Storylines of future change in the EU energy technology innovation system

Tyndall°Centre for Climate Change Research

SET-Nav Strategic Energy Roadmap

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Objective

This study provides insights into storylines of future change in the EU's energy system from the perspective of innovation systems analysis.

This study presents the simulation and analysis of a system in order to answer questions of what the random variables in our econometric models is emphasized or de-emphasized in the four different storylines.

The Energy Technology Innovation System (ETIS)

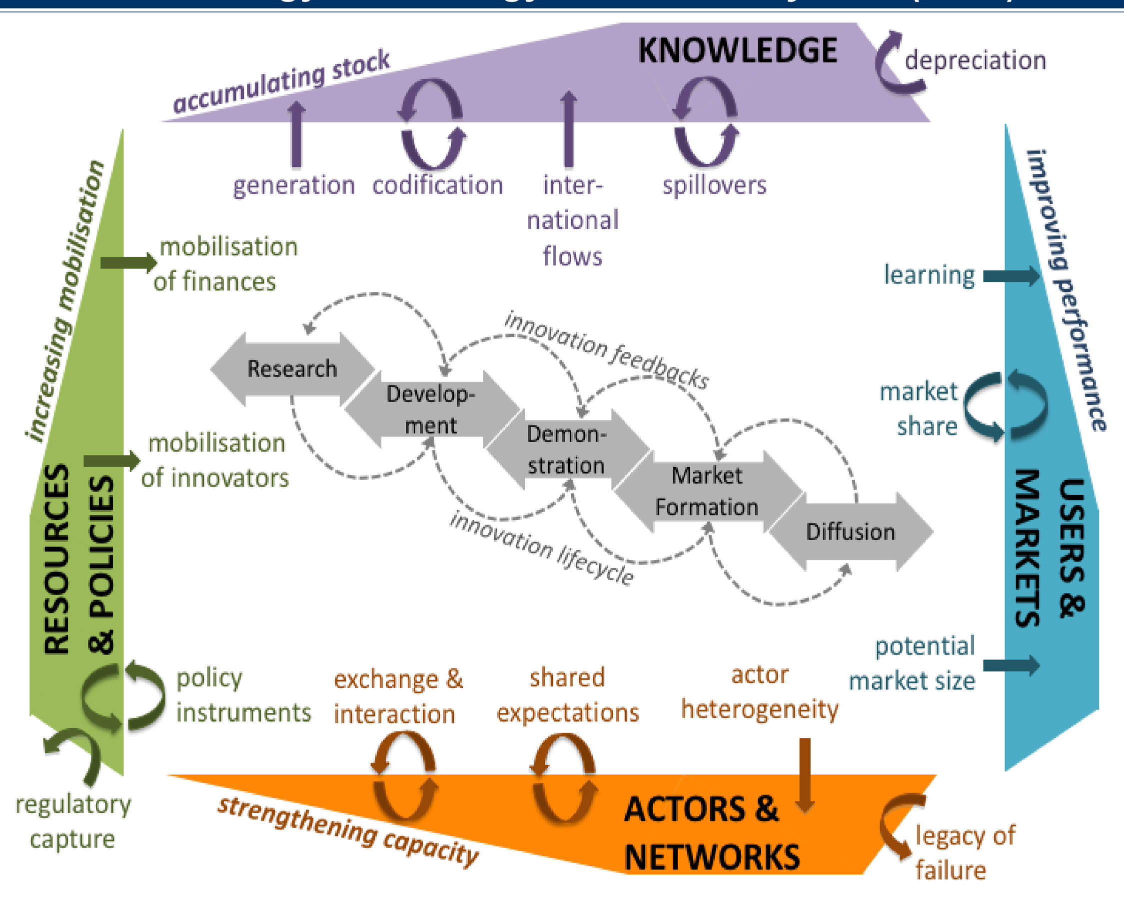

Figure 1. The energy technology innovation system (Grubler & Wilson, 2014)

Indicators of Innovation System Processes

These two dimensions of uncertainty shown in the left panel of Figure 2 combine to create a possibility space which can be explored by the four contrasting storylines shown in the right panel of Figure 2. Working clockwise, the four storylines are:

- **Diversification** = decentralisation + cooperation
- **Directed Vision** = path dependency + cooperation
- **National Champions** = path dependency + entrenchment
- **Localisation** = decentralisation + entrenchment

