Energy modeling that matters for reality

A handbook for deepened structural modeling approaches

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This document is intended to encourage

- discovering the emerging new mindset for a better understanding of energy systems,
- discarding the wrong questions concerning low-energy and low-carbon strategies,
- refusing to answer these questions,
- insisting that research results are not negotiable,
- realizing the limits of mainstream economics for handling transformative energy system issues, and
- considering that saying no is often the best answer that can be given.

We wish to thank the other partners of the ClimTrans project for inspiring discussions, which have shaped this paper. The usual disclaimer applies. This research is partially funded by the ClimTrans project.

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Database

All data used originate from the Austrian Energy Balance as reported in December 2015 by Statistik Austria.

If not indicated otherwise, all Figures and Tables stem from the authors based on this database.

1 Summary: Ten commandments for energy modeling that matters for reality

What went wrong with energy modeling?

Paul Krugman judged "most work in macroeconomics in the past 30 years has been useless at best and harmful at worst."(Cited in Economist June 11th 2009).

We are inclined to propose a similar, albeit more nuanced judgment for most policy analyses that are based on current energy modeling practices. The fragility of model based policy recommendations can be judged for example by the Commission's responses to discussions in the ongoing reference scenario exercises employing the PRIMES model (E3mlab, 2015; European Commission, 2016)..

We thus here follow on the work that has been enlightening, supportive in policy advice and thus extremely useful, as was the case in macroeconomics, here in the case of energy modeling.

Echoing the revealing book of Dan Rodrik (2015) about the use and misuse of economic modeling practices, we summarize our findings and recommendations for a new generation of energy modeling in ten commandments.

(1) There is nothing like the "true" energy model

A model always is a purposeful and simplified representation of aspects of reality. The point is to figure out which model applies best in a given setting, i.e. the research question and real world constraints for modeling.

Often modelers, however, are inclined to stick to "their" model and don't admit that their available model might just not be suited for a given task. In other words: Not only the energy system is subject to the risk of being trapped in path dependencies, also energy-economic modelers are.

(2) New challenges require a fundamentally new generation of energy models

The new challenges for energy modeling are the expansion of the time horizon way beyond the time ranges of conventional economic analyses, the assessment of disruptive transformations in highly complex non-linear socio-ecological systems, and the recognition of risks and uncertainties.

Issues like the transformation to low-energy and low-carbon structures and the upcoming disruptive technologies require a fundamentally new approach to understanding and analyzing energy systems. Most of the current generation of energy models therefore becomes obsolete if used without recognizing these new challenges.

(3) Don't pretend that your model outcomes have a predictive quality

Model results that use statistical methods most often loose rapidly their predictive accuracy if we extrapolate beyond the sample period. The reasons for this to be the case are small sample sizes, poor data quality, structural changes and inadequate model specifications.

You therefore better critically reflect on and do not understand as prediction what the International Energy Agency is telling us about their long-term global energy forecasts in their annual World Energy Outlook or how the European Commission uses conventional modeling frameworks for justifying policy recommendation needs that go beyond a predictive use of data bases.

(4) Think twice if your model is really able to answer a specific question by policy makers

You may be inclined to make very strong, often unrealistic assumptions, e.g. when you are asked about the expected energy prices and their impacts on energy flows. You won't be able to obtain answers without referring to very strong assumptions about the behavior of households, firms and markets. If you do not communicate this modeling caveat to the actors you are advising, then this is not OK.

It might also be a good decision to bring to the attention of policy makers that many of their questions about the impact of specific policy measures are rather outdated. This holds true in particular when modelers don't resist providing answers about the future of energy systems by offering model outcomes under seemingly comprehensive policy aggregation (but in fact hiding the range of crucial assumptions), as has been applied in Austria under the labeling "with existing" or "with additional" policy measures".

(5)
This is a good time for updating our understanding of energy systems

Not only has the economic environment in general undergone a tectonic shift since 2008 when the events on the financial markets triggered the ongoing multiple-economic-crises mode.

The energy sector appears to be the tip of an iceberg that signals a need to search for a better understanding of ongoing phenomena, their causes and their relevance for our well-being. Let's use this window of opportunity in a wiser way than the one that opened up after the global financial crises.

(6)
This is also a good time for extending the scope of reasoning in the context of energy issues

In the past discussions about energy issues were dominated by speculations about the role of fossil fuels with respect to its availability and the use of market power in particular of the oil and gas producers.

Related to a strongly needed reframing of the economic concept of welfare towards a more comprehensive wellbeing approach, the new understanding of energy issues also requires a different mindset with an extended vocabulary that starts with the hardly understood concept of energy related functionalities as the ultimate task to be fulfilled by our energy system.

(7)
Don't confuse agreement among modeling communities with certainty about how the energy system works

Energy modeling exhibits a tremendous inertia because of the amount of effort needed to setup modeling frameworks and the reluctance of model builders to separate from their crafted tools.

This explains why the vast majority of currently used energy models are just not adequate to deal with the new challenges that are marked by breakthrough technologies and rapid decarbonization.

(8)
A poor understanding of the energy system can't be compensated by mathematism

Quite often model builders seem to be tempted to disguise a poor understanding of the underlying issues by sophisticated mathematics. As Nobel Laureate Paul Krugman remarked after the 2008 financial crisis took most economists by surprise: "the economics profession went astray because economists, as a group, mistook beauty, clad in impressive-looking mathematics, for truth."

You should not hesitate to reveal the related The Emperor's New Clothes effect.

(9)
It is OK to say that a specific question by a policy maker can't be answered

There are numerous examples when model builders did not resist providing answers to energy issues that just can't be reliably answered for real world circumstances.

Prominent examples are the effects of low and high oil prices or the impact of energy taxes and subsidies. Modeling results are always dependent on the respective modeling framework employed and the required assumptions and therefore only valid under this very specific abstraction from reality.

(10)
It is OK to tell policy makers that they are putting irrelevant or wrong ques-

An honest and relevant conversation with policy makers more often should refer to the previous Command.

Strategic planning of policy conversations, potentially embedded in co-

tions, at the same time nudging them towards the questions that really matter

generation processes, could open policy and decision-makers eyes for the questions that really matter.

2 A primer into the new energy economics

The intention of this document is to demonstrate how our evolutionary understanding of energy systems requires an accompanying redesign and practice of energy modeling if the profession seeks to be policy relevant.

