ELSEVIER

Energy Policy 35 (2007) 1505–1516

ENERGY POLICY

www.elsevier.com/locate/enpol

Meso-level analysis, the missing link in energy strategies

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Available online 13 June 2006

Abstract

Energy is essential for human societies. Energy systems, though, are also associated with several adverse environmental effects. So far societies have been unable to successfully change their energy systems in a way that addresses environmental and health concerns.

Lack of policy consensus often resulted in so-called 'stop-go' policies, which were identified as some of the most important barriers regarding successful energy transitions. The lack of policy consensus and coherent long-term strategies may result from a lack of knowledge of energy systems' meso-level dynamics.

The meso-level involves the dynamic behaviour of the individual system elements and the coupling of individual technologies, resulting in interdependencies and regimes.

Energy systems are at the meso-level characterised by two typical aspects, i.e. dynamics driven by interactions between actors, and heterogeneous characteristics of actors.

These aspects give rise to the ineffectiveness of traditional energy policies, which is illustrated with examples from the transport sector and household electricity consumption.

We found that analysis of energy systems at the meso-level helps to better understand energy systems. To resolve persistent policy issues, the traditional 'one size fits all' energy policies are not sufficient. In order to tackle the difficult issues, 'redesign of system organisation', 'target group approach', or 'target group induced system re-orientation' are needed.

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Keywords: Meso-level; Energy policies; Complexity

1. Introduction

Energy is essential for human societies. They enable services such as long-distance transport, long-distance communication, labour-extensive agriculture and manufacturing of goods, comfortable housing, and personal entertainment. Energy systems are, however, associated with several adverse environmental effects ranging from perceived landscape distortion from wind turbines (Dohmen and Hornig, 2004) to global climate change from CO_2 emissions from fuel combustion (IPCC, 2001), human deaths because of air pollution (OECD 2001a, Ch 21), and regional climate change (Patz et al., 2005).

Changes in the way societies convert and use energy imply changes in the structure of societies themselves. Mechanisation of all productive sectors increased productivity and improved labour conditions. The downside of these developments is the ever-increasing dependence on energy. While availability of energy services increases the quality of life, changes in energy systems influence human societies. Abrupt increases in oil prices have initiated economic crises in the early 1970s and early 1980s (Doroodian and Boyd, 2003; Farrell et al., 2004; IEA, 2004a), high transport fuel prices have resulted in social unrest and strikes,[1] and high energy prices threaten to push the purchasing power of the poorest households in developed countries below socially acceptable levels. Real shortage, for example due to electricity blackouts, weather conditions, strikes and war, deeply affects the life of virtually everyone in the society concerned (IEA, 2005a). Therefore efficient management of energy systems is beneficial for the wellbeing of societies.

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[1] E.g. French farmers tend to strike when fuel prices are high, Dutch populist politicians often plead for less tax on fuel, and in late 2005 a majority of the Dutch parliament seems to be willing to compensate households for the high oil prices.

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doi:10.1016/j.enpol.2006.04.013

The increasing knowledge of the effects of the current energy system on human health (OECD, 2001a, Ch 21; Or, 2000), global climate change (IPCC, 2001), and security of supply (Helm, 2002; Wit et al., 2003) calls for major changes in energy systems. As a consequence a transition to an energy system that can stand the consequences of major changes in geo-political unstable regions, reduces GHG emissions sufficiently to halt climatic change, and reduces air pollution below (socially) acceptable levels is vital for modern societies.

So far societies have been unable to successfully change their energy systems in a way that adequately addresses environmental and health concerns. Contrariwise, unsustainable[2] fossil-fuel-based energy is heavily subsidised[3] in both OECD and non-OECD countries to secure energy supply and low prices (IEA, 1999; OECD, 2001a; UNEP/IEA, 2002). Consequently greenhouse gas (GHG) emissions are still increasing and the world is more oil-hungry than ever. At the same time, industrialised countries attempt to improve air quality and reduce the emissions of GHGs.[4] Apparently the policy goal of 'security of supply' conflicts with the policy goal of 'environment and health' (see also: Section 4.2). Policymakers have not been able to successfully cope with both 'security of supply' and 'environment and health' due to a lack of coherent strategies. There exists no policy consensus regarding long-term energy strategies, resulting in *ad hoc* policies.

Lack of policy consensus—and the associated *ad hoc* policies—often resulted in so-called 'stop-go' policies of which the 'Californian wind rush' (see e.g., Junginger, 2000) is an infamous historical example. Stop-go policies are the result of over-enthusiasm (hype) followed up by reduction or removal of tax incentives, resulting in a retreat of investments, followed up by the next hype. Stop-go policies have been identified as one of the most important barriers regarding successful energy transitions (IEA, 2004b; Lensink, 2005).

The lack of policy consensus and coherent long-term strategies presumably results from several factors, including conflicting interests of energy suppliers and users, and lack of knowledge of energy systems' meso-level dynamics.

This paper aims to increase understanding of the dynamics of energy systems and to increase insight on the possibilities and limitations of energy policies. Better understanding can contribute to increased scientific consensus and consequently political consensus on long-term energy strategies. The meso-level is taken as relevant for the understanding of energy systems, specifically regarding changes in the energy system. It is acknowledged that energy systems need to be known at the micro-, macro-, and the meso-levels (Lifset, 1999; Rotmans et al., 2003). Increased insight into the meso-level of energy systems can contribute to a more consistent and coherent understanding of energy systems, and thus enhances existing energy analysis methods rather than replaces them.

This paper assesses the additional insights that meso-level research can offer in addition to those at the micro- and macro-levels. Focus is on the relevance of two specific meso-level characteristics—interdependencies and heterogeneous actors—for energy policies. Increased insights in energy systems should contribute to establish consensus in both the scientific and policy arenas. Policy consensus is needed to end stop-go policies and to implement effective long-term energy strategies.