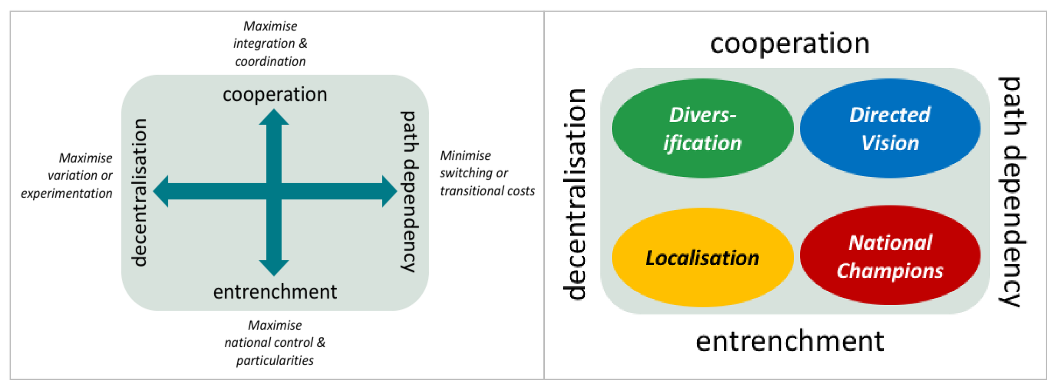

Figure 2. The possibility space for future EU energy systems. Left panel shows a 2x2 scenario typology varying two critical uncertainties; right panel represents four storylines spanning the possibility space.

Indicators of Innovation System Processes

Table 1. Indicators of innovation system processes which are strengthened or weakened in four storylines of future change in the EU energy system. Orange cell = strengthened; Purple cell = weakened; blank cell = no distinctive effect of the storyline.

Innovation system processes	ETIS indicators (and variables in panel regression)	*Diversification*	*Directed Vision*	*National Champions*	*Localisation*
KNOWLEDGE					
Generation	Public energy RD&D expenditure		strengthened		strengthened
Codification	No. of patents				
Spillovers	Energy technology imports (trade)				strengthened
Learning	Learning rate (technology costs)				
RESOURCES					
Policy Stability	Stability in energy RD&D expenditure			strengthened	
Policy Durability	Durability of policy instruments: innovation, regulatory, market-based, and roadmaps	weakened	strengthened	strengthened	
Policy Diversity	Diversity of policy instruments				strengthened
Policy Stability	Stability of policy instruments			strengthened	
ACTORS & INSTITUTIONS					
International Flows	Patent co-inventions (intra-EU)	strengthened			weakened
ADOPTION & USE					
Market Share	Market share (actual market size as % of potential market size)				

Method

Estimate empirically the influence of innovation system processes on three distinct innovation outcomes (patents, coinvention, technology cost).

$$Patents = \beta_1 + \beta_2 \times RDD_{t-1} + \beta_3 \times RDD_{volatility} + \beta_4 \times Coinvention + \beta_5 \times Stock\_Patent + \beta_6 \times Policy_{duration} + \beta_7 \times Policy_{stability/diversity} + \gamma_i + \varepsilon_{i,t}$$

$$Coinvention = \beta_1 + \beta_2 \times RDD_{t-1} + \beta_3 \times RDD_{volatility} + \beta_4 \times Policy_{duration} + \beta_5 \times Policy_{diversity} + \beta_6 \times Trade + \gamma_i + \varepsilon_{i,t}$$

$$Cost\ of\ technology = \beta_1 + \beta_2 \times Capacity_{cumulative} + \beta_3 \times RDD_{cumulative} + \beta_4 \times Policy_{duration} + \beta_5 \times Policy_{diversity} + \beta_6 \times Trade + \gamma_i + \alpha_t + \varepsilon_{i,t}$$

To run a Monte Carlo simulation, we need to assume Orange and Purple cells in Table 1. We generate random draws from a truncated standard normal distribution which cuts off both tails.

Orange cell: Strengthened RD&D expenditure(t-1) is represented by as below:

E.g. RD&D expenditure(t-1)*[Left truncation point(1), right truncation point(2)]

Purple cell: Weakened co-invention is represented by as below:

E.g. Co-invention*[Left truncation point(0), right truncation point(1)]

And then we simulate the Monte Carlo simulation 1,000 times. The simulated mean and standard deviations of the coefficients of the column (1) is in Table 2-4.

Now we can compare the deterministic estimation results in column (1) and column (2)-(5) to see whether the effects of strengthened or weakened coefficients has changed on the outcome variable: number of patents, co-invention, and the cost of technology.

