account pre-fabrication of components and enabling the advanced ICT systems, technologies and solutions for "building-to-building" and "building-to-grid" interactions.

Industrial research and demonstration:

- Improve the viability and cost-effectiveness of mass manufactured, modular, “plug and play” components and systems for deep building renovation, as well as innovative insulation solutions, control, automation and monitoring tools including innovation needed during the construction phase.
- Develop and demonstrate energy efficient, interoperable, self-diagnostic and scalable storage, HVAC systems, lighting and energy solutions for buildings.

[22]Multiple benefits of investing in energy efficient renovation of buildings. Impact on Public Finances Copenhagen Economics, October 2012 (http://www.renovate-europe.eu/Multiple-Benefits-Study)

[23]In accordance with the Energy Efficiency Directive (see recital 16), cost-effective deep renovations lead to a refurbishment that reduces both the delivered and final energy consumption of a building by a significant percentage compared with the pre-renovation levels leading to a very high energy performance. Such deep renovations could also be carried out in stages. The Commission services have indicated (see SWD(2013) 143 final) that the significant efficiency improvements resulting from deep renovation are typically of more than 60% energy savings.

- Develop user friendly Building Energy Management Systems (BEMS) integrating in a single solution different energy efficient production/consumption sub-systems, while contributing to network security and flexibility. Develop self-learning and adaptive systems to significantly reduce the need for human intervention.
- Further develop innovative standards for operation and management of buildings using BEMS and/or metering data.
- Develop and demonstrate solutions improving roof and façade functional characteristics and enabling the building envelope to adapt to a dynamic, variable and complex environment. In this context, innovation exploring solutions to common problems – such as overheating, poor air quality and condensation – found in tighter and more insulated buildings need to be found.
- Develop new design tools to support the integrated design and the collaborative work between professionals, including the sharing of technical information on the building over its whole lifecycle.

Innovation and market uptake:

- Develop solutions to monitor and control the real energy performance of buildings through e.g. data collection and processing, energy performance standards, certification and labelling schemes, or advanced ICT and self-inspection techniques.
- Establish one-stop shops at local level to facilitate ambitious energy efficient renovation of buildings.
- Overcome the socio-economic barriers that restrict the up-take of deep energy renovation of the EU building stock as well as the administrative and standardisation barriers that hinder the implementation of energy efficiency solutions in buildings.
- Support co-operation among Member States in order to ensure best practice and knowledge sharing, supporting the implementation of the EU legislation (notably the renovation roadmaps stemming from the EED/EPBD and continuation of the EPBD and EED Concerted Actions with Member States).
- Support the exchange of good practices, promoting innovation[24], and monitoring the actual performance and quality of front-runners on the market.
- Develop and roll-out appropriate training, certification and accreditation schemes to continuously improve knowledge and skills of building professionals and increase the quality of constructions.
- Develop geo-cluster energy efficiency solutions for renovated and new buildings by identifying synergies among European regions.

Theme 4: Increasing energy efficiency in heating and cooling

Rationale

The heating and cooling sector constitutes around half of the EU final energy consumption[25]. Therefore, it has a central role in the EU's transition towards an energy efficient and decarbonized energy system, where consumers play an active role. Making heating and cooling energy efficient is one of the focuses of the Energy Efficiency Directive (27/2012/EU).

[24] e.g. through prize – based competitions (such as the Solar Decathlon Europe)
[25] http://www.rhc-platform.org

The aim

Increasing energy efficiency in heating and cooling in Europe requires specific R&I actions. There is a need to better identify, analyse, model, map and match efficient and low GHG emissions sources of heating and cooling supply with demand from all sectors (e.g. housing, industry). This activity needs to be done at the local, regional and national levels and be linked to the policy and regulatory framework and requirements. It is important that the technical and economical potentials of new, low GHG emissions and efficient supply sources for heating and cooling are assessed. At the same time it is necessary to increase capacity building and knowledge sharing for planning and integrating heating and cooling into the territorial context[26].

Cost effective technologies to increase efficiency in production, distribution and end-use of heating and cooling should be developed and demonstrated. More specifically, R&I actions should aim to develop modelling, metering, control and solutions that increase the operation, maintenance and overall energy efficiency of heating and cooling systems. As a result, R&I activities should accelerate the market penetration of new energy efficient heating and cooling products and systems.

Heating and cooling systems should progressively integrate and optimise various distributed low GHG emitting, efficient supply sources with flexible demand. R&I actions are therefore needed to develop and demonstrate new business models and enable optimisation through integration with other energy networks (e.g. electricity) and supply sources, including storage *(This need is also addressed under the Integrated Challenge 3)*.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Advanced research:

- Develop models able to forecast heating and cooling demand
- Develop innovative methods to further enhance heating and cooling maps [27] and integrate them with other types of maps and plans (e.g. CO_2 emission maps, urban planning and renewable sources availability analysis)
- Develop solutions that will enable the effective combinations of centralised and decentralised energy production using different energy sources.
- Further develop and improve fluids that combine energy transfer function with thermal energy storage.
- Increase the heat/cold storage density using phase change materials and thermochemical materials.
- Study alternative technologies (e.g. magnetic heating and refrigeration, thermoacoustic) using unconventional cycles.

Industrial research and demonstration:

- Increase the energy efficiency and reduce the cost of heat pump technologies, combined heat and power (CHP) solutions as well as thermal energy storage.
- Develop and demonstrate highly integrated and compact heating and cooling systems and sorption cooling systems driven by low temperature heat sources.

[26]The integration and optimisation of heating and cooling networks at the territorial dimension (e.g. district and city level) is also addressed under Challenge 3, Theme 3

[27]as required by the Energy Efficiency Directive (2012/27/EU)

- Develop and demonstrate systems with heating and cooling and domestic hot water including load forecast and control systems with fault detection, and their features (cost, user friendly elements, plug-in modular format) to enable mass scale deployment.
- Improve the energy efficiency of industrial and large-scale heat pump technologies with broader range of operating temperatures and higher temperature lifts.
- Support the use of fuel cells in CHP for residential, commercial, and industrial applications by reducing their costs, increasing their life-span and efficiency.
- Develop and demonstrate cost and energy efficient, environmentally friendly micro and small-scale CHP, as well as actions aiming to improve efficiency of turbines for CHP using low-temperature resources.
- Develop and demonstrate integrated control platforms for heating and cooling systems. These solutions should ensure the aggregation of various interlinked functionalities and data and allowing for effective "smart" feedback to the system.

Innovation and market uptake:

- Develop, test and deploy standards and benchmarks for assessing the efficiency of heating and cooling systems (e.g. using the low-exergy approach [28]). These should also cover the hydraulic and electrical interconnections for different components in medium and large hybrid systems.
- Support the development and market uptake of energy efficient heating and cooling solutions heat driven white goods, low temperature solutions for domestic hot water preparation and, heat pumps.
- Understand how regulatory frameworks for district heating can support optimisation of the system through planning, zoning, price controls, long term supply contacts, consumer protection, and metering & billing considerations.
- Capacity building and knowledge sharing across market players to ensure that innovative solutions will lead to stronger market uptake and better implementation of the EU legislation (in particular Article 14 of the Energy Efficiency directive). This includes the need for training and certification of heating/cooling professionals.

Theme 5: Increasing energy efficiency in industry and services[29]

Rationale

Enterprises are key drivers for growth and job creation. Altogether, the industry and service sectors represent 39.1% of the total EU final energy consumption[30]. Concerns about decreasing costs to improve competitiveness have prompted many industries to make energy efficiency improvements. In particular, large energy intensive industries (e.g. iron and steel, cement, chemicals, petrochemicals, glass, ceramics) have made substantial energy efficiency improvements over the last decades to decrease costs and improve competitiveness. However, possibilities to save energy remain in most enterprises including in SMEs, for which energy is not a major cost and, therefore, has not elicited so far management and operational focus. Surplus heat is still also produced in large quantities in many industrial processes. In addition, investment in research and innovation remains too low and as a result EU firms face higher energy prices than their international competitors[31].

[28] http://www.iea-ebc.org/fileadmin/user_upload/EBC_Annex_49_PSR.pdf
[29] Theme 5 covers all enterprises, large and SMEs, in both the industry and the services sector
[30] Source: Eurostat, May 2014
[31] EC COM(2014) 14 for a European Industrial Renaissance

The aim

There is a general need to modernise and reduce the carbon intensity of European industry by investing in innovation, resource efficiency, new technologies and skills. Cost effective energy efficiency improvements and solutions for demand side flexibility should be considered at the design phase of manufacturing processes while bearing in mind the complete factory/plant and the full product life-cycle. Since 20 to 50% of industrial energy input is generally lost e.g. in the form of hot exhaust gases, cooling water, or heat losses[32], it is necessary to improve heat recovery systems and increase their market uptake. In addition, industrial waste (e.g. heat, energy, raw material, fuel) needs to be re-used as valuable resources and further development are needed in the field of energy conversion technologies in order to improve global efficiency and process integration. Furthermore, optimization of the value chain should lead to the development and implementation of new business models (e.g. reusing, recycling or reprocessing companies).

In order to identify new ideas, transfer new technologies between sectors and reach a critical mass for the development of advanced and breakthrough technologies, companies need to engage into collective R&I approaches by transcending processes and sector boundaries. These collective approaches should also lead to better demand side management strategies through the clustering of e.g. factories and suppliers while in general, enterprises need to be better integrated in a modernised EU energy system.

Furthermore, there is a need to support the market deployment of innovative energy efficient practices and solutions by supporting the exchange of good practices and information, the wider utilization of adapted energy management systems and benchmarking tools, the development of replicable business models and the continuous improvement of skills for both decision makers and employees.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Advanced research:

- Develop the next generation of net-zero energy using appliances, products, processes and systems.