Section 2 defines the meso-level and elaborates on differences between micro-, macro-, and meso-levels. Section 3 elaborates on specific characteristics of meso-level analysis and the theory of systems changes, which is relevant for meso-level energy analysis and policy options. Section 4 applies meso-level analysis to the transport sector, and Section 5 applies meso-level analysis to the electricity sector.[5] Section 6 concludes with policy recommendations and guidelines for dealing with the meso-level.

2. Positioning the meso-level

Energy systems can be assessed on three distinguished levels: micro, macro, and meso. Fig. 1 shows all three levels and their interrelations.

Energy systems are—in general—considered from the micro- and/or macro-level. We consider the meso-level perspective of energy systems. In the sections below we first elaborate at the micro- and macro-levels. Next we consider the potential contribution of meso-level analysis of energy systems to increased understanding of energy systems.

2.1. *The macro-level*

Macro-level perspectives on energy systems regard the energy system at high aggregation levels and are associated with 'top-down' analysis. Highly aggregated data are favoured when dealing with general problems that require 'policy solutions'. Macro-level energy analysis describes the over-all functioning of systems and is therefore a valuable monitoring and prognostic instrument (see e.g., Focacci, 2003; Kaya, 1990).

A disadvantage of top-down energy analysis is the lack of structure due to the high aggregation level. Decomposition partly helps to overcome this shortcoming; however, the heterogeneity of the underlying data remains neglected.

As a result of neglecting the heterogeneity of the underlying data and following top-down logic, in macolevel analysis the processes at meso- and micro-levels are determined by macro-level dynamics. As a consequence,

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[2] 'Sustainable development' relies on two key concepts: first, the idea of 'needs', and second, the idea of 'limitations' on the environment's ability to meet present and future needs (OECD, 2001c, p. 38).

[3] "Subsidies continue to distort the energy market in favour of fossil fuels" (EEA, 2002, p. 59)

[4] As agreed in the Kyoto protocol (UNFCCC, 1997).

[5] Transport energy use and household electricity consumption are known to be persistently increasing in OECD countries (EEA, 2005; IEA, 2005a; IEA, 2005b; OECD, 2001a).

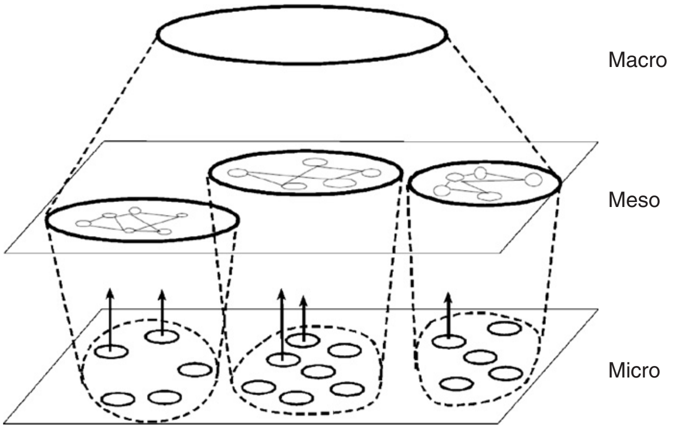

Fig. 1. Schematic representation of micro-, meso-, and macro-levels. *Source*: Geels (2002).

macro-analysis is not able to foresee any trend-breaking events, which results in 'unsurprising' forecasts (Craig et al., 2002). This is known as the 'macro-bias' (Elzen et al., 2002) or 'economic paradigm' (van Beeck, 1999).

For example, the correlation of energy use with GDP worked with high precision for several decades. Nevertheless, projections based on the assumption that a relation that worked successfully for several decades would continue and that GDP growth would follow historic trends failed. The projections exceeded the actual outcomes because economy's growth rates slowed down and because the correlation with GDP was not sustained after the 1970s (Craig et al. 2002).

2.2. *The micro-level*

Micro-level perspectives on energy systems regard the energy system at low aggregation levels and are associated with 'bottom-up' analysis. Disaggregated data are favoured when dealing with specific problems that require 'engineering solutions'. Micro-level energy analysis describes the functioning of elements of systems and is therefore a valuable evaluative/assessment instrument for products (see e.g., Damen and Faaij, 2003; Hondo, 2005; MacLean and Lave, 2003).

A disadvantage of bottom-up energy analysis is limited information on the interaction of system elements on the overall system performance, which results in questionable representativeness of data and allocation problems (Benders et al., 2001; Heijungs and Huijbregts, 2004; Kok et al., 2001). Both issues introduce uncertainty in the aggregated results. As a result of data uncertainty, a greater level of variability is introduced and therefore bottom-up analysis tends to widely 'over-forecast' or 'under forecast' at the top-level (Kahn, 1998). Because technologies are—generally—implemented where the specific local circumstances are favourable, and because contextual requirements—like infrastructure—are neglected, bottom-up methodology introduces an 'optimistic bias' in the data. This 'optimistic bias' results in bottom-up approaches overly optimistic conclusions regarding possible system changes, which is known as the 'engineering paradigm' (van Beeck, 1999). Therefore, bottom-up analysis is unable to assess changes in the energy system, like the implementation of new technologies or the possibility to save energy. This makes bottom-up analysis not suitable for scenario studies.

For example, an EWEA/Greenpeace study indicates that producing 12% of the world's electricity from wind energy in 2020 is feasible (EWEA/Greenpeace, 2003). This optimistic perspective on wind energy is based on bottom-up extrapolations from non-representative data, e.g. this study assumes increasing capacity factors (mainly based on increasing hub-height), and does not foresee electricity grid limitations (mainly based on experiences in Denmark). Nevertheless, this study overlooks that the 'success stories' are the result of specific local circumstances, new turbines are likely to be sited on less windy spots, wind energy in northern Germany faces already the limits of the electricity grid (with about 3% wind energy), and institutional frameworks limit the implementation speed.