2.1 What's new in energy economics

In a nutshell basically two extensions characterize the new thinking in energy economics:

The internal structure of an energy system

The first extension discovers the internal structure of a real world energy system, which can be described by a cascade sequence:

- **Functionalities**
  as the energy services related to thermal, mechanical and specific electric tasks are the ultimate purpose of an energy system.
- **Technologies**
  as for applications in buildings, mobility, and production, and for transformations to electricity and heat determine the related energy flows.
- **Energy mix**
  as the partition of energy into fossils and renewables has impacts in particular for greenhouse gas emissions.

The external interactions of an energy system

The second extension concerns the links of the above described energy system with the broader socio-economic and institutional environment. The core of an energy system, which is characterized by its physical characteristics, communicates in an onion-like structure with the socio-economic sphere and with the institutional and behavioral sphere.

Thus we can identify three encompassing tiers for a comprehensive characterization of an energy system.

- **The physical tier**
  depicts the cascade ranging from functionalities to energy flows and their mix depending on the choice of application and transformation technologies.
- **The economic tier**
  interacts with the physical tier via consumption of energy and investments into stocks that are relevant for energy productivity and energy efficiency.
- **The institutional tier**
  provides mechanisms for coordination and incentives, as markets and regulations, and considers behavioral attitudes.

These extensions follow a reasoning that is summarized in Schleicher (2015) and roots in research projects reported in Köppl et al. (2014) and Köppl and Schleicher (2014).

2.2 What might still be going wrong

Currently the mainstream of energy economics just does not put enough attention to the internal structure of an energy system and does not disentangle the three encompassing tiers presented above. This, however, creates major problems as to the applicability of related modeling approaches for real world energy policy design.

Are selected modeling approaches fit to a particular purpose?

All currently used modeling approaches need a careful evaluation if they fit to a particular purpose. This will be demonstrated by a few examples.

Econometric methods

Statistical methods, as time series analysis or multiple relationships between energy flows, economic activity and prices, are of limited use if the time range of analysis is extended beyond the sample size. The main reasons are structural changes both within and outside the sample period.

Economic structures

The interaction of the energy sector with the other sectors of an economy is usually dealt with either on an aggregate level with GDP related components or on sectoral levels as described by input-output tables. Both approaches suffer from difficulties in dealing with structural changes and sufficient detail for identifying the relevant interactions with the energy system.

Institutional settings

Modeling approaches that deal with partial or general market equilibrium specifications intermingle the above addressed three constituting tiers and might postulate market mechanisms which either are not existent at all or not in equilibria.

2.3 What a deepened modeling approach can achieve

We demonstrate in the sequel, how an extended understanding of energy systems and the related deepened structural modeling approach can be implemented in a full-scale model of the Austrian energy system.

The focus on energy related functionalities

Starting point are databases with the following energy related functionalities:

- Low temperature heat
- High temperature heat
- Stationary engines
- Mobile engines
- Lighting and electronics

This is in striking contrast to conventional approaches that focus on types of energy flows (fossil, non-fossil, heat and electricity) and economic sectors (households, transport, production).

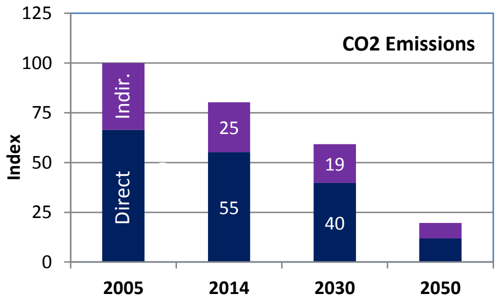
CO_2 emissions are fully related to these functionalities

We are able to partition CO_2 emissions fully to these functionalities as demonstrated in Figure 2-1 to Figure 2-3.

This is done by adding to the fossil energy flows needed a particular functionality also the indirect emissions via the consumption of electricity and heat and the related distribution losses.

Figure 2-1 indicates how an emissions path could look like that reduces 80% of emissions by 2050 compared to 2005.

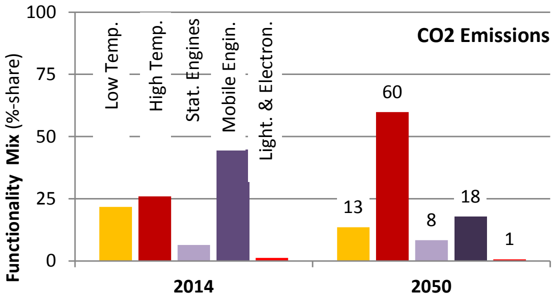
Figure 2-1 CO_2 Emissions – direct and indirect emissions



Emissions related to functionalities

Figure 2-3 indicates the distribution of these emissions according to the functionalities. Currently this emissions peak in mobile engines, i.e. transport activities. By 2050 the remaining emissions will be dominated by functionalities related to high temperature heat, i.e. energy intensive industrial processes.

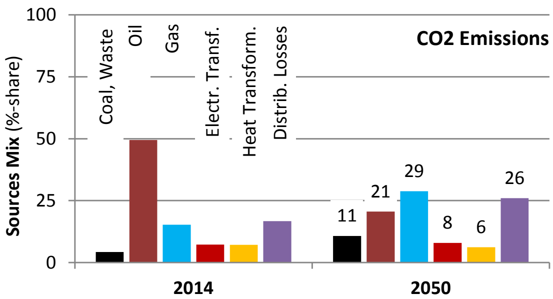
Figure 2-2 CO_2 Emissions related to functionalities



Emissions related to functionalities

Figure 2-3 depicts the distribution of these emissions according to the types of energy used for providing the functionalities. Currently these emissions mainly originate from oil products. By 2050 the remaining emissions show peaks in gas and distribution losses.

Figure 2-3 CO_2 Emissions related to energy types



3 In a nutshell: The building blocks for a deepened structural energy modeling approach

Essential for a deepened structural approach to modeling energy systems is the distinction between the physical structure, its interaction with the socio-economic system and the institutional embedding with its mechanisms for coordination and incentives.

3.1 Tier one: The physical structure of the energy system

The physical structure of the energy system exhibits a cascade structure which spans from functionalities (thermal, mechanical, specific electric) via final energy flows (fossils, renewables, heat and electricity) to primary energy flows (fossils, renewables, nuclear). Each stage of this cascade is related to specific capital stocks.