Industrial research and demonstration:

- Develop new and optimised technologies for energy recovery in industrial processes (including low temperature waste heat in industrial processes such as new refrigerants, CHP processes and distributed vs centralized systems).
- Develop new and optimised solutions for industrial waste, residues and resources re-use. (e.g. for cogeneration).
- Develop and demonstrate new industrial processes and components, as well as optimize existing ones while promoting a cross-sectorial approach. Cost reduction in industrial retrofit and upgrade should become a key innovation priority.
- Develop ICT-based solutions to increase energy efficiency in industry and services, including the development and demonstration of standard and open ICT systems for energy monitoring and control of energy consumption, advanced energy monitoring visualization techniques and tools (e.g. 3D techniques for data analysis), scalable Energy Management Systems (based on ISO50001 that can be applied at SME level - cross sectorial); create advanced predictable simulation and modelling solutions for the design and operation of manufacturing processes and systems.

[32]Source: IEA, IETS annex http://www.iea-iets.org/oslo/iea-iets.nsf/Attachments/47DF4BDBEA3A3AB5C12577DC0034B388/$FILE/Draft+Annex_ExcessHeatRecovery_oct+26.pdf

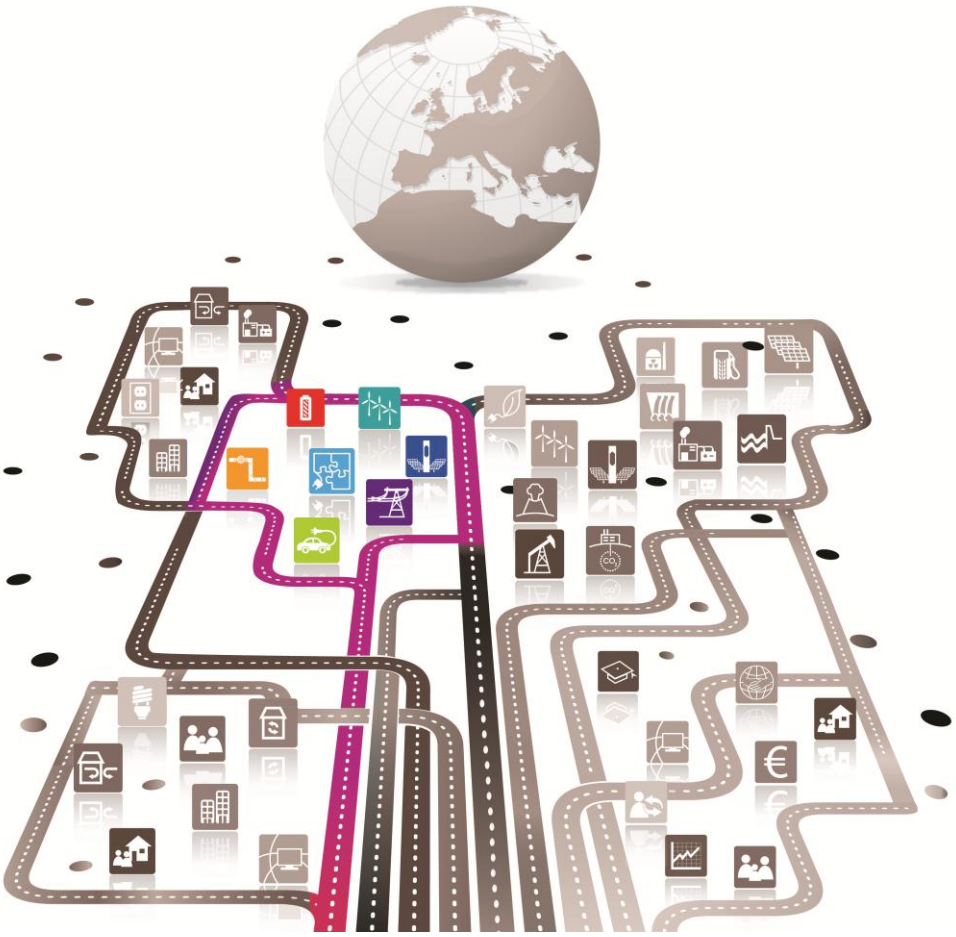
- Develop solutions for value chain optimisation through addressing energy efficiency considerations in the design phase of manufacturing equipment and processes, collective demand side strategies, and integration of the nearby renewable energy sources.
- Ensure inter-operability and connectivity of "smart" technologies used in industry and "smart" grids.

Innovation and market uptake:

- Deploy industrial symbiosis solutions and collective cross-sectorial actions to maximise the efficiency of industrial processes.
- Develop and roll-out methodologies and tools for cross-sectorial Life Cycle and Cost Assessment of energy efficiency solutions in industry.
- Support capacity building, training and exchange of good practices as regards energy efficiency solutions for factory/enterprise design, operation and maintenance, especially in sectors where there is a large untapped potential for energy saving (e.g. green data centres).
- Improve the "energy culture" of enterprises with specific R&I activities and trainings on behavioural change in order to facilitate better institutional investment decision making, and avoid sites being locked into sub-optimal technology.
- Roll–out benchmarking and target improvement programmes, advanced Energy Management Systems and develop a repository of best available technologies and sectorial good practices. Develop innovative energy efficiency services and business models for companies in industry and services, taking into account the whole range of enterprises within the whole energy system and the real impact of the energy efficiency measures on their competitiveness.

2.3. Integrated Challenge 3: System optimisation

Theme 6	***Modernising the European electricity grid and establishing synergies between the various energy networks***
Theme 7	***Unlocking the potential of energy storage and conversion of electricity to other energy carriers***
Theme 8	***Providing the energy system with flexibility, demand response, security and cost-effectiveness***
Theme 9	***Development and demonstration of holistic system optimisation at local/urban level (Smart Cities and Communities)***



Introduction

Renewable energy generation will increase its share of the energy mix in Europe following the 2020 and 2030 energy objectives of the Union, and will move to the centre of energy supply according to the Energy Roadmap 2050. Variable generation from wind and solar sources will contribute to most of the expected growth in terms of installed capacity, creating major challenges to balance supply and demand and requiring an active RES management, including through better forecasting of renewable generation. These challenges will be accentuated by the decentralized nature of energy generation from renewable sources, the emergence of distributed storage and new and potentially flexible demand, particularly related to the growing electrification of transportation.

The optimisation of the system and the balance between supply, conversion, transport and final use of energy, necessitates the development of new methodologies, technologies and solutions that ensure an efficient interaction between the various actors and components of the system, with a holistic approach that takes into account the potential synergies between the various energy networks (electricity, gas, oil, heat and mobility).

The optimisation of the system should be dealt both in terms of operations – in the short term-, through the development of adequate control and monitoring infrastructures and the integration of data and information networks, and in terms of planning and design of the energy system –in the long term- at European, regional, national and local (city) scale, enabling the optimal inter-connection and integration of different energy sources and consumption points, in view of the accomplishment of the Internal Energy Market.

Particular attention should be given to the development of the most promising options, such as smart grids, storage, active demand, synergies between energy carriers and flexible generation as well as the demonstration and replication of these options in real environments, in particular in urban areas. The optimisation of local energy systems through the deployment of low-carbon technologies in combination with ICT and transport networks will improve the energy and environmental performance of European cities and communities.

The development of smart technologies and the deployment of demand side response need to be accompanied with the creation of new business models and new strategies to allow and manage a growing number of participants in the system.

Theme 6: Modernising the European electricity grid and establishing synergies between the various energy networks

Rationale

The development of smarter and more integrated EU energy networks across both Member States and energy carriers is essential to ensure the security of supply and maintain high quality of services for customers. This is particularly important for electricity because, as shown in the Energy Roadmap 2050, electricity is expected to play a highly increased role in the energy system and in the end use sectors.

In April 2011 the European Commission adopted a Communication[33] highlighting the regulatory, standardisation and security aspects that need to be addressed to accelerate the deployment of smart grids in Europe as a key tool to manage the increasingly complex interactions between energy suppliers, grid users and consumers and to allow the latter to manage their consumption and to play a new role in energy efficiency and in the generation and storage of energy. The importance of smart grids is also

[33]Smart Grids: from innovation to deployment, SEC(2011) 463

reflected on the market and regulatory framework being developed under the Directive concerning common rules for the internal market in electricity[34].

The aim

The modernisation of the European electricity grid and an improved interaction between all actors operating in the grid (in particular of renewable energy sources operators) is essential for the decarbonisation of the energy sector by enabling energy savings along the system and facilitating the integration of centralised, decentralized generation and renewable energy sources, as well as electric vehicles and other new loads in the electricity system. Increasing the hosting capacity for renewable energy is essential to reduce curtailment and decrease the congestion of the electricity grid. The deployment of technologies aiming at a more secure and stable electricity grid requires that aspects related to compatibility and interoperability between Member States. It is also important to enhance network monitoring and DSO/TSO cooperation to increase system security and stability in presence of variable generation.

In addition, the enhancement of the interplay and synergies between electricity and other energy carriers - such as gas and local distributed heating systems- will contribute to the optimisation of investments for the energy system as a whole and contribute to its safety and flexibility. The promotion of these synergies necessitates the development of innovative methods and tools for integrated planning, development and operation of the various energy grids, to improve the performance of the conversion methods among energy carriers. This should be complemented with a comprehensive analysis of the whole energy system and of each of the energy networks with regards to the effects of substituting one type of energy supply by another.

