Indicating resilience of energy systems

A novel assessment approach

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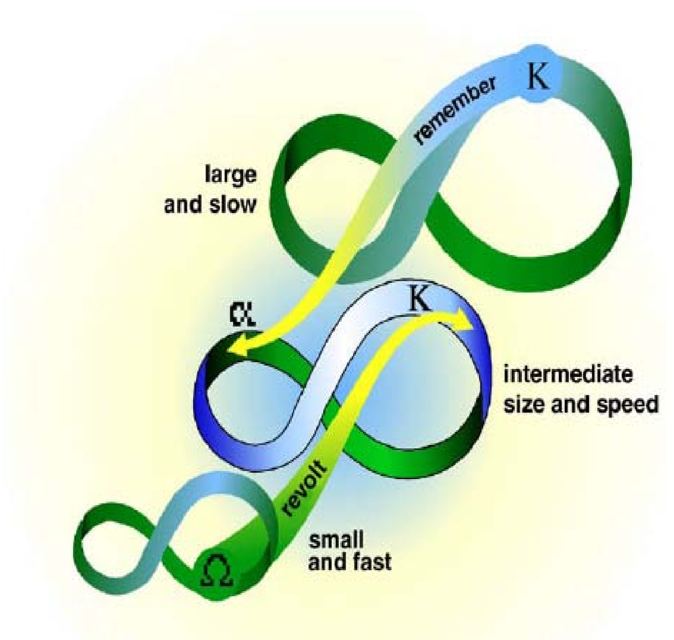
The use of the term Resilience has its root in material sciences and originally describes

Historical resilience definition

> "1: the capability of a strained body to recover its size and shape after deformation caused especially by compressive stress" or
>
> "2: an ability to recover from or adjust easily to misfortune or change". [Enc. Britannica 1824]

The concept of resilience has emerged relatively recently in the scientific debate. The figurative and inspiring term, has been taken up by Holling [1973] to describe ecosystems and has since then been used in other contexts.

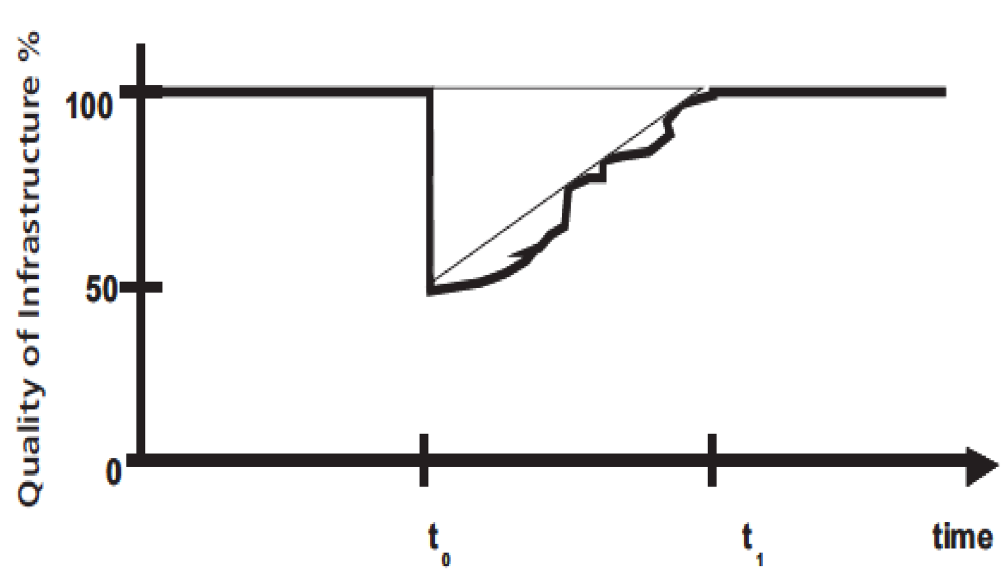


Concept of resilience in ecosystems [Folke 2006]

- periods of exponential change (the exploitation or r phase)
- periods of growing stasis and rigidity (the conservation or K phase)
- periods of readjustments and collapse (the release or Ω phase) and
- periods of re-organization and renewal (the α phase).

Given the broad diversity of concepts it is not easy to find common characteristics, still most definitions emphasize a capacity for successful adaptation in the face of disturbance, stress, or adversity. [Norris et al. 2008]

Given (1) a changing environment, (2) a system too complex to map all interdependencies and thus not fully understood and (3) not only one existing equilibrium state: resilience can be best conceptualized as a learning process, a systems function rather than its structure and can be better conceptualized as process, recognizing that no steady-state exists.



Concept of resilience in engineering [Thierney and Bruneau 2007]

- Response time needed to set a system to its previous state after an external shock (eg. a bridge after an earthquake)

Further not only the maintenance of function to external stress or disaster but also the capability of a system to adapt to positive "surprised" in the short and long term should be taken into account. From an engineering point of view this might be interpreted as the ability to adapt to technological change or innovation.

The resilience definition shaped for energy systems is based on O'Brien and Hope [2010]:

> A resilient energy system exhibits adaptive capacity to cope with and respond to disruptions by minimising vulnerabilities and exploiting beneficial opportunities through socio-technical co-evolution to maintain essentially its function."

It becomes obvious from the above definition that resilience, vulnerability and adaptability are very much interlinked. Vulnerability is often seen as the "antonym of resilience" [Füssel 2007, O'brien et al. 2004]. Here it is argued that especially the capability of a system to adapt should be part of its resilience, but not part of a vulnerability approach.

As resilience emerged as a merely metaphoric concept a single measure of resilience would seem abstract. It is therefore suggested to cluster the indicators in two different indicator sets for vulnerability and adaptive capacity in order to make the underlying assumptions more comprehensive. Thus it is further proposed that resilience be:

$$resilience\ R = \frac{adaptability\ A}{vulnerability\ V}$$

Tierney and Bruneau [2007] developed a framework that can be utilised to identify indicators :

Robustness—the ability of systems, system elements, and other units of analysis to withstand disaster forces without degradation;

Redundancy—the extent to which systems, system elements, or other units are substitutable

Resourcefulness—the ability to diagnose and prioritize problems and to initiate solutions by identifying and mobilizing material, monetary, informational, technological, and human resources; and

Rapidity—the capacity to restore functionality in a timely way,

Indicators encompassing robustness and redundancy can usually be accounted to vulnerability whereas indicators decribing resourcefulness and rapidity tend to be on the adaptability side. More then 50 indicators have been identified and classified (exemplary given below:)

	Criteria	*Indicator / Description*	*Source*
A	*Adaptability of energy system*	*Lifetime (minimize), Modularity (maximize)* *Flexibility of technology is the ability of an energy system to react flexible on changes of frame conditions and demand.*	*[Bohunovsky et al 2006]*
R/A	*Fiscal resilience*	*Fiscal deficit and state of fiscal space (%GDP)* *The government's portfolio of ex ante and ex post financial measures is critically important for the recovery of the economy should a disaster occur.*	*[Mechler et al. 2010]*
V	*Oil and Gas*	*Share of oil and gas installations likely to be hit by a storm of more than 70 m/s gusts within the next 20 years (%)*	*[Williamson et al. 2009]*
A	*Fiscal*	*Domestic investment in renewable energy*	*[Williamson et al. 2009]*
A	*Knowledge*	*Number of technical engineers graduating annually as a percentage of the total population*	*[Williamson et al. 2009]*
A	*Knowledge*	*Availability of hazard maps for floods/droughts*	*[Williamson et al. 2009]*

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