2.3. *Combined micro- and macro-level approaches*

Top-down and bottom-up models tend to arrive at different conclusions (Unruh, 2000; van Beeck, 1999). In order close the gap between bottom-up and top-down approaches, and to overcome the shortcomings of the approaches mentioned above, so-called hybrid top-down/bottom-up approaches have been developed (e.g., Benders et al., 2001; Frei et al., 2003; Jaccard et al., 2004; McFarland et al., 2004). These hybrid approaches improved the understanding of energy systems by linking actual technologies to macroscopic developments. Nevertheless, hybrid approaches generally circumvent rather than cover the meso-level and therefore hybrid approaches do not sufficiently explain energy systems. In-between meso-level analysis is therefore needed to bridge the gap between the macro- and micro-levels.

For example, the MESSAGE-MACRO modelling framework is a sophisticated hybrid top-down/bottom-up modelling framework used for medium and long-term energy scenarios (Messner and Strubegger, 1995; Messner and Schrattenholzer, 2000).[6] Nevertheless, the organisation structure (e.g., institutional framework) is not explicitly implemented and actors are considered homogeneous (e.g., by neglecting differences in responses to carbon taxes by different household groups and different cultures).

2.4. *The meso-level*

Fig. 1 shows that the meso-level is wedged between the macro- and the micro-levels. Therefore, the meso-level describes the energy system from an intermediate aggregation level, often the sectoral-level, and this type of

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[6] See also: http://www.iiasa.ac.at/Research/ECS/docs/models.html.

analysis acknowledges the mutual coherence of groups of actors.

The meso-level involves the coupling of individual technologies and groups of actors, resulting in interdependencies and regimes. Coupling should not be confused with aggregation (Dopfer et al., 2004). Meso-level analysis focuses on the dynamic behaviour of the interdependencies of individual system elements, rather than on aggregating individual system elements. The dynamic behaviour of the interdependencies of individual system elements may result in complex behaviour of the over-all system. Meso-level analysis is associated with so-called systems analysis (Battjes, 1999), and depends on data acquired from both bottom-up and top-down energy analyses.

Meso-level analysis of energy systems makes energy analysis more consistent and coherent by bridging the gap between the micro- and macro-levels. In contrast to the hybrid top-down/bottom-up approaches (see Section 2.3), the gap between the macro- and micro-levels is not circumvented in meso-level analysis. Instead, meso-level analysis focuses on dynamic interactions between individual elements of energy systems as indicated in Fig. 1. Moreover, meso-level analysis provides additional information on system's responses to changes, or—in other words—societies' responses to energy policies.

3. Theoretical framework of the meso-level

Energy systems can be studied at the macro- and micro-levels. Meso-level energy analysis is characterised by two typical aspects, i.e. interdependency dynamics, and heterogeneous actors.

Insights in the heterogeneous characteristics of actors allow understanding of the elasticity of energy demand, policy optimisation, and technological diffusion. Section 3.1 elaborates on heterogeneous actors from a meso-level perspective.

Insights in the interaction-driven dynamics allow understanding of causalities, trade-offs, feedbacks, natural resource management, and long-term energy strategies. Section 3.2 elaborates on system dynamics from a meso-level perspective.

Insights in system organisation allow understanding of options to change systems. Section 3.3 elaborates on the theory of system changes.

3.1. Heterogeneous actors

Macro-level energy analysis is able to cover all relevant actors. The actors, though, are generally treated as being homogeneous. The effect of simplifying heterogeneous actors to homogeneous actors influences the dynamics of the system, especially regarding initiatives to alter the system (e.g., policies). Socio-economic systems are made up of heterogeneous assemblages of individual actors and cannot be well presented when treated as uniform (Chave and Levin, 2003).

Governments, companies, and energy systems themselves differ from country to country and are therefore heterogeneous at the international level. Consumers are yet another heterogeneous group of actors. Consumers may differ in income, educational level, cultural background, habitat (rural or urban), and worldview (see Section 4.2). Therefore different groups of actors have to be approached differently in order to achieve efficient policies (see Section 4.3).

Regarding technological diffusion, it is useful to look at actors in terms of technology adopters. Relevant actors—like companies, consumers, and governments—can all be considered technology adopters. Different adopter categories can be classified as: innovators, early adaptors, early majority, late majority, and laggards (Rogers, 1995, p.262). The heterogeneous aspect of consumers is also the driving force for changes. Transitions happen in different phases and critical mass is obtained via early adopters (see Section 5.3).

The heterogeneous actors are subjected to the 'energy dilemma', i.e. on one hand governments consider energy a basic need and (are inclined to) subsidise[7] the energy production sector substantially, while on the other hand governments consider excessive energy use undesirable and (are inclined to) impose tax[8] on energy use (Helm, 2002). This apparent schizophrenia in energy policies reflects the diversity and hierarchy in energy needs (Frei, 2004). Removal of adverse energy subsidies and changing the tax structure for motor vehicle use—'getting the prices right'—would end the energy policies inconsistency (IEA, 1999). Fully applying the Polluter Pays Principle could, however, also limit access of low-income groups to 'basic energy needs' and thus implies equity concerns (OECD, 2001a, p178).

3.2. Interdependency dynamics

As stated in Section 2.4, the meso-level is determined by 'interactions'. One type of 'interaction' is feedback. Feedbacks induce complex behaviour and organisation (Prigogine and Stengers, 1984).