Technology and market-based solutions need to be developed to enable the appearance of new actors, business models and services, to integrate the flexibility options from the various energy players in order to improve the quality of services and supply and achieve an optimal functioning of the electricity market, improving its overall competitiveness. The increase of the capacity, reliability and flexibility of the grid requires the development and the integration of innovative solutions using ICT, power electronics and new materials that contribute to the minimisation of the costs of expanding, upgrading, interconnecting, maintaining and operating the electricity grid. Special attention shall be paid to data privacy and security in the transmission and distribution system.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Advanced research:

- Develop new grid and market design and planning methodologies and novel grid topologies.
- Develop new tools to improve asset management and the operation of distribution and transmission grids; methodologies to enable scaling up of large scale demonstrations.
- Develop new technologies, innovative components and materials for electric power transmission and distribution, to eliminate technology gaps and push the technology limit in key components.

Industrial research and demonstration:

- Demonstrate interoperable power technologies and validate in real environments the active integration of renewables with centralised power generation, storage (including electric vehicles), considering also rural and isolated location electricity grids. This also includes multi-purpose projects (e.g. interconnector with a multi-terminal hub that could connect offshore wind).

[34]Directive 2009/72/EC

- Demonstrate asset management and operation tools and the new market designs mentioned above.
- Increase network monitoring, generation forecasting, monitoring and remote control, especially in presence of distributed energy sources, and DSO/TSO cooperation.

Innovation and market uptake:

- Develop scenarios and verified grid architecture options for long-term planning of grids.
- Develop new methodologies and integrate them in simulation platforms; investigate new market models to ensure that the projects demonstrating the various solutions can be scaled up and replicated, (including new business models for electric vehicles).
- Define open standard models to ensure interoperability in data exchange, promoting a greater cooperation with European technology manufacturers.
- Address the non-technological issues such as public acceptance of grid infrastructures and the acceptance of new market designs and products by all stakeholders; harmonise regulation and legal frameworks to contribute to speed up the deployment of new solutions.

Theme 7: Unlocking the potential of energy storage and conversion of electricity to other energy carriers

Rationale

Due to the increasing penetration of distributed electricity production from variable renewable energy sources, such as wind and sun in the European electricity grids and the consequent variations of supply, the need for additional hourly, daily and seasonal energy storage is expected to increase. The only large-scale storage technologies commercially available today are reservoir hydropower and pumped storage hydropower. However, there is potential for further development of hydro technologies and hydro planning concepts in order to meet the new challenges of the energy system and to deliver the necessary ancillary services and opportunities for new concepts, which should be investigated. A wide range of other energy storage solutions are under development, suitable for a variety of power ranges and energy storage capacities, each providing unique characteristics with respect to system flexibility[35].

As an important source for balancing the energy system, together with other options, the development of storage will become essential for the decarbonisation of the energy system as it will allow an active RES management and for a higher share of renewables by reducing the need for curtailment and minimising additional grid and balancing infrastructure investments while maintaining the stability and increasing the flexibility of energy system. At the same time, at end-user level, new stationary and mobile electricity storage capabilities combined with innovative energy management tools will provide customers with more options to optimize their consumption and lower costs and to unlock and sell their flexibility to the energy market.

Hydrogen needs to be considered in this context as it can provide a versatile storage solution to compensate the variability of renewables and underpin distributed electricity generation. A successful introduction of hydrogen into the European mobility sector, addressed in theme 13, could also act as a catalyst for large scale flexible hydrogen-based energy storage solutions at a European scale to facilitate the integration of renewables in the electricity system. Hydrogen offers a broad spectrum of potential applications of all storage technologies: from direct use in fuel cell vehicles, through small-scale grid-connected combined heat and power units for residential use, off-grid backup power systems that provide

[35] A comprehensive range of storage technologies and KPIs is in page 85 of annex II. The storage section in the annex II considers the diversity of energy storage in the most neutral way possible, covering all energy storage technology classes: Chemical, Electrical, Electrochemical, Mechanical and Thermal.

uninterruptible power supplies to critical infrastructure, to prime power for buildings and even to megawatt-scale grid-connected installations.

The aim

Storage is needed at different levels of quantity and time (day, week, season), from local to large scales and from slow to fast /charge/discharge/conversion in order to fulfil the needs in all scenarios imposed by the use of variable renewable sources. Most likely, this cannot be covered by one technology only but by a range of technologies, including the use of other energy vectors, and in combination with other sources of flexibility on the demand and the supply side.

While the first solutions are already available in the market, there are still significant technological and financial challenges that need to be addressed. The increasing variability of electricity supply, the lower predictability of demand and the volatility in energy prices, challenge the viability of the business case for energy storage and requires the development of new business models. Therefore, in addition to core issues such as lowering the cost of storage, market, regulatory, environmental and societal aspects need also to be addressed[36].

These storage technologies must also be deployed, integrated and managed in the frame of smart grids and even by a smart energy system approach, since synergies with other vectors and energy networks can be developed such as with heating and cooling, gas, electric vehicles and in a longer term, potentially hydrogen.

Special emphasis should be put on power-to-gas and other technologies allowing the storage and transport of large amounts of electricity from variable renewables over long distances. In view of the benefits that could offer to the energy system at large, it is necessary to assess the potential costs and benefits of various power-to-gas, power-to-liquid and gas-to-power concepts and to ensure that legal and market conditions enable its deployment, while promoting a stronger cooperation between gas and electricity transmission system operators.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Storage

Advanced research:

- Investigate and enhance the potential of a whole range of new materials, new concepts and new technologies for the next generation of storage devices and the integration of these devices in the energy system.
- Optimise further mature storage technologies to decrease their cost and minimise environmental impacts; maximise their capacity, operability and life, operational benefits and ease of use. This includes pumped hydro and cross sector technologies e.g. converting power to gas, fuel, chemical feedstock and heat and the possibilities for "virtual" energy storage.
- Develop standards and interfaces to insert storage technologies in the energy system and explore synergies with the grid and with demand side behaviour. Performance targets for a range of storage technologies up to 2020 to assess the progress beyond the state of the art are included in the annexes.

[36] http://ec.europa.eu/energy/infrastructure/doc/energy-storage/2013/energy_storage.pdf

Industrial research and demonstration:

- Develop modelling systems and planning concepts where the role of storage can be assessed and optimised at energy system level to ensure that storage technologies will be responding to the needs of the network.
- Demonstrate, as a precursor to deployment, storage technologies and taking into account its integration in the energy system in a representative environment, covering as much as possible the different roles of storage as well as different configurations and combinations.
- Improve and upscale manufacturing processes and develop recycling methods to ensure cost-effective deployment.
- Demonstration of integration of storage in the electricity system at several voltage levels, including low voltage, and development of solutions to provide various network/system services from storage.

Innovation and market uptake:

- Develop and adopt common standards to ensure a successful market introduction of storage solutions, allowing a Europe wide deployment.
- Demonstrate and evaluate the feasibility of the business cases (e.g. EVs second life batteries) and related system services, both for global and local market environments.
- Address social acceptance, environmental and safety issues; and carry out a full life cycle analysis in order to have the most efficient closed storage material loop.

Conversion of Electricity to Other Energy Carriers

Industrial research and demonstration:

- Develop and improve methods for the production of low-carbon hydrogen, especially from renewables, as well as for large scale hydrogen storage, re-electrification, distribution and system integration.
- Improve the efficiency and reduce the costs, in particular for electrolysers to improve the competitiveness of hydrogen-based solutions; demonstrate its flexibility at large scale to meet grid requirements; and study the needs of the electrical network to optimize centralized hydrogen production.
- Improve power to methane and power to methanol technologies, including development of catalysts for production of methane and methanol using CO2 as carbon source (links with theme 11)
- Explore rapid responsive chemical processes for valorisation of peak renewable electricity

Innovation and market uptake:

- Address important framework conditions such as regulations, codes and standards, business models and financial support schemes, required to foster widespread commercialisation of these technologies.

Theme 8: Providing the energy system with flexibility, security and cost-effectiveness

Rationale

In addition to the development of smart grids, the accommodation of more variable energy supply from renewable sources, including from remote sites with respect to consumption centres will require vastly

increased flexibility in the energy system. Providing this in a secure and economic way will need to be ensured by contributions from all possible sources in the energy system, such as demand response, flexible generation -including from renewable sources- and cross-energy vector coordination.

The aim

Flexibility solutions need to be further researched and demonstrated for system integration. New market arrangements need to be developed to facilitate the trade of different forms of flexibility services both locally and across national borders. They will require the development of market integration platforms and be linked with smart metering solutions. Fossil fuel power plants and renewable generation need to be adapted to the new realities of the energy system and to improve their flexibility and back-up capacities at appropriate economic conditions. Fluctuations of demand and production need to be integrated in time and space and across energy vectors, exploiting the potential of existing and future infrastructure. In this perspective emphasis has to be given to the security of critical infrastructures. Market frameworks, business models, standard products and services, skills and capacities need to be developed to nurture a speedy ramp-up of flexibility services in Europe.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Demand Response

Advanced research:

- Address user acceptance at industrial, commercial and residential level; develop tools for related market design, for modelling aggregated demand response, and for load forecasting.
- Address verification methodologies and the bases for ICT platforms linking with smart metering systems.

Industrial research and demonstration:

- Integrate demand response in the electricity system; develop integrated solutions to provide various system services from demand response.

Innovation and market uptake:

- Develop market frameworks and business models for the deployment of demand response, including for rural and isolated location electricity grids.
- Design measures and tools to reduce the costs of transactions and enable the participation of larger numbers of actors from a variety of sectors and sizes.

Flexible Generation

Advanced research:

- Devise solutions for increasing the flexibility of renewable power sources such as biomass, hydropower and geothermal, and tools to simulate the contribution of flexible generation to the power system.
- Develop virtual power plant approaches, such as those with small hydropower plants playing a major role.

Industrial research and demonstration:

- Integrate the flexibility from distributed energy sources (DER) conventional thermal and hydro power plants (which is complemented with actions addressed in theme 11 that aim to develop faster ramp rates, reduced start/stop times, reduce minimum load and improve efficiency at all load levels).

Innovation and market uptake:

- Develop models for the valuation of flexibility and market models for estimating rewards, in order to promote investment into flexibility.