Monte Carlo Simulation Estimation Results

Overall effect in each cell is summarized:
Sky blue(changed to insignificant),
Green(changed to significant)

Table 2. No. of patents (2001-2013)

	Base regression	Diversification	Directed Vision	National Champion	Localisation
RDD(t-1)	0.00113***	0.0011334**	0.0011723*	0.0012093*	0.00113*
RDD volatility	-0.0331**	-0.0334419	-0.0345167	-0.0340144	-0.0332442
Coinvention	0.000372**	0.0003735*	0.0003375**	0.0003274**	0.0003449**
Cum_patent	0.0000674***	0.0000647*	0.0000706**	0.000068**	0.0000682*
Policy durability	-0.00658	-0.0064176*	-0.0066888	-0.0074227	-0.0070249*
Policy stability	-0.266***	-0.2595303	-0.2596585	-0.2647871	-0.270636

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3. Coinvention (2001-2013)

	Base regression	Diversification	Directed Vision	National Champion	Localisation
RDD(t-1)	0.00172***	0.0017044**	0.00174**	0.001731**	0.00174**
RDD volatility	-0.0109	-0.0110632	-0.012372	-0.0111662	-0.0124395
Policy durability	-0.00934	-0.0092552	-0.0099039	-0.0093851	-0.0088173*
Policy diversity	0.0768	0.0858564**	0.0707475*	0.0921282**	0.0701551*
Trade	0.0000157***	0.0000162**	0.0000162*	0.0000176**	0.0000161*

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4. Cost of technology (2011-2015)

	Base regression	Diversification	Directed Vision	National Champion	Localisation
Cum_marekt share	-0.00000000332**	-0.00000000330	-0.00000000352	-0.00000000336	-0.00000000305
Cum_RDD	-0.000219**	-0.0002253	-0.000222	-0.0002252	-0.0002153
Trade	-1.69e-07	0.000000240	0.00000182	0.000000455	-0.00000319
Policy durability	-0.00829	-0.0072822	-0.0066993	-0.007571	-0.0116525
Policy diversity	0.573	0.7992782	0.2717717	0.7480483	0.5461742

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Combining the Monte Carlo Simulation Results with the Storyline Interpretations

Problem solving capacity: Changes in the number of patents and co-invention affect the technological problem-solving capacity of the EU innovation system for new energy technologies.

Learning capacity: Changes in RD&D expenditure (t-1) and volatility affect the learning capacity of the EU innovation system for new energy technologies.

System-integration capacity: Changes in policy environment such as durability, stability and diversity affect the system integration capacity of the EU's energy innovation system with respect to new energy technologies.

Informing Energy Systems Analysis and Modelling

Table 5. Problem-solving, learning, and system-integration capacity under each storyline
Overall effect in each cell is summarized as follows: Strengthen; Neutral; Weaken.

	Diversification	Directed Vision	National Champion	Localisation
Problem-solving capacity (patent, coinvention)	Weaken	Neutral		Neutral
Learning capacity (RD&D(t-1), RD&D volatility, trade)		Weaken	Weaken	Weaken Neutral
System integration (policy durability, stability, and diversity)	Neutral Strengthen	Neutral	Weaken Neutral	Neutral

*Cost of technology regressions include only three of the six technology areas (renewable energy, sustainable transport, energy efficient appliances) due to limited data availability, so results from the cost of technology

- **Diversification** story sees a consistent weakening process of problem-solving. However, there is no consistent effects of the system integration capacity, which can be nonnegative. **Heterogeneous actors in a highly distributed series of learning experiments weaken problem solving capacity, particularly co-invention. Granular and modular technologies may enhance system integration capacity.**
- **Directed Vision** storyline sees overall consistent findings: neutral problem-solving capacity, weakening learning capacity and neutral system integration capacity. **It is a bit difficult to find explanations.**
- **National Champion** storyline sees a consistent weakening process of learning capacity, but system integration capacity ranges from weak to neutral. **Emphasis in a centralized energy system weaken learning capacity of new energy technologies. Also, it may weaken system integration capacity because of a huge influence of incumbents.**
- **Localisation** storyline sees a consistent neutral problem-solving capacity and system integration capacity. However, learning capacity changes from weak to neutral. **A differentiated national and subnational energy policy may weaken learning capacity because direction of national and subnational RD&D can be misaligned.**

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