An example of feedback is the OECD pressure–state–response (PSR) framework. Human activities cause 'pressures' on the 'state' of the environment and natural resources. Autonomous feedback between 'pressure' and 'state' appears, e.g., when increased energy consumption leads to increasing oil prices. Non-autonomous feedback appears when information about 'pressure' and 'state' leads to 'response' by, e.g., governments, non-governmental organisations, industries, consumers, and international institutions. Regarding energy, GHG emissions and concerns about resource depletion initiated complex feedbacks resulting in the Kyoto protocol, renewable energy policies, the first Gulf war, and the fashion to drive inefficient cars

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[7] Dogmatic policy response #1

[8] Dogmatic policy response #2

like sport utility vehicles (SUV), all changes on the 'pressure' and 'state' of the environment and natural resources.

At the macro-level, feedbacks are rarely visible. A well-studied exception in the energy systems is the so-called 'rebound effect' of energy efficiency improvement (Bentzen 2004; Birol and Keppler, 2000; Grote Beverborg, 2001; Noorman, 1995). At the meso-level, 'interactions' are more persistent and drive the important processes (Chave and Levin, 2003). Therefore, meso-level dynamics are often dominated by feedbacks.

As a result of dominant feedbacks, energy systems are at the meso-level characterised by typical aspects. First, due to feedbacks, systems may behave according to 'the whole is more than the sum of its parts' (Heylighen, 1992)(see Section 5.1), which makes systems difficult or impossible to analyse by reduction (Lovelock, 2003). This phenomenon makes energy systems hard to be understood intuitively and hinders the development of coherent policies. Feedbacks may also cause the 'lock-in' of inefficient technologies (see Section 4.1). Second, past co-evolutionary developments determine the present institutional organisation, 'institutional lock-in'. The current institutional organisation is unsustainable in a sense that it encourages increasing energy consumption (see Section 5.2).

3.3. *Taxonomy of systems' changes*

As Section 3.2 stated, systems with persistent feedbacks develop structure and organisation. Energy systems are organised as a consequence of their adaptive development in the past. The direct result of system organisation is that options to change the system have different entries at different levels in the hierarchy of the organisation. Therefore system changes are also hierarchically organised. Fig. 2 shows the hierarchy of system changes.

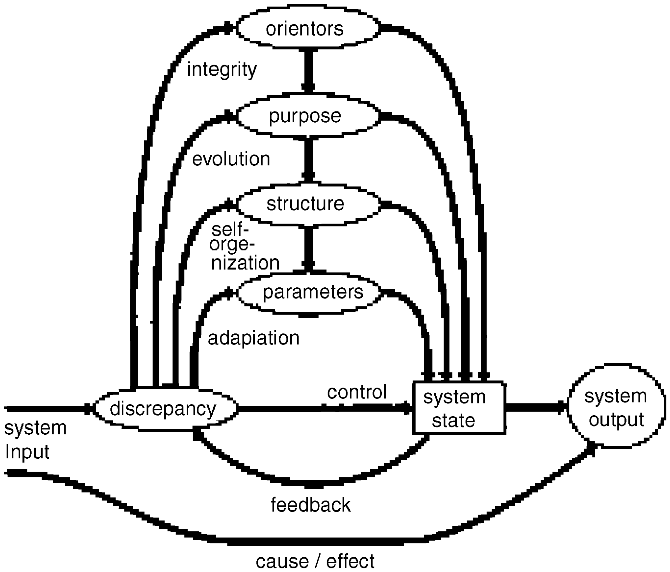

Fig. 2. Hierarchy of system changes. *Source*: Bossel (1994, p. 31).

The way energy systems are organised determines to a large extent the policy options to alter the system. Parameter adaptation, structural re-organisation, purpose evolution, and orientor[9] integrity determine the 'level' of possible system changes. The higher the level of the change, the more change is possible, but realisation of the change will be harder. 'High level' system changes can be considered unrealistic, while 'low level' system changes can be considered unambitious. The quest for energy transitions implies therefore finding feasible options for change at the highest 'level' possible.

The theories related to aspects are discussed in this section: heterogeneous actors, meso-level dynamics, and taxonomy of systems' changes are applied to issues associated with passenger transport, and electricity production and consumption in Sections 4 and 5, respectively.

4. Passenger transport

Passenger transport is one of the most difficult sectors to reduce energy use and GHG emissions (van der Wal and Noorman, 1998). Despite the advances in efficiency of the internal combustion engine (ICE), passenger transport is an ever-increasing energy user. Efficiency improvements of the ICE are generally offset by increases in transport performance (passenger kilometres *per* unit of time), increases in mass and the introduction of energy-inefficient comfort enhancements like air-conditioning. This section elaborates on passenger transport from the meso-level perspective. Focus is on passenger car transport, but public transport is discussed in terms of an energy efficient alternative.

4.1. *Technology lock-in*

Meso-level dynamics can result in adaptive behaviour due to feedbacks (see Section 3.1). Adaptive behaviour can result in organisation of which 'path dependency' or 'technological lock-in' is a type of organisation relevant for energy technologies (Arthur, 1999; Unruh, 2000). Passenger transport is 'locked-in' to ICE technology and the associated liquid fuels.

Passenger transport efficiency improvements can be achieved at different levels of the systems' changes hierarchy (see Section 3.3). Besides attention to ICE efficiency improvements, both scientists and policymakers emphasise the environmental performance opportunities associated with alternative fuels. Alternative fuels include: fuels from Fischer–Tropsch synthesis, natural gas, bio-ethanol, methanol (& dimethylether), electricity, and—of course—hydrogen (Gielen and Unander, 2005).

Hydrogen as a transport fuel is associated with a meso-level transition barrier, i.e. lock-in of traditional fuels.

