NAVIGATING THE ROADMAP FOR CLEAN, SECURE AND EFFICIENT ENERGY INNOVATION

Background report on

Innovation Systems and the SET Plan

Author(s): Charlie Wilson, Louis Coningsby (UEA)

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# SET-Nav
Strategic Energy Roadmap

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Web:	www.set-nav.eu
General contact:	contact@set-nav.eu

About the project

SET-Nav aims for supporting strategic decision making in Europe's energy sector, enhancing innovation towards a clean, secure and efficient energy system. Our research will enable the European Commission, national governments and regulators to facilitate the development of optimal technology portfolios by market actors. We will comprehensively address critical uncertainties facing technology developers and investors, and derive appropriate policy and market responses. Our findings will support the further development of the SET-Plan and its implementation by continuous stakeholder engagement.

These contributions of the SET-Nav project rest on three pillars: modelling, policy and pathway analysis, and dissemination. The call for proposals sets out a wide range of objectives and analytical challenges that can only be met by developing a broad and technically-advanced modelling portfolio. Advancing this portfolio is our first pillar. The EU's energy, innovation and climate challenges define the direction of a future EU energy system, but the specific technology pathways are policy sensitive and need careful comparative evaluation. This is our second pillar. Ensuring our research is policy-relevant while meeting the needs of diverse actors with their particular perspectives requires continuous engagement with stakeholder community. This is our third pillar.
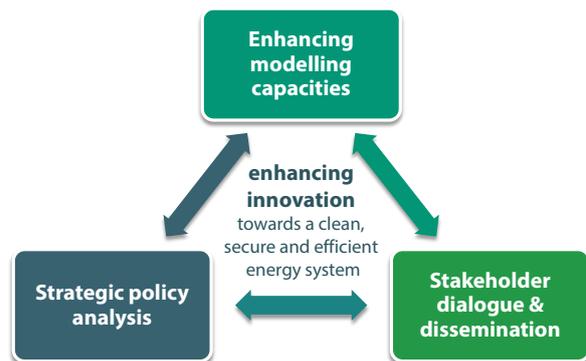
Who we are?

The project is coordinated by Technische Universität Wien (TU Wien) and being implemented by a multinational consortium of European organisations, with partners from Austria, Germany, Norway, Greece, France, Switzerland, the United Kingdom, France, Hungary, Spain and Belgium.

The project partners come from both the research and the industrial sectors. They represent the wide range of expertise necessary for the implementation of the project: policy research, energy technology, systems modelling, and simulation.

Table of Contents

Figures

Tables

1   Introduction

This policy report uses a systemic perspective on energy innovation to inform the EU's Strategic Energy Technology (SET) Plan. The report draws on a wide range of evidence and arguments to make five high level policy recommendations. Each recommendation is supported by a series of specific research insights on innovation systems.

2   What is the SET Plan?

In 2008, the Strategic Energy Technology (SET) Plan[i] was launched to provide strategic planning and coordination of energy research & innovation activities within the EU. The SET Plan was designed to support EU policy objectives on climate change, energy efficiency, and renewable energy, as well as energy security, energy union, growth, jobs, and global competitiveness (Carvalho 2012, EC 2015, Strachinescu 2015). The SET Plan was implemented through European Industrial Initiatives for technologies with near-term market impact (to 2020), and longer-term research actions to 2050.

In 2013, the Commission assessed progress with the SET Plan, and outlined key principles for its revision. These principles included aligning better with longer-term challenges, bridging between energy policy and research & innovation, leveraging existing financial resources, and broadening participation from Member States and private stakeholders (EC 2013).

In 2015 the Commission proposed a revised SET Plan that was more targeted, and that used a whole systems approach to ensure better integration across sectors and technologies (EC 2015). The revised Integrated SET Plan set out four priority areas (renewable energy and storage, smart systems and consumers, energy efficiency, sustainable transport) and two additional areas (carbon capture and storage, nuclear). These six areas were articulated in a set of ten actions. The next steps for the Integrated SET Plan are to detail the level of ambition, implementation, timing and deliverables for each of these ten actions.

The SET Plan Steering Group is the central governance structure of the SET Plan, coordinating extensive stakeholder networks within each action (Joliff-Botrel 2015). The Strategic Energy Technologies Information System (SETIS) hosts the data collection and monitoring function, helping to assess the impact of policy and identify adaptive responses if needed (Corsatea et al. 2015). The SET Plan also articulates links to available EU funding mechanisms for energy research and innovation (Strachinescu 2015).

3   Why is a Systemic Perspective on Energy Innovation Needed?

The European Commission has stated "*the ambition to achieve … a fundamental transformation of Europe's energy system*" (EC 2015). This transformation requires solutions and policies informed by systemic analysis of energy innovation. As the OECD explains: "*Parts of the system … cannot be assumed to be effective in delivering their prescribed functions. … The root of the failure is usually assumed to be the*

inability or unwillingness to coordinate. Responsibility or agency for this failure is distributed throughout the system rather than resting with a particular set of stakeholders. It implies that if problems are systemic, solutions must operate at the system-level, rather than at some part of it" (OECD 2015).