3.1.1 The energy cascade for providing functionalities

Observing application and transformation technologies

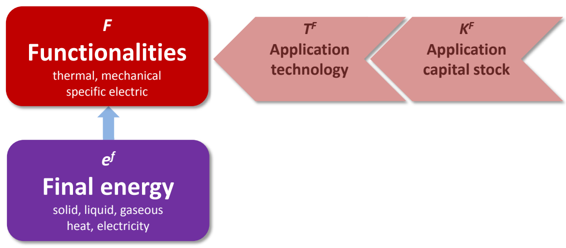
Functionalities and application technologies

Starting point is the provision of the functionalities F which result from final energy flows e^f and from the capital stock K^F that comprises the application technologies $T^F(.)$:

(1.1a) $F = T^F(e^f, K^F)$

This key relationship of any energy system is depicted in Figure 3-1.

Figure 3-1 Provision of functionalities



Final energy via transformation technologies

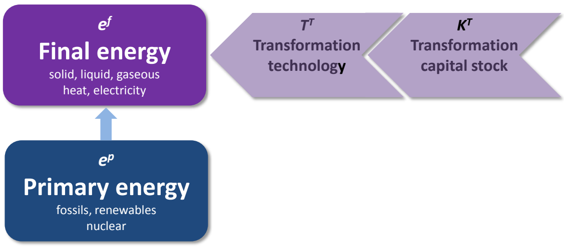
Final energy flows e^f result from primary energy flows e^p by using transformation technologies $T^T(.)$ with the related capital stock K^T:

(1.1b) $e^f = T^T(e^p, K^T)$

We include in our definition of transformation technologies also any distribution activities via networks.

Figure 3-2 indicates these transformation activities of an energy system.

Figure 3-2 Transformation and distribution of energy



Switching to application and transformation productivities

Parametrization with productivities

We parameterize the relationships (1.1) by describing the application and transformation technologies by their productivities $t^F(K^F)$ and $t^T(K^T)$ which in turn reflect the related capital stocks:

(1.2a) $F = t^F(K^F)\cdot e^f$

(1.2b) $e^f = t^T(K^T)\cdot e^p$

Advantages of this implementation

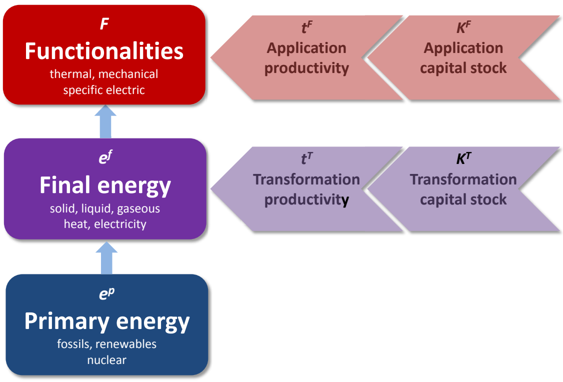
This parametrization is highly supportive for a databased implementation.

The application productivity $t^F(K^F)$ depicts the amount of functionalities, e.g. the volume of heated space, obtained from one unit of final energy. The productivity itself is dependent on the quality and quantity of the related capital stock of the application technology.

Similarly the transformation productivity $t^T(K^T)$ indicates the mass efficiency of a transformation process, namely the amount of final energy obtained from one unit of primary energy.

Figure 3-3 illustrates this parameterization and reveals also the characteristic cascade structure of the energy system.

Figure 3-3 The cascade structure of the energy system



Choosing application and transformation technologies

The basic relationships (1.2), which describe the application and transformation activities of an energy system, can be condensed to

(1.3a) $F = t^F(K^F)\cdot t^T(K^T)\cdot e^p$ *or*

(1.3b) $e^p = t^F(K^F)^{-1}\cdot t^T(K^T)^{-1}\cdot F$

Representation (1.3b) of the physical structure of an energy system reveals how for a given amount of functionalities the demand for primary energy can be reduced by improving the application and transformation efficiency of the system, which in turn requires improvements in the related capital stocks.

Inversion of the reasoning

Relationship (1.3b) also serves what is coined the inversion of the reasoning, i.e. a reversal of the usual flow of argumentation when dealing with energy systems. Instead of starting with primary energy and following its way through the energy system, deliberately the analysis begins with a focus on functionalities, then elaborates options for choosing application and transformation technologies and finally ends up with primary energy requirements.

3.1.2 Adding greenhouse gas emissions

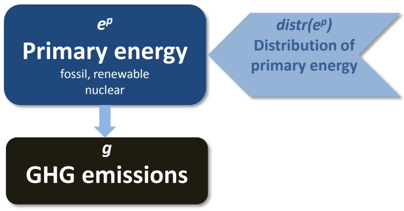
Choosing the energy mix

We now consider in our physical model of an energy system the role of the energy mix, i.e. the distribution of primary energy, which we partition into fossil, renewable and nuclear.

Determining greenhouse gas emissions

This distribution of primary energy is closely tied to all kinds of emissions from energy use, in particular greenhouse gas emissions resulting from fossils, as indicated in Figure 3-4.

Figure 3-4 Greenhouse gas emissions from energy use



Emissions intensity of fossil primary energy

We parameterize greenhouse gas emissions by tying their volume g is tied to the flow of fossil primary energy $e^{p,fos}$ via the emissions intensity g^{fos} of this flow:

$$(1.4) \qquad g = g^{fos} \cdot e^{p,fos}$$

This emissions intensity in turn is dependent on the distribution, namely energy mix, of the fossil primary energy $distr(e^{p,fos})$:

$$(1.5) \qquad g^{fos} = g^{fos}(distr(e^{p,fos}))$$

Shares of renewable and nuclear primary energy

By partitioning total primary energy into its fossil, renewable and nuclear component

$$(1.6) \qquad e^p = e^{p,fos} + e^{p,res} + e^{p,nuc}$$

and defining their shares in total primary energy by $s^{p,\,fos}$, $s^{p,res}$ and $s^{p,nuc}$ *respectively, we obtain*

$$(1.7) \qquad 1 = s^{p,fos} + s^{p,res} + s^{p,nuc}$$

We can link now the volume of greenhouse gas emissions to the emissions intensity of fossil primary energy and the shares of renewables and nuclear in total primary energy:

$$(1.8) \qquad g = g^{fos}(distr(e^{p,fos})) \cdot (1 - s^{p,fos} - s^{p,res} - s^{p,nuc}) \cdot e^p$$