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[9] 'Orientors' are system environment properties that force upon systems and must be considered in the orientation of system behaviour and development (Bossel, 1994, p. 233-237).

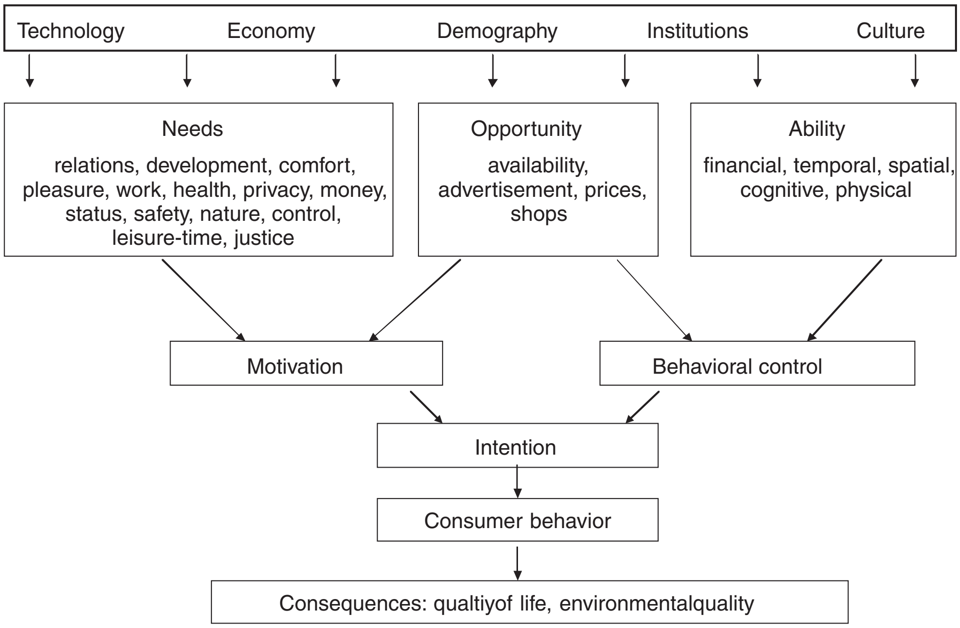

Fig. 3. The needs–opportunity–ability model of consumer behaviour. *Source*: Gatersleben and Vlek (1998); OECD (2001b).

Traditional fuels are locked-in because fuel stations do not have an incentive to sell hydrogen since no one owns hydrogen-fuelled cars, and no one has hydrogen-fuelled cars because fuel stations do not sell hydrogen. Carbon-based renewable alternatives can be mixed with traditional fuels and fuel ICEs. Therefore these fuels do not suffer from the lock-in of traditional fuels and can potentially replace mineral carbon by renewable carbon. The fuel distributing infrastructure determines the possible technological modes.

4.2. Needs, opportunity, and ability of heterogeneous actors

Public transport is more energy-efficient than average passenger car transport (van den Brink and van Wee, 1997) and e.g. a Volkswagen Lupo needs less than 3 l to drive 100 km. Nevertheless most people in industrialised countries do not use public transport or drive Lupo's. Consumer behaviour apparently does not optimise on energy efficiency. The needs–opportunity–ability (NOA) diagram in Fig. 3 is used as a model of consumer behaviour in contrast to the (macro-level) *homo economicus* model of consumer behaviour. Therefore a socio-psychological model is used instead of an economic one.

Consumers are heterogeneous in their needs, opportunities, and abilities regarding personal transport.

- *Needs*: The needs of personal transport are not solely determined by the ability to transport persons, but also by travelling time, comfort, status, perceived safety, and *etceteras*. Moreover, cars are often equipped for purposes happening only a few times a year, e.g. much of the cars used for travelling daily to work are equipped for family holidays.
- *Opportunity*: Successive ownership of cars determines much of the opportunity framework of low-income groups. Regarding high-income groups the opportunity framework is set by automobile producers. The incentive for automobile producers to produce efficient cars is almost solely determined by the market.
- *Ability*: Ones purchasing power determines one's ability to choose a transport mode. Wealthy consumers have more options to choose from, including very efficient, but expensive vehicles like hybrid cars. The less wealthy consumers are often stuck with cheap, old, less-efficient, technologies. Next to purchasing power, educational level determines the ability to assess or estimate the life-cycle costs of transport modes.

As successive car ownership is common,[10] only a fraction of car buyers give incentives to car producers to modify the composition of the future car fleet. Second-hand buyers can only buy cars that the original buyers are discarding. In order to understand who uses what kind of car, the NOA model should be applied consecutively to separate actor categories. The NOA model clarifies the effects of macro-level policy targeted at car producers and first-hand buyers, on the—broadly speaking—quality of life of second-hand car buyers. The NOA model bridges the gap between macro-level policy and meso-level dynamics.

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[10] E.g. between 1998 and 2004, only 22% of the passenger car sales in the Netherlands were sales of new cars (CBS, 2006).

4.3. Transition considerations/policy options

Transitions to far more efficient transport systems are possible and feasible. Both the technological lock-in and the heterogeneous actors, however, need to be considered.

Energy infrastructure is technologically locked-in and therefore changes in energy infrastructure require investments. The transition to the hydrogen-fuelled transport requires huge investments and no clear benefits in terms of energy efficiency improvements. Local harmful emissions, however, are zero in hydrogen-fuelled transport modes. Electrical power shows clear benefits for urban transport. Therefore this transition is only sensible in urban areas and can in such areas be achieved without confronting the associated transition barriers.