A systemic perspective on innovation emphasises the influence that wider social and economic systems have on innovation outcomes. A systemic perspective also identifies a broad rationale for policy interventions which goes beyond correcting market failures.[ii] Structural and transformational failures provide strong additional rationales for policy (Weber and Rohracher 2012). Structural failures blocking successful innovation outcomes include: under-investment in physical infrastructure; institutions creating uncertainty; locked-in behaviour if cooperation is too strong; weak knowledge exchange if interactions are limited; poor capabilities for accessing and learning from new knowledge (Woolthuis et al. 2005, Wieczorek and Hekkert 2012). For research and innovation aiming at system transformation, there are additional transformational failures. These include: lack of shared vision and direction; weak market demand and signals from users; lack of policy coordination; lack of monitoring and policy learning (Weber and Rohracher 2012).

These broad rationales for strategic intervention open up the scope for innovation system policies involving a diverse range of policy instruments[iii] (Wieczorek and Hekkert 2012, OECD 2015). A systemic perspective on innovation emphasises multi-stakeholder governance of innovation processes, and enabling frameworks or conditions to direct innovation activity.[iv]
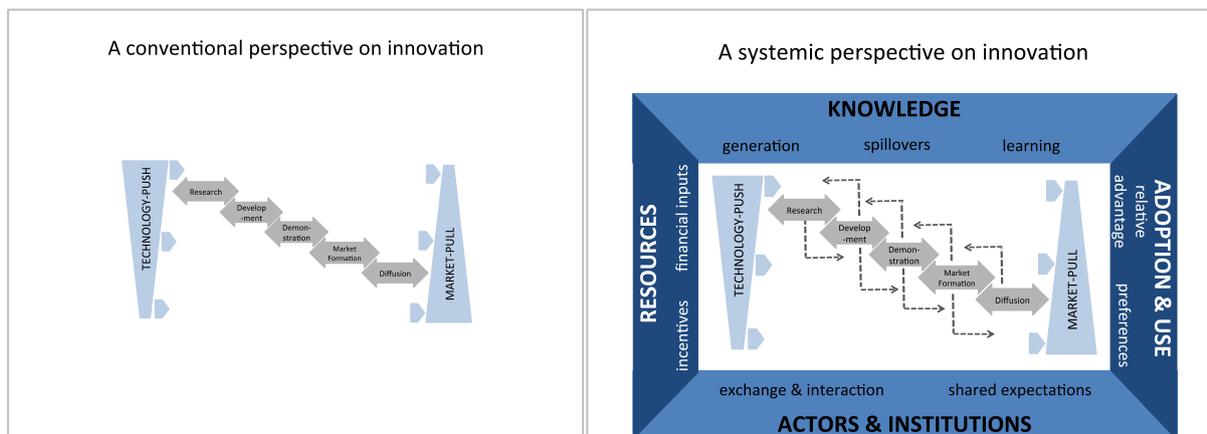
Figure 1. Conventional vs. systemic perspectives on energy innovation.

Source: (Grubler et al. 2012, Wilson et al. 2012).

These innovation processes and their enabling conditions are represented in the right panel of Figure 1. This simple characterisation of an innovation system illustrates how innovation stages and processes like R&D and market diffusion are supported by a broader innovation environment comprising knowledge, actors & institutions, resources, and adoption & use (Wilson et al. 2012).[v]

4 How can Research on Innovation Systems Inform the SET Plan?

A large body of research which takes a systemic perspective on energy innovation provides insights relevant to the SET Plan. These insights are synthesised below, drawing on a review of over 70 scholarly articles and reports[vi], as well as interviews with innovation system experts.[vii] The insights (marked by §) are grouped under five general policy recommendations to support transformation in the EU energy innovation system. These five general recommendations are:

1. *Ensure the SET Plan is directed by a shared vision towards clear goals.*
2. *Ensure the SET Plan builds a strong network among diverse innovation actors.*
3. *Ensure the SET Plan aligns institutions and builds user demand for technological innovation.*
4. *Ensure the SET Plan coordinates an effective mix of stable innovation policies matched to specific innovation needs.*
5. *Ensure the SET Plan generates policy intelligence to support learning and adaptation.*

4.1 Vision, Governance & Leadership

Policy Recommendation

1. ***Ensure the SET Plan is directed by a shared vision towards clear goals.***

Insights from Research on Innovation Systems:

§1.1. *System transformations to solve societal problems require a clearly communicated purpose and sense of direction.*

§1.2. *System transformations need strong and visible political leadership.*

§1.3. *Shared visions establish the legitimacy and credibility of directed system transformations.*

§1.4. *Shared visions are articulated by a wide range of social and political actors.*

§1.5. *Structural failures in innovation systems justify policy intervention to support innovation processes.*

§1.6. *Policymakers play coordinating, facilitative, and also entrepreneurial roles in system transformations.*

§1.7. *Central administrations set key priorities for directed system transformations and monitor progress.*

§1.8. *Portfolio-based approaches spread risks while providing technological focus.*

§1.9. *Foresight and roadmapping tools provide detail on goals, risks, and required policy support.*

The EU's energy challenges require system transformation. A shared vision of transformational change is needed to guide policy efforts [§1.1]. A shared vision has different elements: clear and consistent goals; strong political leadership; a rationale for intervening to address structural failures; a portfolio-based approach to technology support; and implementation roadmaps. A clear vision helps articulate the system transformation required to fulfil strategic goals.

Strong and visible political leadership is required to communicate and implement a vision for system transformation [§1.2]. Political leadership helps establishes the legitimacy and credibility of transformation objectives [§1.3].

> *Example: Long-term, stable targets with broad political support established clear expectations for the offshore wind industry in Germany (Reichardt and Rogge 2016). Stable expectations reduced investor*

uncertainty, stimulated RD&D investments, and led to the construction of new capacity.