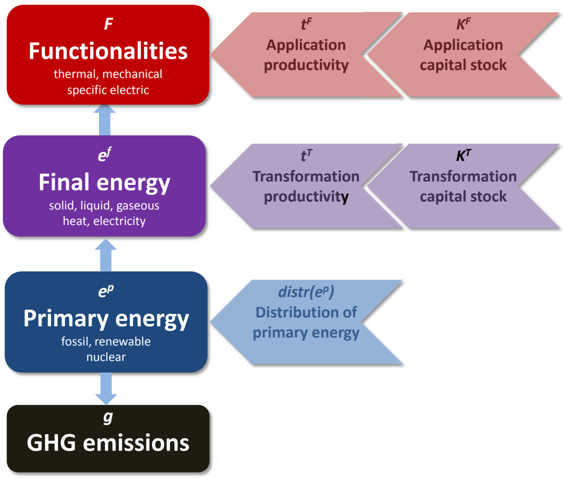
3.1.3 Summarizing the physical structure of the energy system

The constituting features

Collecting the elements that describe the physical structure of the energy system, we arrive at Figure 3-5 with the following constituting features:

- A cascade structure with the focus on functionalities and the supporting energy flows via final and primary energy.
- The accompanying technologies for application and transformation purposes which in turn determine the productivity of the energy flows.
- The distribution of the energy mix with respect to fossil and non-fossil components which determines the carbon and other greenhouse gas emissions.

Figure 3-5 The physical structure of the energy system



The analytical model

Basic model of the physical tier

Corresponding to the cascade structure we obtain the following recursive set of equations for the basic model that describes the physical structure of the energy system and the related greenhouse gas emissions.

Final energy flows

(1.9a) $e^f = t^F (K^F)^{-1} \cdot F$

Primary energy flows

(1.9b) $e^p = t^T (K^T)^{-1} \cdot e^f$

Greenhouse gas emissions

(1.9c) $g = g^{fos}(distr(e^{p,fos})) \cdot (1 - s^{p,fos} - s^{p,res} - s^{p,nuc}) \cdot e^p$

Variables and parameters

This is a list of variables and parameters that are used in the basic physical model.

Functionalities

F functionalities

Energy flows

e^f final energy flows

e^p primary energy flows

$e^{p,fos}$ primary energy flows, fossil

$e^{p,res}$ primary energy flows, renewable

$e^{p,nuc}$ primary energy flows, nuclear

Technologies

T^F application technologies for providing functionalities

T^T transformation technologies for converting primary into final energy

Productivity

t^F application productivity for providing functionalities

t^T transformation technologies for converting primary into final energy

Capital stocks

K^F capital stock for application technologies

K^T capital stock for transformation technologies

Greenhous gas emissions

g greenhouse gas emissions volume

Parameters

$s^{p,fos}$ primary energy share, fossil

$s^{p,res}$ primary energy share, renewable

$s^{p,nuc}$ primary energy share, nuclear

g^{fos} greenhouse gas emissions intensity of fossil fuels

$distr(e^{p,fos})$
distribution of energy mix of fossil fuels

3.2 Tier two: Embedding energy into the economic system

The energy system and the economic system interact mainly via two channels: energy flows and investments for the infrastructure which determine the productivity of energy for providing energy services.

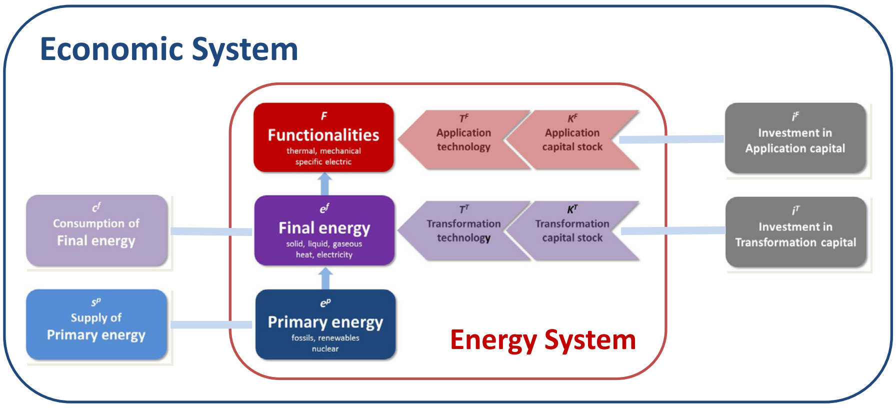
3.2.1 Links between the energy system and the economic system

As can be visualized in Figure 3-6, the energy system as described in tier one is embedded with following linkages into the economic system, which we identity as tier two in our modeling framework:

- Energy flows, as final and primary energy, e^f and e^p, respectively.
- Investments into the capital stocks for application and transformation technologies.

Both types of physical energy flows of the energy system are in the economic system converted via appropriate prices into monetary units.

Figure 3-6 Embedding the energy system into the economic system



Links via energy flows and investments

Links via energy flows

Both types of physical energy flows of the energy system are in the economic system converted into monetary units via appropriate prices.

Assuming a representative energy price p^e, then final energy e^f shows up in the economic system as consumption of energy c^e

(2.1a) $c^e = p^e \cdot e^f$

and primary energy e^p corresponds in the economic system as energy supply s^e

(2.1b) $s^e = p^e \cdot e^p$

Links via investments

Two investment activities in the economic system are relevant for the technologies of the energy system and its related productivities, namely investments into the application and the transformation capital stock.

Investments i^F in the capital stock for application technologies are determined by changes of this capital stock ΔK^F and replacement investments r^F:

(2.2a) $i^F = \Delta K^F + r^F$

Similarly investments i^T in the capital stock for transformation technologies result as:

(2.2a) $i^T = \Delta K^T + r^T$

3.2.2 Basic relationships of the economic system

We proceed by partitioning the economic system into two sectors:

- The energy sector
  covers all activities that relate from the supply of primary energy to the provision of functionalities.
- The non-energy sector
  deals with the remaining activities of the economy and may be further disaggregated into subsectors.