Cross-Technology Options

Advanced research:

- Investigate the complementarities and benefits of closer coordination between electricity, gas and heating systems, and develop big data analysis and cyber security solutions for all energy networks.
- Explore the synergies and potential uses in energy applications of project results in research areas other than energy (e.g. ICT or security research), with a particular focus on the application to smart grids systems and components.

Industrial research and demonstration:

- Develop and demonstrate industrial-scale solutions to improve flexibility and storage, such as the integration of heating and cooling infrastructures with the electricity systems.
- Analyse the threats and vulnerabilities of critical infrastructures and propose innovative approaches to guarantee their security using the most appropriate techniques. This includes the demonstration of solutions for data analysis and cybersecurity.

Innovation and market uptake:

- Roll-out solutions for closer integration of energy networks (complemented by actions within the sub-theme on conversion of electricity to other energy carriers).

Theme 9: Development and demonstration of holistic system optimisation at local/urban level (Smart Cities and Communities)

Rationale

About three quarters of the population in Europe live in urban areas, which account for 70% of the EU's energy consumption and a similar share of greenhouse gas emissions. The role of cities in decarbonising Europe's economy will be even more important since urbanisation will keep rising in Europe, although at a slower pace than in other parts of the world. In order to promote the contribution of European cities in the energy system transition and improve their sustainability it is necessary to tackle in an integrated way the common challenges they are facing and to foster the active participation of the various stakeholders at local level.

In its Communication establishing the European Innovation Partnership on Smart Cities and Communities[37] (EIP SCC) the European Commission recognised the potential of cities for tackling climate change. The EIP

[37]COM(2012) 4701 final

SCC aims at bringing together local authorities, industry and citizens to accelerate the market rollout of sustainable innovative solutions integrating energy, ICT and transport. In 2013 the EIP SCC published its Strategic Implementation Plan[38] establishing the strategy and goals of the partnership, followed by an Operational Implementation Plan[39] to guide further implementation actions. Other EU-supported initiatives like the Covenant of Mayors[40] and the Civitas network[41] have already proven the benefits of creating synergies among cities to share best practices and to scale up new solutions.

The aim

Building on the existing initiatives, it is necessary to step up the efforts aimed at developing and demonstrating innovative low-carbon technologies and services that can be replicated in urban areas and to support the mechanisms that will enhance the market uptake of integrated solutions contributing to the optimisation of the energy system at city level.

It is necessary to foster innovation in the urban context to promote the sustainability of districts, more efficient use of energy and the integration of more renewable energy sources, using Smart Grids technologies, as well as enable innovative value added services for citizens and Public Administrations. Developing integrated infrastructures and processes at local level will contribute to the optimisation of the design, operation and use of the next generation of urban infrastructures and to enhance the links between energy, transport, telecommunications, lighting, water or waste systems and their networks.

An integrated approach and fostering the demand of less carbon/energy intensive transport solutions will promote sustainable transportation at local level. It is essential to support the diversification of fuels and fleets and to improve the energy performance and CO2 reduction of transportation systems notably by focusing on the roll-out of the e-mobility.

Finally, in order to enable cities to become smart cities, the governance models need to be adapted to ensure effective multi-level governance, enabling the interaction between all relevant stakeholders. Moreover, it is necessary to address the financing gaps and to ensure that relevant information is available for decision-making.

In addition, it is also necessary to address the specific needs of smaller communities and rural areas. While having similar challenges in terms of sustainability than those of cities, the scale and shape of these differ from densely populated areas, as well as the opportunities for generating energy from renewable sources, which generally are higher in a rural environment. This requires a specific approach to rural and off-grid / island communities.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Sustainable districts and built environment

Industrial research and demonstration:

- Develop new decision tools for local authorities on refurbishment of districts to near-zero energy levels, which need to be integrated in multi-criteria toolkits.
- Develop auditing tools and frameworks for policies on near zero energy districts & buildings and integrated modelling methods for refurbishment of districts, to increase the capacity of local authorities in planning and implementing renovation strategies.

[38] http://ec.europa.eu/eip/smartcities/files/sip_final_en.pdf
[39] http://ec.europa.eu/eip/smartcities/files/operational-implementation-plan-oip-v2_en.pdf
[40] http://www.covenantofmayors.eu/index_en.html
[41] http://www.civitas.eu/

- Develop solutions linking smart energy network applications and local storage at district level to buildings.

Innovation and market uptake:

- Validate digital platforms for city design and planning, to pilot the auditing frameworks developed, in order to enable their roll-out on a large scale, and to promote the integration of holistic zero energy district solutions and renovation projects in urban planning policies. In this regard, the regulatory aspect of data sharing must be addressed in order to define the different roles and tasks of different stakeholders to promote an effective and not discriminatory use of the data.

Networks of Infrastructures

Industrial research and demonstration:

- Develop and demonstrate technological solutions to increase the performance of existing urban infrastructures and enable new innovative services.
- Develop solutions to enhance the synergies between the various infrastructures as well as new communication solutions; demonstrate standardized and interoperable ICT real-time solutions as well as integrated metering solutions for the different networks.
- Integrate common electrical equipment and storage in different public transport network systems to optimize the infrastructures investments.

Innovation and market uptake:

- Optimize the costs of existing infrastructure and determine and demonstrate the value of integration across different infrastructures.

Integrated infrastructure-based services

Industrial research and demonstration:

- Develop tools for integrated infrastructure planning and new planning approaches for urban space used by the various networks.
- Deploy ICT-based tools, devices and interfaces enabling the citizens to be informed about infrastructure-based services and to provide information for the operation of local infrastructures.
- Create new architectures for integrated networks and new services, integrating information about customers' consumptions, in order to couple local energy sources and the various energy demands

Innovation and market uptake:

- Develop solutions and procedures to integrate public works and to foster common maintenance operations. Develop new business models to increase services based on common infrastructures.

Fuel and fleet diversification

Industrial research and demonstration:

- Demonstrate waste brake energy for batteries in buses and electro-mobility solutions for private and public transportation vehicles; foster the use of bio-based fuels.
- Develop infrastructure and operational solutions to foster zero emission harbours and airports.

Innovation and market uptake:

- Address the non-technological barriers hampering the deployment of electric passenger cars, hydrogen-based transport and other mobility options in cities.

Energy performance of transportation systems

Industrial research and demonstration:

- Develop interoperable infrastructures and data solutions for services and logistics and smart charging solutions for electric vehicles fully integrated into the electricity network.

Innovation and market uptake:

- Design strategies for consumer acceptance of new mobility patterns.

Governance

Industrial research and demonstration and innovation and market uptake:

- Establish platforms for intra-city cross-department collaboration; develop an evaluation and monitoring framework for local policies; and educational programmes on policy evaluation.

Funding and Financing

Innovation and market uptake:

- Establish city strategies and assistance services for local authorities to improve the quality of potential projects in view of ensuring funding; develop platforms and frameworks to ensure the applicability of new innovative financial instruments; and develop business models and other capacity building measures to support complex projects combining several funding options.

2.4. Integrated Challenge 4: Secure, cost-effective, clean and competitive supply

Theme 10	***Accelerating the development of renewable electricity and heating/cooling technologies***
Theme 11	***Enabling carbon capture, CO_2 utilisation and storage technologies and increased efficiency of the fossil fuel-based power sector and energy intensive industry***
Theme 12	***Supporting safe and efficient operation of nuclear systems, development of innovative reactor concepts and sustainable solutions for the management of fissile materials and radioactive waste***
Theme 13	***Developing sustainable biofuels, fuel cells and hydrogen and alternative fuels for the European transport fuel mix***

Introduction

The growing concern over security of supply means that the EU should tenaciously pursue a diverse, reliable and cost-effective supply portfolio, allowing Member States to have a wide choice of viable technologies from which to choose. This should be completed by significant investments to provide solutions to the unprecedented challenges of system integration that could otherwise severely curtail the on-going efforts to diversify Europe's energy supply. This includes fostering the flexibility of energy generation and also promoting a closer integration of different energy production, delivery and storage infrastructures. A more innovative and interconnected energy market that allows new business models will also be paramount to achieving a sustainable and integrated energy system.

Energy supply must be clean. The decarbonisation of electricity production is the centre-piece of the Energy Roadmap 2050. All scenarios studied in the Roadmap show that electricity will have to play a much greater role than now (almost doubling its share in final energy demand in 2050) and will have to contribute to the decarbonisation of transport and heating and cooling. To achieve this, the power generation system would have to undergo a structural change and achieve a significant level of decarbonisation.

Accordingly, clean energy supply will play a major role in the transformation of the energy system. The Union has already taken decisive actions to foster this transformation. EU energy policy supports a shift to low carbon generation technologies. Spurred by the Renewable Energy Directive and support in Member States, there has been a strong growth in renewables and significant reductions in cost. As part of the transition to a low carbon energy system, EU policy has promoted Carbon Capture and Storage (CCS) technologies and a safer nuclear energy generation. The recent proposals for a "European Energy Security Strategy" and a "2030 Climate and Energy policy framework" clearly emphasise the need to maximise the use of indigenous, cost-competitive and sustainable sources of energy. This includes natural gas as an important solution for the energy transition that will take place.

Finally, the EU's energy supply technologies must be competitive. Today, Europe is home to world leading companies that develop low-carbon technologies and services that are precisely the fruit of both its Climate and Energy policy Framework for 2020 and its investments in research and innovation. However this leading position is eroding. Investments must therefore encompass the whole technology supply chain, from materials (including critical raw materials) to manufacturing, ensuring that, whilst reducing EU energy dependence, the EU also secures that its dependence on technologies developed elsewhere is contained. Focused actions are hence required to build European industrial capacities to deliver supply chains that are resilient to global competition and fit for export markets.