Visions for system transformation should also be articulated by a wide range of social and political actors [§1.4]. A widely-shared vision further establishes legitimacy and credibility (Alonso et al. 2016). The cast of actors involved in a shared vision should not be limited to industrial and research organisations. Inclusive and participatory approaches are useful for engaging NGOs, public authorities, interested citizens, and others (OECD 2015).

> *Example: Open forums provided an opportunity for public and private actors to develop a shared vision with specific goals for wind energy in Denmark (Borup et al. 2008). This is one factor that helps explain Denmark's successful wind industry when compared with neighbouring countries which had a less widely-shared vision for wind sector development.*

Shared visions should clearly articulate the legitimacy of policy intervention. The policy rationale for system transformation extends beyond market failures to the structural failures which characterise incumbent innovation systems [§1.5]. Structural failures blocking transformation include weak networks for knowledge exchange, locked-in institutions, under-investment in infrastructure, or poor competencies for learning (Woolthuis et al. 2005, Weber and Rohracher 2012).[viii]

Mitigating structural failures requires an expanded and entrepreneurial role for innovation policy to facilitate, coordinate, and intervene in innovation system development [§1.6] (Weber and Rohracher 2012, OECD 2015).

Central administrations like the European Commission are well positioned to set coherent system-wide priorities and goals [§1.7]. These provide strong and clear signals of political intent to innovation actors (Mowery et al. 2010). Central administrations can also systematically monitor and evaluate policy performance (Foxon et al. 2010).

Innovation is irreducibly uncertain (Grubler and Wilson 2014). Portfolio-based approaches spread risks while providing technological focus [§1.8].[ix] Portfolios must be system-wide, spanning across supply, end-use, and network technologies (Wilson et al. 2012).[x] Prioritisation across a technology portfolio provides strong signals of intent to support planning and investment decisions by relevant stakeholders (Ruester et al. 2014).

Forecasting and roadmapping tools help policymakers develop specific transformation objectives, highlight future risks and identify requirements for policy support [§1.9] (Carayannis et al. 2016). Forecasting and roadmapping tools can also be used to devise technology portfolios.

> *Example: The global solar energy sector uses technology roadmaps to guide sector-wide R&D investments and increase awareness and deployment (Amer and Daim 2010). The sector has recently experienced 40% average annual growth rates, higher than any other renewable or non-renewable energy sector.*

4.2   Actors, Networks & Knowledge Exchange

> ***Policy Recommendation:***
>
> **2.   *Ensure the SET Plan builds strong networks among diverse innovation actors.***

Insights from Research on Innovation Systems:
> *§2.1.   Important actors in an innovation system include regulators, market intermediaries, and users, as well as firms and research institutes.*

Innovation actors are many and diverse [§2.1]. Important actors include industry and research institutions, as well as universities, branch organisations, NGOs, public authorities and end users (Borup et al. 2008, OECD 2015). Effective networks connecting innovation actors should be as inclusive as possible (Winskel et al. 2014, Alonso et al. 2016).

A strong network between innovation actors increases the availability of knowledge and flow of information [§2.2]. Actor networks are the mechanisms for knowledge exchange and spillovers between domains of application (Grubler and Wilson 2014) [§2.3]. Exchanging knowledge about innovation system functioning should not be in tension with intellectual property protection. Knowledge exchange may relate to advocacy, governance, investment opportunities, end-user preferences, and so on. Knowledge exchange also enables collaboration at multiple scales.

There are many ways to build multi-actor networks and facilitate knowledge exchange. These include conferences, industry consortia, workshops, technology platforms, networking events and other collaborative programmes [§2.4] (Becheikh et al. 2006, Rizzi et al. 2014, Alonso et al. 2016).

> *Example: The Cluster for Energy and Environment (CLEEN) was set up in 2008 in Finland as a limited liability company to create cooperative networks around clean energy technologies (Chiavari and Tam 2011).[xi] CLEEN intensified innovation in strategic areas through collaboratively produced research programmes. These supported long-term co-operation among industry, SMEs, and academic researchers, including a commitment to shared research output.[xii]*

Actor networks can improve the effectiveness of governance for system transformation [§2.5]. Strong multi-actor networks support flatter hierarchies, more inter-agency coordination, and more distributed policymaking (OECD 2015). Policymakers can strengthen the coordination and distribution of governance through multi-actor networks through high-level councils, parliamentary validation and public consultations (OECD 2015).

The balance between collaboration and cooperation in multi-actor networks changes as innovation systems mature [§2.6]. Emerging innovation systems benefit from experimentation, diversity and cooperation (Borup et al. 2008). Collaboration among new coalitions of actors helps overcome inertia and resistance from incumbents. More established innovation systems benefit from market formation and competition (Winskel et al. 2006).

> *Example: Multi-actor networks in the Danish wind energy sector were characterised initially by experimentation and collaborative learning (Borup et al. 2008). This helped the sector mature through the 1980s. Policies re-focused in the 1990s on market formation, for example, through higher feed-in tariffs. Multi-actor networks reshaped around increasingly mature markets.*

Niches are specific market settings in which innovations are first tested commercially but with some level of protection from full market competition.[xiii] Actors in market niches have specific needs which

can be supported by innovation policy including public procurement [§2.7] (Negro and Hekkert 2010, Negro et al. 2012).