Energy sector of the economic system

The supply of the energy sector s^e is provided by domestic production q^e and imports m^e:

(2.3a) $s^e = q^e + m^e$

The demand of the energy sector d^e comprises consumption of energy c^e for households, companies and the public sector as well as exports of energy x^e:

(2.3b) $d^e = c^e + x^e$

Non-energy sector of the economic system

Similarly the supply of the non-energy sector s^n results from domestic production q^n and imports m^n:

(2.4a) $s^n = q^n + m^n$

The demand of the non-energy sector d^n deals with consumption of non-energy c^n (for households, companies and the public sector) but also adds investments i^n for this sector and for the energy sector i^F and i^T for the application and transformation capital stock as well as exports of non-energy products:

(2.4b) $d^n = c^n + i^n + i^F + i^T + x^n$

Both in the energy and non-energy sector an additional demand component for inventory changes could be added.

The essence of a structural specification

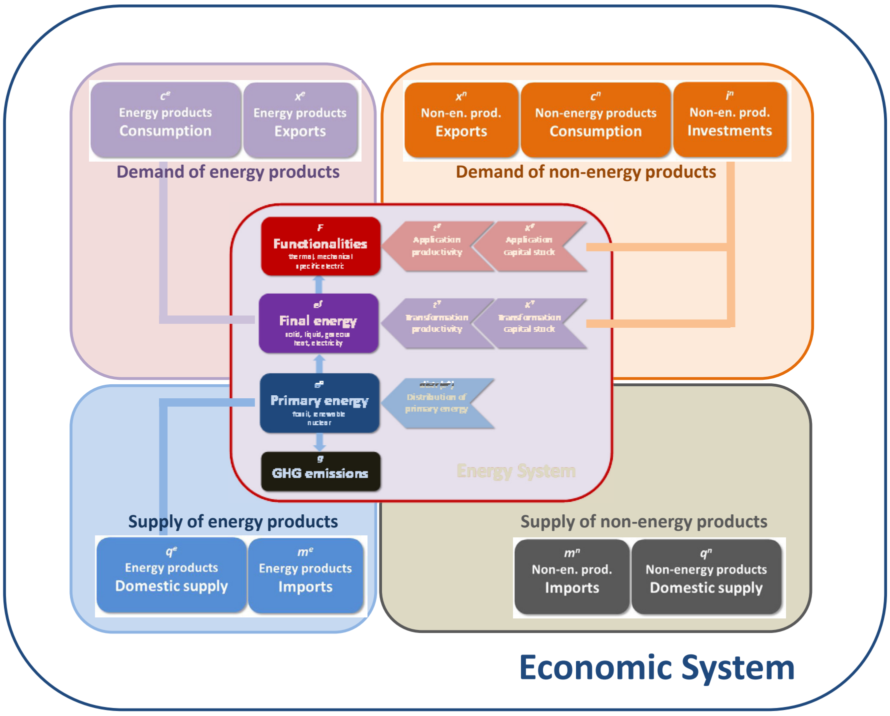
At this point of the exposition of the deepened modeling framework it seems worth reminding that so far we have only proposed relationships that describe either physical identities, as in the energy system of tier one, or monetary identities without claiming any causalities or behavioral assumptions. This will explicitly be dealt with in tier three.

We therefore do not postulate, e.g., in tier two of our modeling framework that demand will equal supply either in the energy or in the non-energy sector.

3.2.3 Summarizing the basic structure of the economic system

Figure 3-7 visualizes how the energy system interacts with the economic system. The main linkages are the flows of final and primary energy and the investments that determine the productivity of the application and transformation technologies.

Figure 3-7 Interactions between the energy system and the economic system



The analytical model

Links between the energy and the economic tier

The links via energy flows:

Consumption of final energy

(2.5a) $c^e = p^e \cdot e^f$

Supply of primary energy

(2.5b) $s^e = p^e \cdot e^p$

The links via investments:

Investments in the capital stock for application technologies

(2.5a) $i^F = \Delta K^F + r^F$

Investments in the capital stock for transformation technologies

(2.5b) $i^T = \Delta K^T + r^T$

Basic model of the economic Tier

The basic supply and demand relationships for the economic model:

Supply of the energy sector

(2.6a) $s^e = q^e + m^e$

Demand of the energy sector

(2.6b) $d^e = c^e + x^e$

Supply of the non-energy sector

(2.7a) $s^n = q^n + m^n$

Demand of the non-energy sector

(2.7b) $d^n = c^n + i^n + i^F + i^T + x^n$

Variables and parameters

This is a list of variables and parameters that are used in the basic economic model.

Energy flows in physical units

- e^f final energy flows
- e^p primary energy flows

Energy products in monetary units

- d^e demand of final energy products
- c^e consumption of final energy products
- x^e exports of final energy products
- s^e supply of primary energy products
- q^e domestic supply of primary products flows
- m^e imports of final energy products

Non-energy products in monetary units

- d^n demand of non-energy products
- c^n consumption of non-energy products
- i^n investments in non-energy capital stock
- i^F investments in application technologies capital stock
- i^T investments in transformation technologies capital stock
- x^n exports of non-energy products
- s^n supply of non-energy products

q^n domestic supply of non-energy products
x^e exports of non-energy products

Capital stocks in monetary units
K^F capital stock for application technologies
K^T capital stock for transformation technologies

Prices
p^e energy price

3.3 Tier three: Considering coordinating institutions, attitudes and incentives

We have discovered so far how the energy system is embedded in the economic system. We continue by asking how in this onion-like structure in an additional tier the economic system is driven by institutions and mechanisms for coordination and shaped by attitudes and incentives.

3.3.1 Causality driven interactions

In the two tiers considered so far no interactions based on postulated causalities were specified. We proceed now by taking into account the possibility of causalities based on economic activities and prices.

Activity based interactions

Non-energy sector

There is strong empirical evidence that in the non-energy sector the main components of demand, as consumption c^n and investment i^n, and the supply from imports m^n respond to indicators of economic activity as the volume of production in the non-energy sector q^n:

(3.1a) $c^n = c^n(q^n)$

(3.1b) $i^n = i^n(q^n)$

(3.1c) $m^n = m^n(q^n)$

In an econometric specification these relationships are parameterized by income elasticities. The related issue is the stability and validity of these parameters beyond a sample period.