Theme 10: Accelerating the development of renewable electricity and heating/cooling technologies

Rationale

The Energy Roadmap 2050 shows that renewable energy will move to the centre of the future energy mix in Europe, as one of the non-regret options, in all scenarios. The EU's rich indigenous renewable resources are also vital to efforts to significantly improve energy security. Today, avoided imported fuel costs due to the increasing use of renewable energy amount to at least EUR 30 billion a year[42].

The Renewable Energy Directive, 2009/28/EC, has driven a rapid deployment of renewable energy. In 2012, energy from renewable sources was estimated to have contributed 14.1% of EU final energy consumption[43] and should reach the objective of 20% in 2020. Looking beyond 2020, the Commission has proposed to increase the share of renewable energy to at least 27% by 2030. This means, for example, that the share

[42]COM(2014) 330
[43]COM(2014) 330

of renewable energy in the electricity sector could increase from 21% today to at least 45% in 2030. The rapid expansion of renewable energy raises significant challenges for the electricity system in terms of its integration as well as the cost to energy consumers, as most market development in the EU is currently driven by national support schemes. In addition, such a large scale expansion requires the use of all renewable energy sources in Europe. This requires the acceleration of development of new options that are emerging today.

The aim

The realisation of the trajectory set by the Union in terms of renewable energy deployment requires R&I to further reduce technology and non-technology cost throughout the whole life cycle, improve performance and foster technology deployment to market. In addition, there is a need to develop European supply chains and globally competitive manufacturing processes, which will ensure Europe's independence, not just in terms of renewable resources, but also in terms of industrial capacity to manufacture renewable energy technologies. Cross-cutting research at system level is also essential for determining how very high levels of renewable energy technologies can be connected to smart grids and storage at house-hold, communal, national, and European levels, taking into account the increasing use of smart appliances. This should be complemented by efforts to ensure a more accurate assessment and a better management and exploitation of our renewable resources – be it biomass, solar, wind, marine or subsurface resources. All these actions should include a comprehensive analysis of their economic and environmental impact on a life cycle basis.

All these activities should be complemented by an exhaustive analysis of their economic impact, measured in terms of levelized cost, as well as an assessment of the competitiveness and innovation of European industry, taking into account R&D developments in the international arena and technology market expectations.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Wind Energy

Advanced research:

- Develop advanced turbines and components (for onshore and offshore applications, including floating technology); and accurate methodologies for wind resource assessment.

Industrial research and demonstration:

- Demonstrate components and technologies for offshore applications; and new logistics, assembly and decommissioning processes.

Innovation and market uptake:

- Grid integration and spatial planning for innovations regarding new market design, financing, and end-of life policies taking into account environmental and social aspects as well as support to first scale commercial projects of innovative technologies to reach the market and to lower the perceived risk for cost-reducing innovations in offshore wind.

Photovoltaic Energy

Advanced research:

- Develop novel low cost and/or high efficiency PV technologies; enhanced PV module and system conversion efficiencies with extended lifetime, increased sustainability throughout the whole lifecycle and lowered materials consumption.

Industrial research and demonstration:

- Develop and demonstrate new pilot production lines to validate advanced/automated manufacturing processes; new multi-functional PV solutions (incorporating new technologies, system designs and system integration) to reduce cost; operational strategies for effectively and sustainably integrating PV in the energy system and in the built environment at reasonable cost.

Innovation and market uptake:

- Develop financing and risk mitigation options for large-scale manufacturing plants, to address regulatory, financing and societal solutions for mass-deployment and market-based exploitation of PV investments accounting for the status and future perspectives of the EU PV industry; support training and education for photovoltaics.

Concentrating Solar Power

Advanced research:

- Develop innovative receivers and heat transfer fluids; increased reliability with improved control and operation tools (also by means of a more accurate assessment of the solar resource); new hybridisation and better integration concepts (e.g. with desalination plants), innovative storage media and concepts, reduction of water consumption by developing anti-soiling coatings.

Industrial research and demonstration:

- Develop components such as mirrors and supporting structures; advanced CSP plants of various size and demonstrate hybridisation concepts (e.g. with biomass), optimise the operation of current storage systems and validate in the field innovative dry-cooling systems, accounting for the status and future perspectives of the EU CSP industry.

Innovation and market uptake:

- Develop standards (e.g. in terms of commissioning procedures) and options to export electricity as foreseen in the Renewable Energy Directive, in particular by targeting the construction of innovative plants that would sell the electricity to another country.

Solar Heating and Cooling

Advanced research:

- Develop cost competitive components, smarter controllers and simplified storage options for solar compact hybrid systems in single family and multifamily homes; test components for solar active houses with at least 60% of the heating needs covered by solar energy, and develop the next generation of medium temperature collectors for industrial processes.

Industrial research and demonstration:

- Develop innovative solar compact hybrid systems and innovative solutions for new-built solar active houses; investigate refurbishment options in existing buildings and study large scale solar collector arrays for industrial processes.

Innovation and market uptake:

- Address system performance monitoring requirements, procedures for testing and certification, new business models and standardisation of components in buildings.

Ocean Energy

Advanced research:

- Develop methodologies for site characterisation; develop devices, components and materials; grid services and inter-array interaction and array design and modelling tools.

Industrial research and demonstration:

- Test and demonstrate ocean energy components, technologies and systems and arrays; demonstrate marine technology access and logistics.

Innovation and market uptake:

- Deploy early commercial array and grid integration, including standards; manufacturing and mass-production techniques taking into account the whole supply chain; framework for consenting procedures and environmental and socio-economic assessment; assess impacts on marine ecosystems and methodologies for power take-off systems; support to training and education.

Geothermal Energy

Advanced research:

- Geothermal power generation: Improve deep geothermal drilling, materials, reservoir engineering and resource exploration, considering also the use of Enhanced Geothermal System (EGS) in CHP applications
- Geothermal heating and cooling: Improve borehole heat exchanger materials.

Industrial research and demonstration:

- Geothermal power generation: Develop an EGS flagship programme; and resource assessment technologies.
- Geothermal heating and cooling: Develop ground-coupling technologies; and combined production of heat and power.

Innovation and market uptake:

- Geothermal power generation: Address public acceptance and risk mitigation which are crucial to attract investments
- Geothermal heating and cooling: Provide technological solutions for up-take in existing buildings; and environmental risk assessment.

Hydropower

Advanced research:

- Refurbish existing power stations, retro-fit existing storage hydropower to increase capacity and install pumped hydro; improve the performance of turbines, pumps and reversible turbines; develop methodologies to exploit untapped hydropower resources, including actions[44] to develop sustainable pumped storage (greenfield or existing installations, exploiting low head sites or sites with low potential).
- Improve the environmental design of hydropower for better solutions to environmental effects and societal acceptance.

Industrial research and demonstration:

- Develop multi-purpose projects with excellent grid connection to contribute to grid stability by optimising demand response using high efficiency equipment with wider head ranges.
- Improve the performance of reversible pump turbines with focus on variable speed pump turbines, high-heat pump turbines; develop practical applications of environmental design, fish migration solutions, sediment handling, social acceptance).

[44]Addressed within the actions under *Theme 8: Unlocking the potential of energy storage and hydrogen.*

Combined Heat and Power from Biomass

Advanced research:

- Develop sustainable bio-liquids for example by upgrading bio-oil quality to be used in CHP installations; materials for small and micro CHP installations; disruptive technologies, such as solar gas from biomass using solar energy directly.

Industrial research and demonstration:

- Develop sustainable biomass feedstock supply; biogas production and up-grading to biomethane; develop high-efficiency biomass conversion systems such as thermally treated biomass fuels for CHP applications; cost and energy efficient, environmentally friendly micro and small scale CHP; high efficient large-scale or industrial steam CHP with enhanced availability and increased high temperature heat potential (up to 600°C); high efficiency biomass conversion systems for tri-generation/poly-generation at medium to large scale and fuel cell-based (micro-)CHP units for domestic, commercial and industrial use, including treatment of the biogas to reach the required purity levels.

Innovation and market uptake:

- Demonstrate at full scale sustainable bio-based fuels in the heating sector; and high efficiency biomass conversion systems developed under industrial research and demonstration.

Theme 11: Enabling carbon capture, CO_2 utilisation and storage technologies and increased efficiency of the fossil fuel-based power sector and energy intensive industry

Rationale

Fossil fuels will continue to be used in Europe's power generation as well as in other industrial processes despite the growing deployment of renewable energy generation. Therefore, the 2050 target of decarbonisation can only be achieved if the GHG emissions from fossil fuel use are reduced by between 93 and 99%[45]. This will require the deployment of more efficient coal technologies such as advanced ultra-supercritical power plants coupled with high efficiency air pollutant control devices, and ultimately the application of Carbon Capture and Storage (CCS) fuelled power. To facilitate the deployment of CCS, the EU has put in place the necessary legal framework with Directive 2009/31/EC ("CCS Directive") for the environmentally safe geological storage of carbon dioxide; and included CO_2 transport networks in Europe's Energy Infrastructure Priorities.[46]

The decarbonisation of the power sector has important implications for fossil fuelled power (and cogeneration) plants. With the growing share of renewable power in the energy mix, fossil fuel power plants will have to increasingly shift their role from providing base-load power to generating fluctuating back-up power to control and stabilise the electricity system. This operational flexibility provides a significant technological challenge, in particular for those plants fuelled by coal.