> *Example: Tax relief on R&D-related wages has proved highly effective in supporting start-up energy companies in The Netherlands (Chiavari and Tam 2011).*[xiv] *Up to 64% reductions on the first €220,000 of R&D-related wages, as well as bonuses, are available for these niche-level actors. This has worked to support their inclusion in emerging multi-actor networks.*

Multi-actor networks enable the flow and exchange of available information. But *new* knowledge and competences are essential for system transformation [§2.8] (Jacobsson and Karltorp 2013). Entrepreneurial knowledge supports the development and diffusion of low-carbon technologies (Hekkert and Negro 2009). Research programmes, university courses, and vocational training provide opportunities for skills development (Jacobsson and Karltorp 2013, OECD 2015). New skills and competences should be aligned with strategic research and innovation priorities (Soriano and Mulatero 2011).

4.3   Institutions, Users & Infrastructures

> *Policy Recommendation*
>
> **3.   *Ensure the SET Plan aligns institutions and builds user demand for technological innovations.***

Insights from Research on Innovation Systems:

> *§3.1.   Formal and informal institutions are important elements of innovation systems which can be shaped by policy.*
> *§3.2.   Coordinated and aligned institutions complement technological innovation.*
> *§3.3.   Uncoordinated or misaligned institutions stagnate technological innovation.*
> *§3.4.   Vested interests of incumbent actors resist change to incentive structures, institutional frameworks and investment patterns.*
> *§3.5.   Transitional assistance for incumbent actors helps overcome resistance to change.*
> *§3.6.   Market demand for low-carbon innovations needs to be actively created among prospective users.*
> *§3.7.   Users play different roles in transitions, including as producers, legitimators, and participatory citizens.*
> *§3.8.   Strategic infrastructure investments are required for system transformation.*

Innovation systems have institutional and organisational characteristics that influence the development and diffusion of technological innovations [§3.1] (Wieczorek and Hekkert 2012, OECD 2015). Innovation policy can shape institutions to support successful innovation outcomes (Bergek et al. 2008b). This might include the deliberate creation of formal institutions such as technical standards, labour laws, or risk management rules. Policy can also help develop informal institutions such as pro-environmental norms, social legitimacy, trust, or risk tolerance (Negro et al. 2012).

Coordinated and aligned institutions complement technological innovation [§3.2]. Policy support for alignment is important, but relatively uncommon (Hekkert and Negro 2009). Alignment between technology-push and market-pull policies creates clear expectations, low risk investment environments, and productive knowledge flows.

Conversely, uncoordinated and misaligned institutions stagnate the development and diffusion of innovations [§3.3] (Hekkert et al. 2007, OECD 2015). Policies should aim to reduce misalignment

between institutions including the incentive structures created by policies themselves (Grubler and Wilson 2014). Misaligned incentives create tensions with emerging low-carbon innovation systems and send unclear signals to investors.

> *Example: Biomass digestion in Germany benefitted from alignment between policy support (e.g., 1990 Electricity Feed-in Act), entrepreneurial activities to create and diffuse new knowledge, and lobbying efforts (e.g. the German Biogas Association). Alignment between these institutions in an emerging innovation system helped counteract competing industries and form new markets for biomass digestion (Hekkert and Negro 2009).*

> *Example: Biomass digestion in The Netherlands suffered from misaligned institutions in its early development phase. Biomass digestion was recognized as a solution to the problem of surplus manure waste. But it was not recognized as a source of renewable energy and so received limited policy support.*[xv] *This in turn reduced financial investment and the creation of relevant new knowledge. Institutional misalignment undermined market formation and was not conducive to successful deployment (Hekkert and Negro 2009).*[xvi]

A common form of misalignment is between the new institutions of emerging innovation systems and vested interests. Incumbent actors and organisations resist changes to incentive structures, policy frameworks and investment patterns [§3.4] (OECD 2015). Transitional assistance can help incumbent actors develop the capabilities to engage constructively in system transformation [§3.5] (OECD 2015). This first requires policymakers to identify influential incumbent actors.

Markets for system-transforming innovations do not already exist. Market demand needs to be actively created [§3.6] (Mowery et al. 2010). Market-pull instruments such as feed-in tariffs or differential taxes build user confidence and demand, particularly if their long-term intention is clearly communicated (Rogge and Hoffmann 2010). Market-pull instruments are also more effective if they are predictable and persistent (Negro et al. 2012, Reichardt et al. 2016).[xvii]

Users play many different roles in system transformations, beyond that of final consumer. Users can also act as legitimators, intermediaries and producers [§3.7] (Schot et al. 2016). Policy can support users' many roles in energy innovation processes (Alonso et al. 2016).

> *Example: Users of solar PV and wind power in Germany played an important role in establishing the legitimacy of local energy projects and generating clear expectations for market growth (users as legitimators) (Schot et al. 2016). Users stimulated the diffusion of solar collectors in Austria through bulk purchases, user clubs, excursions and self-help support (users as intermediaries) as well as by self-building and installing collector systems (users as producers).*

System transformation implies radical changes in how and why society produces and consumes energy. This includes the transformation, replacement and establishment of new physical infrastructures of production and consumption [§3.8] (OECD 2015). Lock-in to existing infrastructures is an example of structural failure in innovation systems. Policies are critical for overcoming barriers to constructing new infrastructure such as transmission grids, pipelines, or storage facilities (Azar and Sandén 2011). These barriers include large upfront investments, construction coordination issues, and large sunk investments in existing infrastructure (Negro et al. 2012, OECD 2015).