Energy sector

Similar causal relationships may be postulated for the energy sector by postulating that consumption of energy c^e is caused by final energy flows e^f and domestic supply q^e and foreign supply m^e are driven by primary energy flows e^p:

(3.2a) $c^e = c^e(e^f)$

(3.2b) $q^e = q^e(e^p)$

(3.2c) $m^e = m^e(e^p)$

The related econometric specifications by energy elasticities need also to be checked with respect to stability and validity.

Physical energy system

Causal feedbacks may be proposed from the economic tier also to the physical energy system.

The amount of functionalities could be influenced by economic activity in the non-energy sector q^n and the related incomes:

(3.3) $F = F(q^n)$

Although this seems to be a plausible assumption, an econometric specification meets limits with respect to the availability of time series for functionalities.

Price based interactions

Non-energy sector

Hypothesis about price driven interactions for the non-energy sector would involve the following specifications for consumption c^n and investment i^n as well as domestic q^n and foreign supply m^n, depending on domestic and foreign prices p^q and p^m, respectively:

(3.4a) $c^n = c^n(p^q)$

(3.4b) $i^n = i^n(p^q)$

(3.4c) $q^n = q^n(p^q)$

(3.4d) $m^n = m^e(p^m)$

These relationships are typically parameterized by price elasticities. Data analysis based on econometric methods reveals that the significance of these relationships is rather fragile.

Energy flows

Price driven hypotheses for the supply and demand of energy flows, either in physical or in monetary units, typically postulate relative prices between various energy types p^e and not-energy prices p^q being relevant:

(3.5a) $e^{supply} = e^{supply}(p^e/p^q)$

(3.5b) $e^{demand} = e^{demand}(p^e/p^q, q^n)$

The specified direct and cross-price reactions, mostly parameterized as elasticities, need strong additional assumptions from neoclassical demand theory in order to obtain estimates based on time series samples.

Energy mix

For the distribution of the primary energy mix $distr(e^p)$ energy prices p^e could be considered:

(3.6) $distr(e^p) = d(p^e)$

A verification of such a hypothesis by data analysis is even more difficult because of the underlying investment activities, which in turn may be driven by non-price decisions.

3.3.2 Market-based coordination

As a next step in our exposition of modeling designs we introduce hypotheses about the overall coordination mechanism.

Although markets seem to be the preferred coordination mechanism for economic activities this is not necessarily based by evidence if we are dealing with the energy sector. Even if we stick to market mechanism, it is useful to distinguish between a Keynesian type and a neoclassical type of market coordination.

Keynesian type coordination

A Keynesian type market coordination would assume that supply basically adjusts to demand, thus giving less attention to potential supply restrictions.

In the sequel we partition the economy into a non-energy and energy sector and denote the relevant economic variables by superscripts *n* and *e*, respectively.

Quantity equilibrium of the non-energy sector

Stating total supply of the non-energy sector by domestic production q^n and imports m^n and total demand by consumption c^n, investments i^n and exports x^n, the quantity equilibrium for the non-energy sector would require:

(3.7a) $q^n + m^n(q^n) = c^n(q^n) + i^n(q^n) + x^n$

Since this specification also allows some components to react with respect to domestic economic activity q^n, any additional demand will generate multiplier impacts.

Quantity equilibrium of the energy sector

Similarly we obtain a quantity equilibrium for the energy sector. We postulating that demand components comprise energy consumption c^e, which is driven by the volume of final energy consumption e^f, and energy exports x^e. We further assume that this energy demand is fully met by domestic supply q^e and imports m^e, both driven by the volume of primary energy e^p:

(3.7b) $q^e(e^p) + m^e(e^p) = c^e(e^f) + x^e$

Neoclassical type coordination

A neoclassical type market coordination emphasizes the role of prices for equilibrating demand and supply, thus considering at least some supply restrictions.

Price equilibrium of the non-energy sector

A neoclassical flavored specification for the non-energy sector postulates the dependency of demand and supply components from the domestic price p^q and the import price p^m:

(3.8a) $q^n(p^q) + m^n(p^m) = c^n(p^q) + i^n(p^q) + x^n$

Under the assumption that there is a price adjustment for products of the non-energy sector towards an equilibrium between supply and demand, this equilibrium price $p^{q,equ}$ will determine the quantities of the supply and demand components.

Price equilibrium of the energy sector

For the energy sector a neoclassical setting would postulate demand and supply relations for final and primary energy and again a price adjustment towards a market equilibrium:

(3.8b) $e^{supply}(p^e/p^q) = e^{demand}(p^e/p^q, q^n)$

In our basic model such a price equilibrium could be postulated for the energy sector:

(3.8c) $q^e(p^e/p^q) + m^e(p^e/p^q) = c^e(p^e/p^q) + x^e$

Thus the interacting equilibria of the non-energy sector (3.8a) and the energy sector (3.8c) would determine equilibrium prices $p^{q,equ}$ and $p^{e,equ}$, respectively, which in turn would determine the corresponding non-energy and energy quantities.

It is obvious that all actors in the energy and non-energy sector would need a substantial amount of information in order to end up in these interacting equilibria.

3.3.3 Non-market based coordination and incentives

The energy sector typically reflects many economic decisions that are not based on markets but incentives from the non-market agenda, in which also vested interests may be of stronger relevance.

Path dependency

Most decisions in the energy sector are determined by the relevant infrastructure or the capital stocks that determine the available application and transformation technologies. This is the existing stock of buildings and machinery, the network of roads and railways, and past investments for generating and providing energy.

Many policy decisions, as the building of hydro generation units on the Danube and hydro storage in the Alps or the nuclear power plants in

France are by-products of military strategies. Other energy infrastructure, as the railway system of Switzerland or the public transportation system in Vienna has been deliberately motivated by offering these services to the society.

Over the past years investments into roads have in Europe in almost all states obviously by far exceeded those into railways. These facts create path dependencies and just can't be easily reversed, e.g. by energy prices.

Deepened structural models should be able to handle these path dependencies and to assist in identifying windows of opportunity for transformative changes in the energy system.

What motivates energy related decisions by consumers?

Consumers seem to be in their energy related choices in particular dependent on infrastructure that was decided upon by other entities, either private or public. It is this dependency that motivates regulations, which enhance decisions that serve both the interest of investors of infrastructure and their users.

What motivates energy related decisions by companies?

With respect to energy related decisions in companies, at least between those in the energy sector and the non-energy sector needs to be distinguished.

In the non-energy sector, in particular in energy intensive industries, there is an inherent interest for cutting energy costs by improving energy efficiency. This motivation holds also for all other resources.