According to the Energy Roadmap 2050, natural gas will be critical for the transformation of the energy system. Substitution of coal (and oil) with gas in the short to medium term (until at least 2030 or 2035) could help to reduce GHG emissions using existing power plant technologies. However, natural gas is becoming expensive and in the EU and its resourcing poses a security of supply risk. For this reason, some

[45] Impact Assessment of the 2050 Roadmap – SEC(2011)288, p. 52, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011SC0288&from=EN

[46] COM(2013) 711

Member States have decided to consider domestic shale gas in their energy mix. The Commission adopted in 2014 a Recommendation (2014/70/EU) laying down minimum principles on the exploration and production of hydrocarbons using high volume hydraulic fracturing, to support Member States which wish to carry out exploration and production of shale gas, while ensuring that the public health, climate and environment are safeguarded, resources are used efficiently, and the public is informed. Moreover, the natural gas grids in Europe are an important part of the energy infrastructure. Therefore, there is now a sound opportunity to implement new functionalities in these grids, which will reinforce their role as transporters of sustainable energy forms such as synthetic gas produced by RES.

It is noted that coal is still used extensively around the world for electricity generation. On average, the efficiency of the existing coal-fired power plant fleet is quite low, about 33%. High efficiency coal combustion technologies such as those used in advanced ultra-supercritical power plants can raise power plant efficiency to about 50%. Due to the large number of coal-fired power generation units around the world, such high efficiency combustion technologies can reduce CO2 emissions from these units, and ultimately the application of CCS will ensure its full contribution to a low-carbon sustainable energy system.

The aim

In order to realise the long term decarbonisation targets set by the Union, R&I on CCS is needed to lower the energy penalty induced by the adoption of capture technologies, identify the regions with potential for safe and permanent geological CO2 storage, optimise the safe operation of storage sites, promote confidence in CO_2 storage and build public awareness of CCS as well as develop a cost- and resource-effective application of CCS in the power sector and industrial operations and promote CO_2 utilisation. Enhanced European cooperation is particularly needed in these areas. In addition, R&I is required to develop new cost-effective solutions for highly flexible new and existing fossil fuel power plants (including those co-utilising renewable fuels), capable of meeting demand and renewable generation fluctuations, at minimal fuel consumption and emissions, while reducing the impact of cycling operation on service life expenditure, while not impeding the potential CO_2 capture readiness of the power plants. This includes the development of clean coal technologies characterised by a low environmental impacts also in terms of water consumption and of residue disposal. R&I is also needed to expand the knowledge base and make scientific recommendations for best practices aiming at minimising the environmental footprint of unconventional hydrocarbon extraction (including tight gas, shale gas and shale oil).

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

CCS

Advanced research:

- Develop proof of concept for novel, cost-competitive and efficient CO2 capture technologies for application in power generation and industrial processes; develop improved methods for storage site characterisation, exploitation and monitoring.
- Design and operate CO_2 pipeline and shipping transport systems; and develop the necessary research infrastructure; develop a European Atlas of potential storage sites; develop methodologies for the design transport infrastructure.

Industrial research and demonstration:

- Pilot promising capture technologies.
- Develop and pilot integrated CCS solutions addressing flexibility.
- Develop and demonstrate bio-CCS

- Develop cost-effective engineering solutions for safe storage management and remediation.
- Start-up and manage of up to six new storage pilots.
- Develop pilots for effective design and operation of CO_2 transport systems.
- Develop cross-sectoral CO_2 capture and CO_2 storage/re-use.
- Ensure the effective and sustainable use of the subsurface taking into account the potential for competing energy applications, e.g. the storage of hydrogen or air; or for geothermal applications.

Innovation and market uptake:

- Address the start-up and manage CO_2 storage demonstration projects and pan-European transport networks for CO_2; develop tools and methods to identify, evaluate and optimise opportunities for lowest-cost and highest-value deployment of CCS; understand system integration, operability and cross-cutting issues.

Conversion of captured CO2 to useful products

Advanced research

- Develop processes (and their life cycle analysis) for the most promising pathways for CO2 utilisation (e.g. synthetic fuels and chemicals).
- Develop and demonstrate routes for the conversion of CO2 to chemicals as key building blocks for the chemical industry, leading to a variety of large scale products

Industrial research and demonstration:

- Demonstrate industrial scale production of fuels, polymers and chemicals from CO2
- Demonstrate a pilot for mineral carbonates production from CO2

Clean Coal and Flexible/Back-up Generation for conventional thermal power plants

Industrial research and demonstration:

- Develop faster ramp rates, reduced start/stop times, reduce minimum load and improve efficiency at all load levels.
- Increase operational flexibility of fossil fuelled power plants with CCS.
- Improve high efficiency coal combustion technologies such as advanced ultra-supercritical technology
- Develop faster ramp rates, reduced start/stop times, and reducing minimum load and improving efficiency at all load levels, as well as developing maintenance strategies and environmental compliance approaches for increased flexible operation
- Develop advanced automation to simulate transient behaviour, forecast potential outcomes, and optimize plant operation in real time

Unconventional Fossil Fuels

Advanced research:

- Develop tools for the prediction and monitoring of environmental impacts of shale gas extraction and of underground coal gasification operations.
- Investigate the potential storage of CO_2 in underground coal gasification (UCG) operations
- Assess the environmental impact of methane hydrates exploitation.

Industrial research and demonstration:

- Reduce the environmental impact of oil and gas extraction and production (including hydraulic-fracking); investigate the potential for CO_2 storage in shale gas operations.
- Assess cost reduction and safety of UCG; produce an inventory of potential coal-bed methane (CBM) and coal-mine methane (CMM) resources.
- Investigate the potential methane hydrate resources, including safe and cost-effective extraction techniques and options to store CO_2 in methane hydrates.

Innovation and market uptake:

- Develop a European protocol for approving unconventional hydrocarbons operations, UCG and CBM demonstration.

Theme 12: Supporting safe and efficient operation of nuclear systems, development of innovative reactor concepts and sustainable solutions for the management of fissile materials and radioactive waste

Rationale

With a share of about 30% in EU's electricity production[47], nuclear energy provides today most of the low-carbon electricity consumed in the EU. The 2050 Energy Roadmap shows that nuclear energy will remain for the years to come an important constituent of the EU power generation mix. Nuclear energy plays an important role in the energy mix of 14 Member States and contributes to the competitiveness of EU's energy system, security of supply and independence from fossil fuels.

The Euratom Treaty provides the legal Framework to ensure the safe and sustainable use of nuclear energy across Europe and helps non-EU countries meet equally high standards of safety and radiation protection. With the Nuclear Safety Directive (2009/71/EURATOM) and its latest amendment (2014/87/EURATOM), EU nuclear stress tests, safety requirements of the Western European Nuclear Regulators Association (WENRA) and the International Atomic Energy Agency (IAEA), the EU became the first major regional nuclear energy actor with a legally binding regulatory framework as regards nuclear safety. Furthermore, this legal framework has been recently complemented by Directive 2011/70/Euratom that establishes a Community framework for the responsible and safe management of spent fuel and radioactive waste (both from fission and fusion systems), and the Directive 2013/59/EURATOM laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. In addition, the EU is a world leader in research for the development of fusion technology and is a key actor in the International Thermonuclear Experimental Reactor (ITER) programme.

The aim

The implementation of these regulatory frameworks and the further development of nuclear fission addressing both innovative reactor concepts and advanced fuel cycle technologies as a key option for a secure, clean and efficient energy system requires continued R&I investments. R&I investments[48] are urgently needed to provide both near - and long - term solutions to ensure 'a safe and efficient operation of nuclear systems, development of innovative reactor concepts and sustainable solutions for the management of radioactive waste'. This should target in particular the extension of operating lifetimes, as well as the safety of future closed fuel nuclear cycle systems. Research shall further demonstrate long-term solutions for the management of radioactive waste in Europe through the development of geological disposal. These efforts should be accompanied by multidisciplinary research on the risks of low doses of radiation. Next generation nuclear fission reactors such as Generation-IV systems have the potential to demonstrate long term nuclear energy options. R&I efforts are also needed to retain and improve competences and know how, and to improve the efficiency and effectiveness of the European Research Area thereby contributing to maintaining high levels of knowledge and industrial competitiveness in the nuclear field. Fusion technology is an attractive long-term energy solution now considered for clean and

[47] SWD(2014) 330 final/3

[48] As confirmed by the European Group on Ethics in Science and New Technologies (EGE) , and further concluded in the European Commission Symposium on 'Benefits and Limitations of Nuclear Fission for a Low Carbon Economy' in 2013,

large-scale electricity generation towards the end of the 21st century. Cross-cutting fusion/fission synergies shall be encouraged. All this needs to be accompanied by the development of European supply chains and globally competitive manufacturing processes, to ensure Europe's technology independence and exploit the associated potential for industrial growth and job creation.

Actions

The following actions are considered essential by the stakeholders to deliver the objectives:

Advanced research:

- Address the safe and efficient operation of nuclear power plants addressing plant safety, risk assessment and severe accidents, innovative Light Water Reactor Generation-III design, small modular reactors; effects of low doses of ionising radiation.
- Address the sustainability of waste management and use of fuel resources notably considering partitioning and transmutation; nuclear materials for operation under Generation-IV conditions and innovative materials to improve plant safety and efficiency; alternative fast reactor technologies.
- Optimize the integration of nuclear reactors in energy systems including in particular the development of novel concept for cogeneration of heat and electricity from nuclear fission.

Industrial research and demonstration:

- Ensure a safe and efficient operation of nuclear power plants addressing the integrity assessment of systems, structures and components; improvement of reactor operation, fuel, waste management (both from fission and fusion systems) and dismantling.
- Address the sustainability of waste management and use of fuel resources including the development, licensing, construction and commissioning of the high priority demonstration plants for the Generation-IV fast reactors (allowing for the testing of various fuel cycle options including recycling of fissile materials and transmutation of minor actinides); nuclear fuel reprocessing and fabrication of fuel for the demonstration plants; geological disposal; interim spent fuel and high level waste storage.
- Optimise nuclear plants in energy systems including specific examples of optimization of integrated production by renewable energies (e.g. wind turbines) and nuclear power plants; promotion of cost reduction innovation to improve the economics of nuclear energy while preserving a high safety level.