> *Example: Seven pilot regions for electric transport infrastructure in Austria have been created since 2008 under the "Model Regions Electric Mobility" initiative. Infrastructure investments enabled electric mobility in practice and showcased its functionality and attractiveness. User feedback enabled further refinements and lessons for larger scale roll out (OECD 2015).*

4.4   Policy Mix, Coordination & Stability

Policy Recommendation

4.   *Ensure the SET Plan coordinates an effective mix of stable innovation policies matched to specific innovation needs.*

Insights from Research on Innovation Systems:

§4.1. *Effective innovation policy for system transformation has strategic goals consistent with shared visions.*
§4.2. *Internationalising innovation governance helps policy coordination in line with strategic goals.*
§4.3. *A mix of policies is necessary to address diverse structural and transformational failures.*
§4.4. *Policy mixes contain technology-push and market-pull instruments.*
§4.5. *Effective policy instruments are tailored to the needs of specific technologies and innovation contexts.*
§4.6. *Stable long-term policy frameworks establish clear expectations and provide strong signals to investors.*
§4.7. *Supporting experimentation helps to destabilise incumbent innovation systems which favour incremental change.*
§4.8. *Appropriately timed and sequenced innovation policies match the changing needs of innovations through development and diffusion.*
§4.9. *Policy support can be reduced as innovation systems become self-sustaining.*
§4.10. *System transformation requires significant financial resource mobilisation.*

Effective innovation policy has strategic goals which reflect shared visions for innovation outcomes such as system transformation [§4.1]. Innovation policy often focuses on specific sectors or countries. Resulting cross-sectoral or pan-national research & innovation can be misaligned with strategic priorities (Weber and Rohracher 2012). Internationalizing innovation governance is a means of improving policy coordination linked to system transformation goals [§4.2] (Skea et al. 2013, Wieczorek et al. 2013, Wieczorek et al. 2015).

A mix of innovation policies is needed to address the various market, structural and transformational failures blocking system transformation [§4.3] (Wieczorek and Hekkert 2012). A balanced policy mix includes both technology-push and market-pull instruments [§4.4]. Resulting system-wide incentives more effectively stimulate innovation if they are well aligned.

> *Example: The Green Growth Strategy in South Korea used a balanced technology-push and market-pull approach to stimulate a transition towards a low-carbon energy system. Technology-push instruments included increases in green technology R&D expenditure, a strategic portfolio of 27 low-carbon technologies, certification for green products, technologies and SMEs. Market-pull instruments included the 2011 Renewable Portfolio Standard for power generated by renewable technologies (OECD 2015). This policy mix provided system-wide support for low-carbon technologies while gradually dis-incentivising unsustainable technologies.*

Economy-wide or technology-neutral policies tend to favour incremental market-ready solutions and risk reducing the option value of diverse portfolios. A policy mix containing technology-specific instruments helps establish favourable conditions for the development and diffusion of low-carbon technologies (Azar and Sandén 2011). Policy instruments tailored to the needs of specific technologies provide stronger support [§4.5] (Watson 2008, Jacobsson and Bergek 2011, Reichardt and Rogge 2016). Financial support or targets for market growth can also be differentiated to match technology needs (Reichardt et al. 2016). Technology-specific push and pull measures still need to be coordinated and

aligned with the shared visions and priorities for system transformation (Soriano and Mulatero 2011).

System transformation takes time and sustained commitment from stakeholders (Grubler 2012, OECD 2015). A stable long-term innovation environment provides necessary certainty to investors [§4.6] (Grubler and Wilson 2014). Lengthening policy time horizons and transparently evaluating policy effectiveness on a pre-determined timeline helps to avoid undermining market confidence (Grubler and Wilson 2014). Internationalising energy system governance can also help create more stable policy support over the longer-term (Wieczorek et al. 2013). Conversely, short-term political cycles can lead to 'stop-go' policy environments. The provision and then removal of policy support for low-carbon technologies is a structural failure in many innovation systems (Negro et al. 2012).[xviii]

> *Example: The ethanol industry in Brazil benefited from long-term innovation policy frameworks.[xix] A diverse coalition of stakeholders ensured the sustained provision of subsidies and market support for ethanol via the Proalcool programme for over four decades (Meyer et al. 2014). The programme's stability was maintained despite technical challenges and external shocks including oil price volatility and political regime changes.*

> *Example: Every two years between 1998-2009 subsidies for renewable energy technologies in The Netherlands were stopped and then reintroduced, often in alternative forms (Negro et al. 2012).[xx] This undermined successful market deployment.*

Interdependencies within innovation systems create stability (Borup et al. 2008). Stability insulates the knowledge, skills and competences that sustain incumbent technologies. This favours incremental change while blocking transformative innovation (Borup et al. 2008). Experimentation helps break this pattern. Policy can encourage experimentation, for example by supporting small-scale demonstration projects and maintaining technological variety throughout demonstration and commercialization [§4.7]. Diverse technology portfolios also reduce the risks and costs of failure should some innovations prove unsuccessful (Grubler and Wilson 2014).

The needs of innovation systems change as technologies move through RD&D to market formation and commercialization stages (OECD 2015). Well-timed and well-sequenced innovation policies provide support for low-carbon innovations throughout each innovation stage [§4.8].[xxi] Policy flexibility and stability are not inherently in tension if the strategic direction and alignment of policy incentives remain consistent. Monitoring ongoing developments also identifies whether support can be gradually removed as innovation systems become self-sustaining [§4.9] (Jacobsson and Bergek 2004).

Mobilising greater financial resources is critical for successful system transformation [§4.10] (Watson 2008, Chiavari and Tam 2011, Jacobsson and Karltorp 2013). Financial investments in low-carbon technologies are well below the level required by long-term visions for energy and climate change (Carvalho 2012). Public funding should identify opportunities to leverage substantial additional private investment (Soriano and Mulatero 2011). Financial innovations such as specialized investment banks and accounting systems can help accelerate capital-raising or reduce the costs of investing (OECD 2015).