The energy sector is facing increasing decision problems, which are rooted in the emerging transition of the structures of this sector. There are obvious vested interests, e.g. in the fossil industry and the closely linked automobile industry, at least to slow down this transition.

Ultimately the current energy sector will need to be completely redefined by switching from a business model based on selling energy flows to a business model that offers the provision of energy related functionalities.

What regulation drives transitions?

There are no easy answers about a recommended regulatory setup that would enhance innovation towards desired structural changes, in particular to low-energy and low-carbon structure in the energy system.

We definitely can't rely only on charismatic persons like Elon Musk whose electric storage technology and electric cars may become a game changer for the electricity grid and private transport.

We are currently experiencing a penetration of technologies for renewables which was unexpected just a few years ago.

We are able to discover, however, many superficial barriers for innovation, as open or hidden subsidies for fossils or the prohibition to build private electricity grids.

What is more, we have to move beyond a purely technology-centered approach to foster transitions in the energy system. Social innovations, such as changes in lifestyles, are currently prohibited by implicit social norms and basic capitalistic incentive structures but would have to be brought in line with the planetary boundaries we are facing.

The relevance to model designs

All these aspects considered so far with respect to non-market based coordination and incentives have implications for the design of models. Again it is the recommendation to deepen the structural specifications in order to improve the handling of these issues.

3.4 More tiers: International and global interactions

The modeling framework that has been developed so far within a three tiers structure can be further embedded into international and global interactions. Two of them deserve particular attention, namely the impact of global emissions constraints and the carbon content of international trade flows.

3.4.1 Implications of global emissions constraints

Global emissions constraints

National energy policies are subject to global emissions constraints. Jonas and Zebrowski (2016) present national reduction targets under the following assumptions:

- Global per capita GHG emissions equity is achieved by 2050 (meaning that in 2050 the limit of emissions required to support living and wellbeing of any individual will be equal for anyone, regardless of his/her nationality, age, etc.)
- Net emissions from land-use change (LUC) are reduced linearly to zero until 2050
- The remainder of the unmanaged biosphere returns also to an emissions balance (zero net emissions) until 2050.

Implications for Austria

The first part of Table 3-1 summarizes the implications of global GHG emissions budgets for the period 2000 – 2050 corresponding to warming targets of 2 °C, 3 °C, 3 to 4 °C and above 4 °C for the cumulative emission constraints relevant to Austria.

The second part of this table presents levels of Austria's per capita emissions as of 2010 and required 2050 levels of these emissions (together with percentage reductions) corresponding to the considered warming targets.

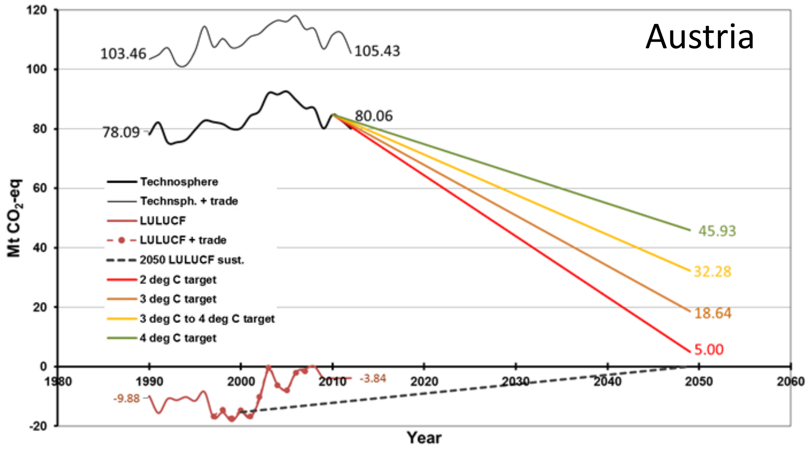
Table 3-1: Implications of global emissions constraints for Austria

			Warming target			
			2 °C	3 °C	3 °C - 4 °C	≥4 °C
Sector	**2000 - 2010 cumulative emissions w/o trade**	**2000 - 2010 cumulative emissions with trade**	**2010–2050 cumulative emission w/o trade**			
	Mt CO_2-eq	**Mt CO_2-eq**	**Mt CO_2-eq**	**Mt CO_2-eq**	**Mt CO_2-eq**	**Mt CO_2-eq**
Techno-sphere	1037.72	1351.79	1796.10	2068.96	2341.83	2614.69
LUC	-61.03	unknown	-242.45 (Imperative: Net emissions from LUC reduce linearly to zero until 2050!)			
Sector	**2010 Per-capita emissions w/o trade**	**2010 Per-capita emissions with trade**	**2050 Global emissions equity target [in t CO_2-eq/cap]**			
			0.6	**2.1**	**3.6**	**5.2**
			2010–2050 emission reduction w/o trade			
	t CO_2-eq/cap	**t CO_2-eq/cap**	**% / cap**	**% / cap**	**% / cap**	**% / cap**
Techno-sphere	10.11	13.31	94	79	64	49
LUC	-0.46	unknown	100% (Imperative: Net emissions from LUC reduce linearly to zero until 2050!)			

Source: Jonas and Zebrowski (2016, Table 13)

Figure 3-8 presents Austria's historical GHG emissions and linear GHG emission reduction (target) paths as of 2010 enabling Austria to meet agreed warming levels of 2 °C to 4 °C in 2050 and beyond.

Figure 3-8 Austria in an emissions constrained world



Source: Jonas and Zebrowski (2016, Figures 10b – 13b compiled)

3.4.2 Carbon content of international trade flows

Production-Based Accounting (PBA) versus Consumption-Based Accounting (CBA)

Conventional greenhouse gas (GHG) emission inventories record emissions released by the agents (e.g. industries or residents) within the geographical borders of a nation. This territorial emission accounting framework, also known as Production-Based Accounting (PBA), is the approach used by the United Nations Framework Convention on Climate Change (UNFCCC).

Studying emissions from a Consumption-Based Accounting (CBA) perspective, commonly referred to also as Carbon Footprints (CF), provides a complementary perspective to PBA (Peters and Hertwich, 2008; Davis and Caldeira, 2010). Emission inventories using CBA record emissions induced by residents' consumption irrespective of where in the world those induced emissions take place.