Innovation and market uptake actions:

- Reinforce the safe and efficient operation of nuclear power plants by promoting pre-normative research for new design and operating conditions, establishment of shared and/or exchange codes and standards; strategy providing methods to progressively enlarge consensus among stakeholders for an effective standardisation and/or inter-comparison of reactor component assessments and continuously improving the safety level of the nuclear installation by promoting harmonisation and shared design approaches and licensing processes.

Theme 13: Developing sustainable biofuels, fuel cells and hydrogen and alternative fuels for the European transport fuel mix

Rationale

The transport sector is the second largest energy consumer in Europe being responsible for 33% of the total energy consumption and for about 25% of the total European GHG emissions[49]. It is important to note that there has been a 27% GHG emissions rise since 1990. At the same time, it is the only sector depending as much as 95% on fossil fuels. The decarbonisation of the transport sector is recognised as a major challenge in the Energy Roadmap 2050. Today, biofuels, notably nearly exclusively crop biofuels, have a share of around 5% of the fuels used in the EU transport sector. A portfolio of sustainable advanced biofuels, hydrogen and other alternative liquid and gaseous fuels, including LNG, will hence be necessary in order to improve the EU security of energy supply, to achieve the ambitious European goals aiming to reduce the GHG emissions from transport by at least 60% by 2050 set in the Transport White Paper 2011[50] and to reach the 10% target for renewables in the final energy consumption in transport by 2020 set by the Renewable Energy Directive 2009/28/EC, as well as the overall EU 2020, 2030 and 2050 objectives in energy, transport, climate, economic and social policies.

The aim

Comprehensive R&I actions are needed to foster the development of an inclusive portfolio of transport fuels, ensure their quality, sustainability and enable their commercialization. Among the challenges to be addressed for advanced biofuels, as matter of priority is the need to enable the commercial availability of advanced biofuels at large scale by 2020, aiming at production costs that allow competition with fossil fuels, as well as securing the availability at large scale of sustainable, low GHG emission on lifecycle basis and low cost biomass. The energy enhancement of non-exploited biomass should be further empowered. R&I effort is also needed to make hydrogen and fuel cells a competitive and sustainable solution for the decarbonisation of the transport sector with particular emphasis on cost reduction, improvement of performance and reliability, clean hydrogen routes and establishment of adequate refuelling infrastructure. In addition, long-term research is also necessary to promote the development of new technological concepts, such as power to liquid and gaseous fuels, which will allow the introduction of non-biomass and non-fossil fuel based alternative fuels in all transport sectors.

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Sustainable Advanced Biofuels

Advanced research:

- Develop novel integrated process concepts that reduce the investment needed for biofuel production; and innovative biomass conversion routes that enhance the feedstock basis, maximise biomass utilization, and improve performance and lower costs.

Industrial research and demonstration:

- Develop and demonstrate biofuel processes at industrial scale with better economic and environmental performance than the ones currently available in the market (e.g. incorporate new or improved biochemical/ thermochemical/chemical conversion and upgrading technologies,

[49]Eurostat, EU transport in figures, statistical pocketbook 2013
[50]COM(2011) 144 final

valorise co-products); new cost-effective biomass supply and processing chains that unlock unexploited non-food biomass potential (e.g., evaluate their feedstock flexibility, diversity, cost reduction, availability and sustainability in an integrated way and seek synergy between energetic and material use).

Innovation and market uptake:

- Roll out at commercial scale the sustainable and efficient production of advanced biofuels and the continuous feedstock supply through scaling-up of a number of economically viable and sustainable value chains and through additional and diverse biomass mobilization based on cost efficient supply systems, as well as enable market access of first-of-a-kind commercial demonstration projects.

Hydrogen and Fuel Cells

Advanced research:

- Develop advanced novel materials and components for fuel cell and hydrogen –FCH- (and other low carbon fuels compatible with fuel cells) technologies.
- Model, simulate and analyse key processes and mechanisms for hydrogen production and conversion.

Industrial research and demonstration:

- Develop the capabilities necessary to initiate fuel cell electric vehicles (FCEVs) deployment across Europe for road, rail, maritime or aeronautics applications and APUs (auxiliary power units) and establish the necessary hydrogen refuelling infrastructure; develop low carbon fuels compatible with fuel cells; and distribution methods with a low carbon footprint at a competitive cost for transportation and other applications.

Innovation and market uptake:

- Address non-technological aspects to facilitate mass-market rollout of FCH technologies, such as demonstration of their socio-economic, environmental and energy benefits throughout the whole life cycle.
- Increase public awareness and acceptance.
- Define and establish relevant Regulations, Codes and Standards.
- Identify business models and design financial support mechanisms for market introduction.

Advanced Alternative Fuels

Advanced research:

- Develop sustainable catalysts and process technologies for CO_2-based and CO_2-neutral liquid and gaseous fuels (when considering the whole life cycle) such as methanol, ethanol, green gas or other fuel molecules using renewable energy.
- Study artificial photosynthesis.
- Develop modelling tools and techno-economic evaluations.

Industrial research and demonstration:

- Pilot plants for CO_2-based and CO_2-neutral fuels.
- Demonstrate selective conversion of CO_2 to methanol, ethanol, or other fuel molecules using renewable energy (addressed in Theme 11).

Innovation and market uptake:

- Facilitate the deployment of new options with long-term prospects, such as fuel from photosynthetic microorganisms (in water and land environments) and from artificial photosynthesis mimics.
- Address the market uptake and scale-up a number of economically viable and sustainable value chains in the transport sector based on biogas, LNG and biomethane for heavy freight transport and maritime applications.

3. Cross-cutting aspects

Introduction

The transition to a more sustainable energy system and the development and deployment of innovative low-carbon energy technologies will have a profound impact on economic growth and jobs and on European societies as a whole, especially since this will happen in an increasingly competitive and changing international environment. The implementation of the transition will require a more vigorous social dialogue and active participation of consumers and concerned stakeholders as well as the development of new skills and more responsive education systems and methods to mobilise the necessary financial resources to invest in energy supply and energy efficiency. It is therefore important to address more effectively these common needs across the various energy technology sectors by identifying the links and interfaces among them and integrating them in the relevant policy dialogues and support programmes. Such a holistic approach will require targeted R&I actions in multiple fields and disciplines.

3.1. Education

Rationale

Meeting the EU's decarbonisation objective and ensuring security of energy supply and competitiveness will affect employment and jobs, requiring better education and training and a more vigorous social dialogue. The scale of the challenge is considerable. A rough analysis performed for the SET Plan Education and Training Roadmap[51] reveals that in 2012 the main low-carbon energy fields[52] employed around 9 million people[53]. Considering the 2050 vision, the performed analysis shows a projected doubling of the workforce by 2030. In parallel, a large number of the current workforce in these and adjacent sectors should undergo re-training, making the challenge even more acute. This is further complicated by the challenge education institutions face in attracting quality students to follow science, technology, engineering, and mathematics (STEM)[54] and related programmes. In addition to the growing demand for human capital, the low carbon energy sector is a constantly evolving field which requires the development of new skills and competences.

The aim

There is a need to update education and training programmes for professions in the energy sector at all levels with new research-based and industrial knowledge and to provide adequate interdisciplinary integration of knowledge from relevant fields. Furthermore, interaction among higher education and training institutions, businesses and research institutes should be encouraged in terms of curricula development, mobility programmes and access to research and industrial infrastructure such as laboratory, pilot projects and test facilities for practical training in real environment. Academic and training institutions need to ensure that they support professors/instructors to gain the required knowledge in new developments. Education and social frameworks should aim to attract quality students to follow STEM and other related programmes in the energy field. Quality assurance of the energy education, national and cross-border, should be addressed both for higher education and lifelong learning. Awareness and insight should be provided for decision makers and policy makers. The public should also be better informed of the energy transition, to implement and make use of innovative energy services, solutions and applications in Europe to their full extent.

Actions

The following actions are considered essential to deliver these objectives:

Advancing higher education and lifelong learning and fostering the link between education and training institutions, business and research institutes:

- Develop innovative and industrial-based educational programmes for the energy sector, targeting both higher education and lifelong learning.
- Establish human resources and skills observatories for low-carbon energy technologies.
- Develop a quality assurance framework for higher education and lifelong learning programmes on energy.

[51] http://setis.ec.europa.eu/setis-deliverables/education-training-roadmap

[52] 'bioenergy', 'carbon capture and storage', 'concentrated solar power', 'electricity grids', 'energy efficient buildings, thermal energy networks and smart cities integration aspects', 'energy storage', 'fuel cells and hydrogen', 'geothermal energy', 'nuclear energy', 'photovoltaics', and 'wind and ocean energy'

[53] Within this figure, around 1.2 million are directly engaged within the value chains of low carbon energy supply technologies (up to 2 million if we consider also the bioenergy agriculture and forestry supply chain); around EUR 6.2 million are engaged on the demand side, energy efficient buildings having the highest share; about 900 thousand are employed in the electricity and thermal networks value chains, including energy storage developments.

[54] STEM fields or STEM education is an acronym for the fields of study in the categories of science, technology, engineering, and mathematics.

- Develop energy-related education programmes for decision-makers.

Infrastructure support to higher education and lifelong learning:

- Ensure access to research infrastructures, pilot and demonstration facilities to support education and professional training.
- Develop and make available e-tools (e-Infrastructures) for energy education.

Raising awareness, developing behaviour and enhancing knowledge, skills and competences among citizens and the young generation:

- Organise energy-related campaigns for citizens.
- Develop programmes and innovative solutions to enhance knowledge, skills and competences among the young generation inside and outside the school environment.