> *Example: Public R&D investment in solar PV in Japan has yielded €2.6 billion in economic benefits since 2005 (Chiavari and Tam 2011). In contrast, a lack of public R&D for biomass digestion in The Netherlands prior to 2003 meant a market for the technology was not formed (Hekkert and Negro 2009).*

4.5   Monitoring, Evaluating & Learning

Policy Recommendation

5.   *Ensure the SET Plan generates policy intelligence to support learning and adaptation.*

Insights from Research on Innovation Systems:

> *§5.1. Policymaking for energy innovation is open-ended and uncertain.*
> *§5.2. Policy intelligence helps anticipate emerging opportunities, risks of failure and alternative options.*
> *§5.3. Policy intelligence identifies the specific and changing needs of different innovation systems.*
> *§5.4. Systematic monitoring and evaluation enables learning for future policy improvement.*
> *§5.5. Indicators of innovation policy impact go beyond traditional input-output measures.*
> *§5.6. Monitoring data is needed on the structure, functions and performance of different innovation systems and on the impact of innovation policy.*
> *§5.7. Addressing structural and transformational failures in innovation systems are important evaluation criteria for innovation policy.*

Policymaking for innovation is an open-ended and uncertain process [§5.1]. Systematic monitoring and evaluation of policy effectiveness ensures directed system transformations are responsive and robust to ongoing developments. Policy intelligence helps anticipate emerging opportunities, risks of failure and alternative options [§5.2]. Innovation policies can then be designed to anticipate and capitalize on opportunities while remaining robust to future challenges and innovation failures (Grubler and Wilson 2014, OECD 2015).

Innovation systems are highly specific at sectoral, national and international levels (Hekkert et al. 2007, Borup et al. 2008). Policy intelligence provides information on the specific needs of different innovation systems [§5.3] (OECD 2015).

> *Example: The innovation systems for wind energy in Nordic countries differ significantly in terms of maturity, the strength of industrial networks, and the variety and scope of participating actors and institutions (Borup et al. 2008).*

Policymakers can adapt generic policy mixes to meet these specific needs (Negro and Hekkert 2010, Negro et al. 2012, Bergek et al. 2015). Policy responsiveness to differentiated and changing contexts improves effectiveness. Responsive policy can be stable in addressing strategic priorities and related needs, but also flexible in exploiting emerging opportunities (Grubler 2012).

> *Example: The Strategic Planning Effort (FOKUS) in Sweden includes provision for evaluating and monitoring national RD&D spending.[xxii]. Evaluation identified a university start-up gap in the energy innovation system. This generated a policy response in the form of a new business development unit (Chiavari and Tam 2011).*

Monitoring and evaluation is the main way to generate policy intelligence. Other ways include foresight tools, technology roadmapping, business strategies, and portfolio management (OECD 2015). Systematic policy monitoring and evaluation allows learning from experience to inform future adaptations and improvements [§5.4]. Policymakers should be actively involved in monitoring and evaluating innovation policy as they are best placed to understand the innovation systems for which they are responsible (Hekkert et al. 2007).

> *Example: Monitoring and evaluation has contributed to the success of offshore wind energy in Germany (Reichardt et al. 2016). Monitoring alerted policymakers to slower than anticipated cost reductions. This led to the German Renewable Energy Act introduced in 2000 being adapted in 2004,*

2009 and 2012 to strengthen financial support for the sector (Reichardt et al. 2016).

Example: Limited capacity for monitoring and evaluating electric vehicles in Austria meant policymakers poorly understood the lower than expected levels of diffusion. Relevant policies have not been successfully adapted to support the uptake of electric mobility (OECD 2015). [xxiii]

Policy responsiveness and effectiveness relies strongly on high quality monitoring data. Required indicators extend beyond traditional measures of innovation inputs, such as R&D investments, and outputs, such as patents [§5.5]. Monitoring data is needed on the structure and functions of innovation systems, and how these are impacted by innovation policy [§5.6] (OECD 2015). Analysis of innovation system functioning helps identify blocking or inducement mechanisms that policies can seek to remove or strengthen respectively (Bergek et al. 2008a). Monitoring and evaluation should track the achievements of innovation policy in addressing structural and transformational failures [§5.7] (Chiavari and Tam 2011, Weber and Rohracher 2012). Substantial financial commitments are required to establish and maintain monitoring capacity (OECD 2015).

5 How do the Policy Recommendations Apply to the SET Plan?

Table 1 maps the five general policy recommendations onto the main elements of the SET Plan. These elements are grouped under strategy, governance, and mechanisms. The mapping in Table 1 identifies how and where the SET Plan can incorporate the policy recommendations provided by a systemic perspective on energy innovation.

Table 1. Policy recommendations mapped onto SET Plan elements.

Notes: shade of green denotes strength of mapping (dark = strong correspondence … light = weak correspondence).