Passenger transport can also be more energy efficient without transitions to different modes, thus without a so-called modal shift. Road pricing, vehicle and fuel taxes are quite often imposed in policies to discourage automotive fuel consumption and to fully reflect the social and environmental costs of growing motor vehicle use (OECD, 2001a, p. 178). However, different categories of car owners have different needs, opportunities, and abilities to shift to more efficient transport modes. Moreover, the opportunities of one category of car owners are determined by the behaviour of another category of car owners. Consequently, fuel taxes might be considered unfair as to cut off the basic need for transport to the lowest income groups. On the other hand, energy taxes have little effect on the purchasing power of medium and high-income groups. Moreover, tax deductions for employer provided motor vehicles are in favour of relatively large and inefficient new-bought cars, which enter the second-hand market a few years after. Therefore, policies to reduce passenger transport fuel consumption need to be diversified to the car owner categories the policies want to address. New-bought cars in general, and especially employer-provided motor vehicles deserve special attention and targeted policies, because this small category determines the opportunities of the other categories. Rather than the 'one size fits all' approach of a carbon tax, 'policy packages'[11] can approach different groups of actors differently. Policy packages can fulfil the wishes of different actor categories simultaneously and therefore smoothen the path to political consensus.

5. Electricity production and consumption

5.1. The whole differs from the sum of the parts

When (electricity) energy technologies are compared in a LCA-like manner, the functional unit tends to be kWh (Gagnon et al., 2002; Goralczyk, 2003; Hondo, 2005; Kammen and Pacca, 2004; Sims et al., 2003; Sundqvist, 2004). This functional unit makes sense both from the macro- and the micro-levels, but not from the meso-level because multiple interactions dominate electricity production.

Power plants do not operate isolated, but interact with each other in order to meet energy demand. When 'new' energy technologies—like wind turbines and solar PV—penetrate the system, conventional energy technologies need to adjust their operating strategies, which results in system losses. Therefore the amount of avoided primary energy from wind turbines or solar PV depends on the way the system of the conventional power plants responds to these technologies. Fig. 4 shows model results of such system responses applied to the Netherlands.

Total fractional coverage (TFC) stands for the amount of renewable electricity produced (wind and solar) divided by the total demand for electricity. In Fig. 4, the x-axis shows the solar/wind ratio, and the y-axis shows the amount of fossil fuels saved *per* amount of renewable energy produced.

As shown, solar and wind are relatively efficient at low TFC values. Moreover, mixing solar and wind does not influence the over-all performance strongly. When wind and solar supply is low, conventional power plants can remain faithful to their 'old' strategy and save fossil fuels by lowering their output.

At high TFC values solar and wind save relatively less fossil fuels, and mixing solar and wind does influence the over-all system performance strongly. When wind and solar supply is high, conventional power plants have to

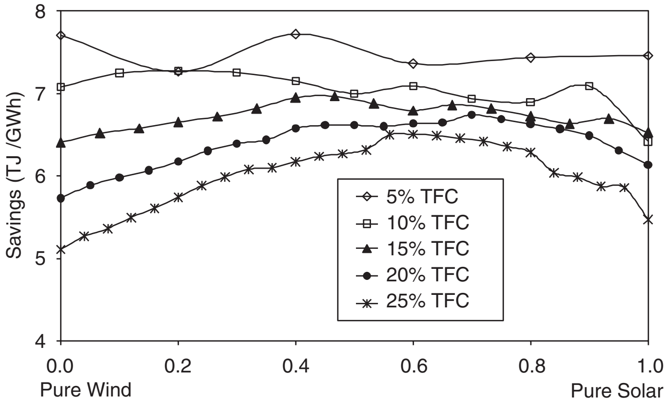

Fig. 4. Efficiency of solar PV and wind energy in the Netherlands. *Source*: based on Schenk et al. (submitted for publication). (Note: savings = avoided fossil fuels per amount of renewable electricity produced, TFC = total fractional coverage: the % total electricity demand covered by wind and solar electricity.

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[11] "Because of the complexity of many of the most urgent pressures on the environment, (…) single policy instruments will seldom be sufficient to effectively resolve these problems. Instead, combinations of policy instruments will be required which target the range of actors affecting the environment, draw on synergies for realising the different environmental policy objectives and avoid policy conflicts, and which address any social or competitiveness concerns about the policy instruments." (OECD 2001a, Ch 25).

abandon their 'traditional' strategy and lower their output far from their designed part-load operations. At those low part-loads, power plant efficiencies are significantly lower than at full-load, resulting in lower over-all system efficiency. Moreover, specific dynamics of solar and wind do interfere differently with the conventional power plants, and mixing them influences the over-all system performance. As a consequence, 'the whole differs from the parts' and therefore average figures are misleading when applied to medium- or long-term energy scenarios and energy policies (Hitchin and Pout, 2002).

Fig. 4 shows that—due to interactions between actors—for energy systems 'the whole differs from the sum'. The latter effect is relevant for long-term energy strategies. The electricity system can be very sensitive to relatively small changes. Long-term energy strategies should not solely focus on efficiency and diversity of primary sources, but also consider the interdependencies of the system elements. Including this aspect affects long-term energy strategies. Without interdependencies included power plants like Integrated Gasification Combined Cycle (IGCC), and Combined Heat and Power (CHP) are preferred because of their efficiency. Unfortunately they are also very inflexible and thus decrease the flexibility of the electricity producing system, and thus make it harder for large-scale wind energy to be implemented.

Similar reasoning also affects primary energy sources. Primary energy supply is often simply aggregated and renewable energy sources are often compared to traditional energy sources by means of kilowatt-hour prices. These practices are not correct from the meso-level perspective. Wind energy cannot be compared to gas turbines, due to the dynamic character of the energy technologies. Gas turbines are used to cover peak demand in electricity demand, while wind energy is produced depending on the weather and independent on electricity demand. Moreover e.g. mixing wind energy and solar PV saves significantly more fossil energy than using just one of these technologies.