3.2. Socio-economics in support of policymaking

Rationale

The transition to a secure, competitive, clean and efficient energy system will require significant investments in technologies and solutions, for which the operating principles and business models depart significantly from those for traditional technologies. The main changes expected for the future energy system are governed not only by technological aspects but above all by political, economic, institutional, and social issues.

As a consequence of energy's central role in our society the choice of a particular portfolio of technologies has far-reaching impacts not only on the energy system, but also on the environment, the economy and society. These often conflicting impacts, and the resulting trade-offs as well as the consequences of different policy interventions and measures need to be better understood. Managing the transition of the energy system in a sustainable and inclusive way is paramount.

There is hence a pressing need for a robust and transparent analytical framework that provides policy makers with extensive interdisciplinary knowledge and allows them to assess the linkages, synergies, and disconnects between energy technologies and services, infrastructure, markets, business creation and consumer behaviour,. Such a framework will also permit robust analyses of the future evolution of the European energy system and its inter-dependencies.

Within this framework, it is also important to take into account the history and inertia of current energy system. Interdisciplinary analysis needs to understand how to move away from the technologies, infrastructures and interests that constitute legacy energy systems.

The aim

The definition of policies supporting the energy transition requires improved methods and tools to assess the social, political, economic and environmental dimension of energy systems, considering costs and benefits for consumers and for society as a whole. In order to ensure comparability and alignment in policy formulation and evaluation, it is necessary to learn from and integrate existing energy system assessment methodologies into a common framework, including possible common sets of indicators, and to improve the current complex multi-level energy governance framework (European, national, regional). This will ensure that the management of the energy transition receives the adequate institutional attention.

Hence, it is essential to improve the cooperation between public authorities, companies, end users and research institutions. The collaboration between stakeholder communities is particularly important to ensure the collection of energy–relevant data at the local/regional level to feed into targeted local transition policies and measures, as well as to collect, assess and benchmark energy related best practices at regional, national, European and international level.

The energy transition can only take place with an active engagement and participation of society regarding the future of the energy system. To ensure the engagement of citizens with energy issues, new strategies and methods are needed to increase participation in the energy policy debate and stimulate social innovation initiatives to contribute to a low-carbon energy system. Similarly, innovative strategies need to be pursued that raise the awareness of consumers and stakeholders, engage local communities and reinforce and build capacities to enable and support the energy transition.

Actions

The following actions are considered essential to deliver these objectives:

Analysis, modelling and foresight:

- Develop an integrated analysis of the energy system and its components, in particular aiming at the development of new assessment frameworks for the energy system as well as investment programmes; establish a European energy modelling forum; adapt the Life Cycle Analysis (LCA) methodology to assess energy systems; integrate short term variations in long term models; develop a methodology to assess the geopolitical and risk dimensions; and improve investment models for integrated energy system analysis.
- Develop an integrated analysis of energy transition strategies, and in particular assess the role of strategy formulation in guiding energy transitions across the EU; develop a framework and implement a platform for low-carbon transition strategies.
- Collect energy data and facilitate access to the knowledge base, in particular through the development of ICT tools to visualise energy data in pursuit of the EU 2020 and 2030 targets.

Societal impacts of the energy transition:

- Analyse the potential distributed impacts of energy transition strategies, including the identification of impacts on "winners and losers"; and provide evidence to inform strategies to manage these impacts on infrastructures and technologies, the energy system and the economy.
- Increase the understanding of the behaviour of social and political actors, in particular through public opinion surveys and the comparison of perceptions and assessment of the role of underlying social dynamics of different stakeholder groups across Europe.
- Facilitate and enable public participation in the energy transition, such as the development of a framework for understanding and enabling public engagement in the energy transition and new methods and tools to encourage citizens to adopt more sustainable consumption patterns.

Improved innovation processes for the transition to sustainable energy:

- Study the interactions between public policy and firm level innovation in the sustainable energy sector.
- Elaborate new policy instruments aimed at stimulating low-carbon technologies along the innovation chain and improve industrial competitiveness through a multilevel energy governance assessment model.

3.3. Innovative financing

3.3.1 Innovative financing for energy efficiency

Rationale

In the EU, the scale of investment needed to meet the 2020 energy efficiency target is estimated to be around EUR 100 billion per year[55]. In addition, to fulfil the ambitious agenda for energy efficiency towards 2030, further sources of finance will have to be gradually unlocked. Although the EU has increased the amount of public funds available for energy efficiency, in particular through EU Structural Funds (around EUR 38 billion expected to be allocated for low carbon-economy), it is clear that the scale of the financing challenge cannot be addressed by the public or the private sector alone via existing financing mechanisms and products.

The aim

There is a need to address the persistent financing barriers that hinder the mass-scale deployment of innovative energy saving technologies in the market. These include the lack of adequate capital allocation, resulting in the lack of appropriate innovative financing products, and insufficient (financing) demand.

The energy efficiency market is still seen by investors and lenders as risky and fragmented. It lacks robust financial and technical performance data track record, it is characterized by numerous small-scale operations with high transaction costs, and by insufficient long-term regulatory stability.

There is therefore a need to support the development of robust investment vehicles for energy efficiency allowing the aggregation, standardisation and re-financing on secondary markets, as well as appropriate benchmarks against which (once aggregated) underlying asset portfolios would be valued and rated. There is also a need to develop energy efficiency-specific project risk assessment tools

On the financing demand side, project promoters and technology developers need to acquire the skills and knowledge necessary for the development of large-scale, bundled or pooled energy efficiency investments, enabling to reduce costs and attract private financing. Further, they need to have access to appropriate and affordable up-front capital or project financing tools. Additionally, consumers and decision makers should understand the full benefits of energy efficiency investments (both energy and non-energy related).

Actions

The following actions are considered essential by the stakeholders to deliver these objectives:

Industrial research and demonstration:

- Develop and implement standardised methodologies for measurement, reporting and verification of energy savings in order to increase investors' confidence.
- Encourage on-bill financing schemes (e.g. open standards for assessing metering data and devices) and other innovative solutions linking the energy savings with other benefits for consumers and physical assets.

[55]Estimation based on the energy efficiency communication Impact Assessment, SWD (2014) 255 final.

Innovation and market uptake:

- Provide project development assistance to build a credible pipeline of innovative energy efficiency programs and projects and foster the uptake of innovative financing solutions for energy efficiency in the EU. Support project bundling and pooling solutions in order to reduce transaction costs.
- Support the development and replication of innovative financing schemes (e.g. public guarantee solutions for energy efficiency investment in industries, cooperative citizen ownership, micro-finance, utility based programmes). Pay specific attention to the need to develop financing models for comprehensive renovations of buildings, addressing both property and rental markets and enabling long-term financing.
- Develop a track record for energy efficiency investments through the development and demonstration of a framework for (performance) data standardization, sharing, and aggregation.
- Establish frameworks, standards and securitisation models to support the creation of secondary market instruments (e.g. energy efficiency-related asset-backed securities). Support the development of energy efficiency-specific project risk assessment tools, benchmarking and rating solutions which could be reflected in the risk-assessment and rating techniques of investors, lenders and valuators; develop and demonstrate new business models for and financing products of the finance sector.
- Remove the barriers hindering the development of the energy efficiency services market in particular in the public sector, and foster the development, demonstration and standardization of new types of services/contracts.
- Develop schemes and programmes to foster dialogue with and training for investors and financiers. Support the exchange of good practices between finance, energy industry, service providers, public authorities, technology providers and consumers/prosumers.

3.3.2. Innovative financing for energy supply

Rationale

In the EU, the scale of investment needed in the power sector and energy networks by 2020 has been estimated at more than EUR 1,000 billion [ref] and this trend is likely to continue up to 2030. Part of these investments should be targeted at rolling to the market innovative generation assets and network infrastructures to ensure that the energy transition is based on increasingly competitive and performing technological solutions. Technology developers currently experience difficulties in raising finance for their first-of-a-kind commercial demonstration projects. The reasons are manifold. First-of-a-kind commercial demonstration projects in the field of energy supply require high volume of investment and are considered high-risk projects, which, in addition, are difficult to evaluate. Secondly, banks are more risk-averse under difficult market conditions, which is the case in the low carbon energy field where market conditions are not stable and tendencies differ between EU Member States; In the current economic environment, balance sheets of banks are constrained by tightened credit standards reducing their capacity to provide medium and long-term finance. In addition, to ensure bankability, most of these first-of-a-kind commercial demonstration projects call upon new business models that require an evolution of the energy market framework, creating an important source of uncertainty for commercial finance to invest in such projects.

The aim

Better understand the underlying business and financial risks related to the financing of the SET-Plan first commercial scale projects, to increase market information and transparency and to formulate actions to remove the identified financing bottlenecks.

Actions

The following actions are considered essential to deliver these objectives:

Advanced research:

- Develop a reference risk-assessment framework for first-of-a-kind commercial demonstration projects.
- Develop new innovative concepts of financing schemes tailored to the need of first-of-a-kind commercial demonstration projects.

Innovation and market uptake:

- Develop financial and technical advisory services to foster notably best practice exchange between finance, energy industry, energy service and technology.
- Promote initiatives for an increased coordination between existing risk sharing instruments at EU level and national/regional financial resources to enable coordinated or combined financing solutions for first-of-a-kind commercial demonstration projects and innovative SMEs and mid-capitalisation companies.

4. Annex I: Parts I, II, III, IV - Detailed Contributions from the Stakeholders

The detailed contributions by the stakeholders are available online at http://setis.ec.europa.eu/set-plan-implementation/towards-integrated-roadmap-and-action-plan. The research & innovation actions have been grouped in four Parts, as follows:

- Part I - "Energy Efficiency".
- Part II - "Competitive, Efficient, Secure, Sustainable and Flexible Energy System".
- Part III - "Fostering Innovation in Real Environments and Through a Market-Driven Framework".
- Part IV - "Cross-cutting aspects".