Ensure the SET Plan …	STRATEGY		GOVERNANCE		MECHANISMS	
	priority areas and actions	action-specific targets and roadmaps	steering group and management	stakeholder networks	monitoring and reporting	funding mechanisms
1 … is directed by a shared vision towards clear goals.	dark	dark	dark	dark	light-grey	light-grey
2 … builds a strong network among diverse innovation actors.	light-grey	dark	light	dark	light-grey	light
3 … aligns institutions and builds user demand for technological innovation.	light	dark	dark	dark	light	light-grey
4 … coordinates an effective mix of stable innovation policies matched to specific innovation needs.	light-grey	dark	dark	light	light	dark
5 … generates policy intelligence to support learning and adaptation.	light-grey	light	dark	light	dark	light

1.   *Ensure the SET Plan is directed by a shared vision towards clear goals.*

The SET Plan must be articulated in a clear vision for system transformation, communicated through strong and visible political leadership, and shared among a wide range of innovation actors. The vision and purpose of the SET Plan should be consistent with broader EU energy objectives for the internal market, competitiveness, energy security and climate change (Carvalho 2012). The SET Plan should also embed a clear rationale for policy interventions to address structural failures blocking system transformation. The strategic direction of the SET Plan is articulated in the priority areas and their actions, each of which is further developed through roadmaps. The portfolio of actions should align clearly with the goals of the SET Plan. Portfolios should target technologies which support green growth, increase international competitiveness, or are resilient to future shocks (Ruester et al. 2014). The

SET Plan should also strategically target technologies in which individual Member States under-invest.[xxiv] The SET Plan steering group is an important structure for setting priorities, coordinating activities, and evaluating progress towards the overall vision. SET Plan policymakers must be involved not just in co-ordinating and facilitating roles, but also in entrepreneurially leading the required system transformation.

2.   Ensure the SET Plan builds a strong network among diverse innovation actors.

Setting targets and elaborating roadmaps for each of the actions provides a formal mechanism for the SET Plan to build stakeholder networks. These may be specific to an action, or span actions if related to common strategic elements such as coordinating between Member State and EU-level policy. SET Plan networks should involve many different innovation actors in knowledge exchange. Entrepreneurial risk-takers and those involved in establishing market niches play particularly important roles in forming new innovation systems. Available funding mechanisms to support specific SET Plan activities provide an additional basis for interaction between stakeholders.

3.   Ensure the SET Plan aligns institutions and builds user demand for technological innovations.

Identifying requirements for institutional change and alignment is an important part of the SET Plan, both strategically and at a more specific implementation level. Action-specific roadmaps, informed by diverse stakeholders, provide the most relevant opportunity for identifying these system challenges. Policies should target institutional misalignments, including weak market demand and resistance to change by incumbent interests. The SET Plan's indicators and reporting function allows institutional alignment and market demand to be monitored on an ongoing basis.

4.   Ensure the SET Plan coordinates an effective mix of stable innovation policies matched to specific innovation needs.

A mix of policies is needed to address the range of market and structural failures in the EU's energy innovation system. A diverse policy mix requires coordination to ensure policies are aligned with one another and with strategic goals articulated in the SET Plan's action-specific roadmaps. The SET Plan steering group and management structures provide the locus for this coordination role. Funding mechanisms linked to the SET Plan provide a specific means of aligning policy objectives with available public resources. Monitoring further supports the responsiveness of SET Plan policy mixes to the changing needs of innovation actors as innovation systems mature.

5.   Ensure the SET Plan generates policy intelligence to support learning and adaptation.

Innovation systems are dynamic. Experience provides opportunities for learning. Systematic monitoring using appropriate indicators informs adaptive policymaking. Monitoring and reporting is a key element of the SET Plan. The SET Plan's steering group and management should embed learning in its governance. The broader shared vision for the SET Plan should be robust to future change. However, policy mixes identified in the SET Plan's action-specific roadmaps, and the scope of available funding mechanisms, may need adapting to changing circumstances. Stakeholder networks both enable effective monitoring, and provide additional insight into policy effectiveness.

6 References

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Notes

i Both 'SET Plan' and 'SET-Plan' are used as abbreviations in official documents and the SETIS website. We have used the non-hyphenated 'SET Plan' throughout as this is the form used in the EC Communication on the revised integrated strategy (Communication from the Commission C(2015) 6317 final).

ii Conventional studies of innovation focus on science and knowledge generation. Resulting innovation policy for system transformation tends to be narrowly focused on "*the generation of endogenous radical novelty*" [OECD 2015], i.e., the potential for science and technology R&D to develop novel solutions to societal problems. Conventional approaches to innovation policy focus on 'pushing' technology development to compensate for the market failing to adequately incentivise innovation. Policies mainly provide innovation incentives either financially (e.g., research funding) or through protection of intellectual property. Correcting these market failures is the conventional rationale for innovation policy. However this is poorly matched to the vision, goals and structure of the SET Plan.

iii Policy instruments for innovation systems include [OECD 2015]: (1) *redesigning organisations* and transferring authority; (2) accumulating *policy intelligence* through monitoring; (3) creating and sustaining *long-term visions*; (4) funding *R&D* and innovation; (5) funding *critical infrastructure*; (6) providing skills *training and education*; (7) using *public procurement* to create lead markets; (8) designing *standards* to reduce uncertainty; (9) using *regulation* to clarify risks and prohibit activities; (10) changing informal '*rules of the game*' to nurture new communities of interest; (11) supporting *networks* and public-private partnerships; (12) *engaging the public* in shared visions; (13) implementing *innovation programs* to demonstrate feasibility of new applications.

iv "*Policy success in fostering systemic innovation is hampered by an over reliance on single market failure rationales, short-term political processes (i.e. election cycles), and fragmented governance structures and processes … government's role must become quite different from one focused on solving pure market failures. It must not only play its role as a coordinator and facilitator but it must also become more entrepreneurial in enabling transitions. System innovation is also not just an economic, technological or managerial process, but also a political and cultural project that will require leadership, inclusiveness and a shared societal vision to drive it*" [OECD 2015].