5.2. *Institutional organisation and electricity consumption increase*

Electricity supply is determined by electricity demand. Electricity demand is still increasing in OECD countries and signs of saturation are not visible yet. This section shows how the organisational structure (and also the institutional framework) may explain this phenomenon. The system seems to be 'designed' to increase demand. Policies to decrease electricity consumption have not resulted in (long) periods of decreasing consumption until present because the applied policy instruments are not effective.

In the current system, individual households purchase electrical appliances that increase wellbeing. Housekeeping has never been less time-consuming, due to electrical appliances like micro-wave ovens, dishwashers, and vacuum cleaners. Entertainment and communication is also electricity based by means of personal computers, televisions, audio-equipment, DVD-players, and *etceteras*. These appliances require households to purchase electricity. Households have also incentives to reduce energy use as it will reduce their energy bill.[12]

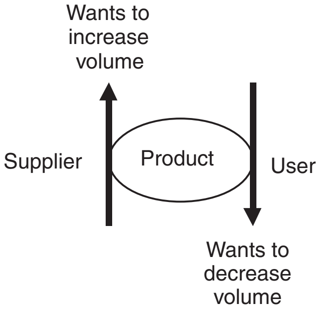

Fig. 5. Conflicting incentives. *Source*: OECD (2004a); OECD (2004b).

Electricity producers, on the other hand, do not have incentives to sell less energy to households. Contrariwise, the more electricity is sold, the higher the profit usually is for the electricity company. Therefore, there is little or no incentive from these companies to increase the energy efficiency of the consumers' energy services. Fig. 5 shows the conflicting incentives of energy suppliers and energy consumers.

The conflicting incentives lead to ever-increasing energy use because of the asymmetric relation between energy companies and individual households. 'John Doe' is neither specialist in energy efficiency, nor is the energy use of a new device his major concern. The most remarkable, however, is the long time delay between energy use and bill payment. 'John Doe' is never able to understand what parts of his actions eventually resulted in his energy bill. Therefore households with incentives to cut expenditures on their energy bill are virtually paralysed by lack of information.

LCA studies show that—in general—the lion's share of energy use is allocated to the user phase rather than the production phase. Electrical equipment is, however, designed for comfort, performance, and low production costs. As a result, several apparatus are designed with external transformers and stand-by functions, both consuming electricity non-stop and accounting for 12% of the electricity consumption of the average household (Harmelink and Blok, 2004). Producers of electrical equipment have no or little incentive to reduce the life-cycle energy use of their products. As long as incentives are conflicting, energy policies will have 'red-queen game'[13] dynamics and

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[12] It should be noted that the desire to save energy is often not dominant at the moment of purchasing.

[13] Red-queen games are named after the red-queen character in Lewis Carroll's "Through the looking glass". See for an application of red-queen game concept on economics: (Baumol, 2004).

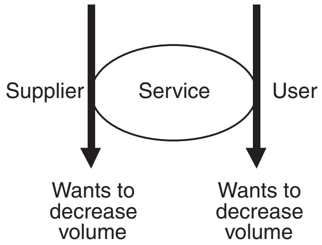

Fig. 6. Aligned incentives. *Source*: OECD (2004a); OECD (2004b).

energy efficiency will at best compensate increasing demand: 'running to stand still'.[14]

5.3. *Transition considerations/policy options*

Electricity production is complex in a sense that 'the whole does not equal the sum' and therefore comparing electricity prices as top-down assessment and LCAs as bottom-up assessment does not provide sufficient information. Reduction of GHG emissions due to renewable electricity production depends strongly on local conditions and therefore path-following of countries like Denmark does not *per se* result in more sustainable electricity production. Consequently, policies that specifically support distinct renewable energy technologies, like wind or solar PV, are likely inefficient and should be reconsidered.[15] Instead policies should focus on GHG emissions and geopolitical circumstances of the energy resources.

The organisational relation between households, energy companies, and producers of electrical devices should be reconsidered. Fig. 2 shows that the orientor of the system is the highest parameter in the systems' hierarchy, and in the case of electricity production and consumption the orientor is pointing in the wrong direction. Energy companies should be transformed from energy sellers to service-oriented companies.[16] Households should not own electrical devices anymore, but obtain services. Fig. 6 shows how in a service-oriented organisation, incentives are aligned towards less energy consumption.

A possible option to realise service-oriented household energy systems is to make use of the fact that actors are heterogeneous and fit into different adopter categories (Rogers, 1995, p. 262). Early adaptors should be approached with 'cool toys',[17] e.g. electrical devices equipped with wifi in order to provide direct feedback to the consumer. Moreover, by doing so electrical devices can—in the end—be controlled by the energy company and reduce peak-load demand.

6. Conclusions

Assessment of the meso-level of energy systems reveals insights in addition to micro- and macro-level analyses. These insights allow the design of environmentally and socially sustainable energy policies.

6.1. *System insights*

Meso-level analysis provides insights in energy technologies relevant for long-term planning. Meso-level energy analysis is characterised by two typical aspects, i.e. interdependency dynamics, and heterogeneous actors.

Interdependency dynamics may result in quite different figures than those foreseen based on macroscopic indicators, especially when renewable energy sources are considered. For example, Section 5.1 shows how 'the whole differs from the sum' regarding electricity production. A main feature of interdependency dynamics is institutional organisation. Institutional organisation can be independent in a flexible organisation, or dependent in a rigid organisation.

Heterogeneous actors result in heterogeneous responses to policies, because the needs, opportunities, and abilities of the relevant actors differ. In order to design environmentally and socially sustainable energy policies, the relevant actors need to be categorised and the interactions between the categories need to be assessed.[18]

Fig. 7 presents a diagram summarising the relevant meso-level characteristics, interdependency dynamics, and heterogeneous actors. Both characteristics are relevant regarding energy policies; therefore the meso-level characteristics determine the 2×2 matrix of energy policies. Section 6.2 elaborates on the policy implications of the 2×2 matrix of meso-level characteristics.

6.2. *Policy implications*

Meso-level analysis is relevant for energy policies. A consequence of not understanding systems sufficiently is to implement the wrong policy, or 'to bet on the wrong horse'. Regarding renewable energy betting on wrong horses followed by drastic changes in policies—so-called 'stop-go' policies—is very harmful for the development of renewable energy technologies (Lensink, 2005). Policy-makers should develop policies that can be expected to

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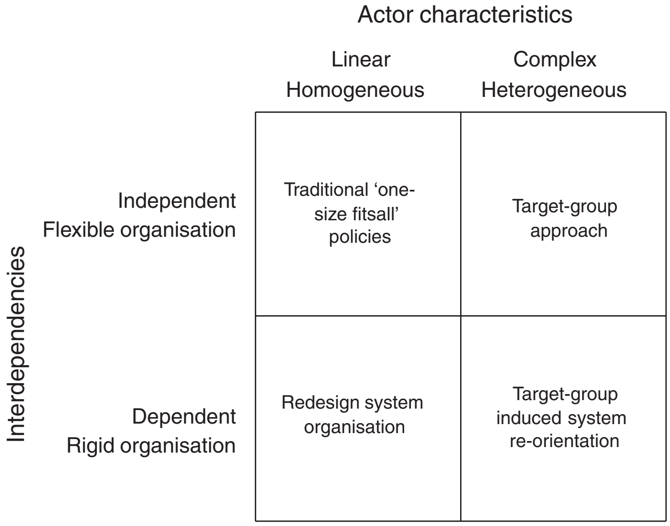
[14] Actually, the red-queen said: "You see, it takes all the running you can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that." (Carroll, 1946, p. 189).

[15] The IEA strongly advices the Netherlands to stop supporting solar PV in the Netherlands (IEA,2004b). In general focus should be on environmental goals rather than subsidising a particular technology in order to encourage innovation (Dobesova et al., 2005).

[16] This 'service-oriented strategy' has proven to be successful in several industrial sectors (OECD, 2004a, OECD, 2004b).

[17] Coolness is a necessity!

[18] See also: One size fits all? Policy instruments should fit the segments of target groups. C. Egmond, R. Jonkers, G. Kok, *Energy Policy*, In Press. Target group segmentation makes sense: If one sheep leaps over the ditch, all the rest will follow. C. Egmond, R. Jonkers, G. Kok, *Energy Policy*, In Press. A strategy and protocol to increase diffusion of energy related innovations into the mainstream of housing associations. C. Egmond, R. Jonkers, G. Kok, *Energy Policy*, In Press.



Interdependencies	Actor characteristics: Linear, Homogeneous	Actor characteristics: Complex, Heterogeneous
Independent, Flexible organisation	Traditional 'one-size fitsall' policies	Target-group approach
Dependent, Rigid organisation	Redesign system organisation	Target-group induced system re-orientation

Fig. 7. Energy policies in relation to meso-level characteristics. *Source*: based on Perrow (1984, p. 327).

remain effective on the long run, rather than subsidising the 'technology of the week'.

Stimulating single technologies should be considered as an attempt to change energy systems on a 'low' level of the hierarchy of system changes, while changes on 'higher' levels allow for more flexibility. Policy targets with too much detail—like prescribed percentage of renewable energy, percentage of biofuels, and waste paper recycling rate—do not *per se* aid curbing GHG emissions. The focus should be on the institutional framework that can help a transition towards a sustainable energy system, rather than filling in the details.

Policies to enhance system changes towards more sustainable energy systems are—in general—focussed on uniform approaches. The heterogeneous actors' aspect of meso-level theory, however, suggests that differential approaches are potentially more effective than uniform approaches. Moreover, differential approaches allow the design of environmentally and socially sustainable energy policies, which provide an escape from the 'energy dilemma' mentioned in Section 3.1.

The adaptive nature of the energy system at the meso-level also explains some of the important transition barriers. The organisation of the system (institutional framework) is the key barrier to transitions.

Environmental policy and policy instruments are: regulations and standards, voluntary agreements, environmental taxes and charges, tradable permits, deposit refund systems, damage compensation, and subsidies[19] (Barde, 1995). These policy instruments apply best to systems with flexible organisation and when actors can be considered homogeneous. The IEA comes up with three major strategies to reduce electricity consumption quickly: raise electricity prices, encourage behavioural changes, and introduce more efficient technologies (IEA, 2005a). Straightforward policies are effective when actors can be treated homogeneously, subsystems are flexibly organised, and interactions between actors are linear. Long-term strategies are: minimum energy efficiency levels in building codes, minimum appliance efficiency standards, load management programmes, weatherisation programmes, and general information campaigns to encourage energy conservation (IEA, 2005a, p. 73).

Finally, when organisations are rigid, straightforward policies squeeze actors between the 'system' and the 'policy measure'. In these situations, traditional policy measures are inefficient and redesign of system organisation is needed to achieve paths towards sustainable development. The notion that allows the system to escape from technological lock-in requires high-level system changes like synchronising incentives is shown in Section 5.2.

When organisations are rigid and heterogeneous aspects of actors dominate, a combined strategy of target-group-induced system re-orientation is required.

Acknowledgements

We would like to thank Sander Lensink and the anonymous reviewer of this journal for their valuable comments on earlier drafts of this paper.

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[19] Subsidies are regarded as inefficient on the long run (Barde 1995; Löfgren, 1995; Zylicz, 1995).

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