v There are many different theories, analytical frameworks and approaches to research on innovation systems. Innovation systems are commonly linked to specific technologies or technology classes, but have also been studied at sectoral and national levels. There are also both structural and functional approaches to innovation systems.

vi An annotated bibliography of all reviewed publications is provided as an online supplement to this policy briefing. Three publications were particularly useful and are recommended as further reading. First, OECD [2015] provides an extensive synthesis of evidence on system transformation. Second, Wieczorek & Hekkert [2012] link structural and functional perspectives on innovation systems to outline systemic policy instruments. Third, Negro et al. [2012] review the various ways in which innovation systems can fail and so provide a comprehensive rationale for innovation systems policy. The authors' own work provides a fourth overview reading, particularly Grubler & Wilson [2014] in which policy recommendations for effectively-functioning innovation systems are generalized from a diverse set of innovation case studies.

vii The authors are very grateful to experts who suggested key literature to review and other comments: Maria Carvalho (LSE), Tim Foxon (University of Sussex), Matthew Hannon (Strathclyde University), Jonathan Radcliffe (University of Birmingham), Peter Taylor (University of Leeds), Anna Wieczorek (Eindhoven University), Mark Winskel (Edinburgh University).

viii One characterisation of structural failures distinguishes infrastructural failures, institutional failures, interaction/network failures, and capabilities failures [Weber and Rohracher, 2012].

ix Innovation policy which overly relies on the success of a single technology or technology class can result in failure [Grubler and Wilson, 2014]. In the early 1980s, the US government strongly backed the development of synfuels to substitute for imported oil. A substantial $4.5 billion investment to rapidly upscale synfuel technologies ultimately failed to meet production goals due to technological, institutional and economic challenges [Grubler and Wilson, 2014].

x Technology portfolios also need to accommodate the varying national resource bases and interests within the EU [Soriano and Mulatero, 2011; Borup et al., 2008]. Pushing innovation which is at odds with these resource bases can be damaging.

xi As of 2011, CLEEN has launched the following collaborative multi-actor networks: Smart Grids and Energy Markets, Measurement, Monitoring and Environmental Assessment, Future Combustion Engine Power Plant, and the Carbon Capture and Storage Programme.

xii Strong commitments to the planning and implementation of research programmes were secured by requiring a 50-50 industry-academia split in research output.

xiii Examples include municipal bus fleets for alternative vehicle technologies, or off-grid applications for small-scale renewable power systems.

xiv The WBSO R&D Promotion Act was implemented in 1994 to encourage private R&D investment in The Netherlands. It is regarded as the single most important R&D policy instrument in the country [Chiavari and Tam, 2011]. The WBSO is a tax credit scheme which reduces the tax on a company's R&D wage bill in proportion to the number of R&D hours worked and the hourly wages of R&D staff. Evaluations of the policy have shown that for every €1 of WBSO tax relief, €1.74 of private R&D investment has been achieved. The policy reduces the tax payable on R&D related wages even further for start-up energy companies.

xv In 2003 the Dutch government set targets to increase its share of green electricity. Government introduced a feed-in tariff system which, for the first time, included biomass digestion [Hekkert and Negro, 2009]. Biomass digestion therefore received greater policy support.

xvi The relative success of biomass digestion in Germany and relative failure in The Netherlands emphasizes important differences between seemingly similar innovation systems [Borup et al., 2008]. This reinforces the importance of policy intelligence on the specific needs of different innovation systems.

xvii Many other authors note this point, including: [Azar and Sanden, 2011; Borup et al., 2008; Jacobsson and Bergek, 2006; Rogge and Hoffmann, 2010].

xviii Negro et al. [2012] found 'stop-go' energy policies to be hampering the development and diffusion of low-carbon technologies in 37 of 51 case studies.

xix Widespread adoption of ethanol-fuelled vehicles in Brazil was also supported by a well-balanced policy mix comprising both technology-push and market-pull instruments [Chiavari and Tam, 2011]. The National Ethanol Programme (Proalcool) awarded subsidies to producers, consumers and the car manufacturing industry. The government also invested in relevant infrastructure such as ethanol pumps at fuel stations. These measures supported an increase in both the supply and demand for ethanol-based products.

xx As examples, energy taxes were started in 1998 and stopped in 2001. Renewable energy subsidies promised for 2002 were actually introduced with lower than promised tariffs in 2003. These subsides were also stopped unannounced in 2006. New renewable energy technology subsidies were introduced in 2007 followed by subsequent cancellation in 2009 [Negro et al., 2012].

xxi Strong policy intelligence helps policymakers identify appropriate supporting policies and incentives at particular stages of development and diffusion [OECD, 2015].

xxii FOKUS is the strategic planning process used by the Swedish Energy Agency, initiated in 2006. It formulates the vision, sets priorities, and identifies the short- and medium-term goals of the programme for energy RD&D, innovation and commercialisation. To achieve these goals, it targets a wide range of measures ranging from basic research and support for large scale demonstration plants to product development [Chiavari and Tam, 2011].

xxiii The development and diffusion of Austria electric vehicles is coordinated under three policies: the Austrian Climate and Energy Fund (financing); the Austrian Research Promotion Agency (programme administration); and the KPC Public Consult (programme administration).

xxiv The centralized strategic coordination provided by the SET Plan can reduce the risk profile of investments and so enable certain technologies to be supported [Ruester et al., 2014].