Accounting emissions along the supply chain of a product

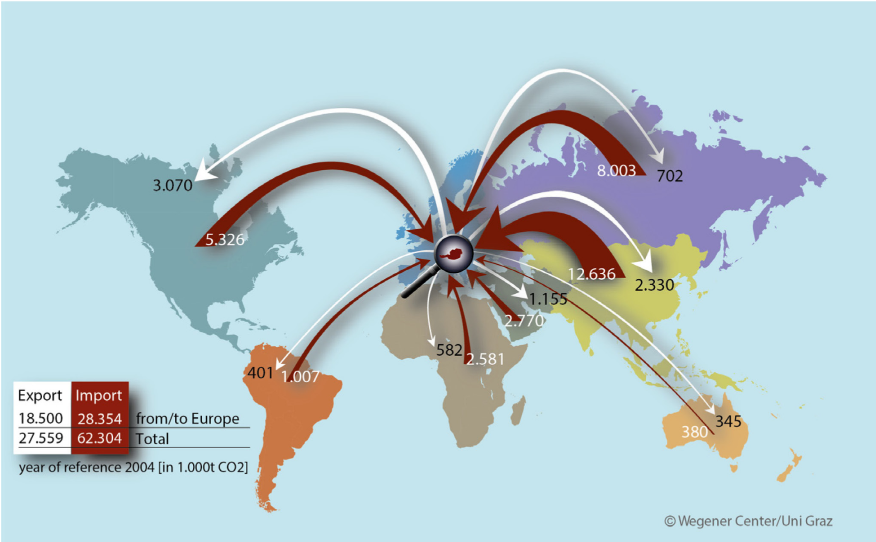
Since production and consumption occur very often in different geographical locations, these two distinct emission accounting frameworks tend to show different pictures on the amount of emission allocated to a nation which could potentially serve as a policy base (for an evaluation of the relative advantages and shortcomings of the latter see Steininger et al., 2015).

Regarding CBA emissions, one could for example think of the emissions generated in the production of a car imported from China. However, emissions might not only occur in China but throughout the supply chain, such as in countries exporting inputs to China. In the case of CBA, all the emissions occurring along the production chain are attributed to the final consumer of the car.

CBA evidence for Austria

Alternative emission inventories propose attributing emissions to the consumers inducing emissions irrespective of where in the world those induced emissions take place. To enable effective consumption-based policy design we first need to understand which products are the most intensive ones in embodied emissions in trade, and where in the world and in which activities their implicit emissions are triggered. For Austria findings include that: i) the emissions needed to sustain Austria's consumption are 50% larger than those reported by the conventional production-based accounting system (for their regional structure see Figure 3-9); ii) more than a third of national consumption-induced emissions occur outside the EU-28 where none of the EU-caps applies; and iii) the single most important sector abroad where these emissions occur is electricity generation.

Figure 3-9 Carbon content of Austrian foreign trade



Source of data: Munoz and Steininger (2010)

3.5 Dealing with uncertainty

Uncertainties within model based energy policy analyses have to be adequately dealt with in order to enable modeling outputs to be used as a sound basis for policy recommendations and eventually the design of real world energy policy.

3.5.1 Classifying uncertainty

Classification of uncertainty according to nature and source

Uncertainties can be classified along different lines, depending on the context and scope. It is largely agreed that uncertainty is comprised of (at least) two different dimensions: the inherent nature of the uncertainty (epistemic or aleatory) and the location or source of uncertainty, which describes where, in applied situations such as energy modeling, the uncertainty manifests.

Epistemic and aleatory uncertainty

While *aleatory uncertainty* (or *statistical uncertainty*) describes the inherent randomness and natural variability of complex socio-ecological systems and their components, epistemic uncertainty (or systematic uncertainty) results from imperfect knowledge about the system under consideration. Though quantifiable with probabilistic modeling techniques, aleatory uncertainty is typically seen as irreducible (Skinner et al., 2014; Uusitalo et al., 2015). Epistemic uncertainty on the other hand can be quantified and reduced by increasing relevant knowledge. Translated to energy modeling, this requires improving modeling techniques and there underlying assumptions regarding structures (cause-effect processes) and functional forms, as well as quality of input data.

Sources of uncertainty

Focusing on environmental risk assessment, Skinner et al. (2014) identified seven main *sources* (or *location-types*) of uncertainty that are also relevant for energy-economic modeling:

Table 3-2: Sources of uncertainty relevant for modeling

Nature of uncertainty	Source of uncertainty	Definition
Epistemic	**Data uncertainty**	The *availability*, *precision*, and *reliability* of input data is a crucial driver of modeling results. Identifying potential sources of uncertainty within input data, whether experimental or empirical, can help to distinguish between reliable and unreliable sources.
	Language uncertainty	Linguistic uncertainties stem primarily from a lack of clarity in e.g. expressing ideas or communicating results. They comprise three types: ambiguity, underspecificity and vagueness.
	System uncertainty	Can be defined according to the source pathway–receptor relationship, which constitutes the three main phases of system understanding: *cause*, which concerns a lack of clarity regarding the source(s) of an outcome; effect, relating to the influence a particular source has upon the *receptor(s)*; *process*, which concerns either not understanding the risks or not identifying something vital to a successful assessment.
	Model uncertainty	Any model is a simplified and purposeful abstraction from reality – simplifications and assumptions are necessary features of the modeling process. Nevertheless, a (conceptual) model always has to be fit for purpose and capture the essential features – no more, no less – of the real-world system. Next to parameter and output uncertainty, the most important form of model uncertainty is related to structure, i.e. the representation of real-world cause-and-effect processes.
Aleatory	**Variability or natural uncertainty**	Is the inherent unpredictability of any human or natural system and thus cannot be reduced or eliminated.
	Extrapolation uncertainty	Is based on unavailability of adequate information and data, which may require extrapolation of existing data. When extrapolation becomes necessary, the related uncertainty is aleatory in nature due to the natural variability involved. An increase in epistemic knowledge may prevent the need for extrapolation.
Combination	**Decision uncertainty**	Exists when multiple options, often accompanied by differing objectives (by different actors), are available to satisfy (part of) the criteria leading to a decision.

3.5.2 Reducing uncertainty by deepened structural modeling

We suggest that our extended understanding of energy systems and the related deepened structural modeling approach can be a powerful framework to tackle and reduce epistemic uncertainties in energy-economic modeling.

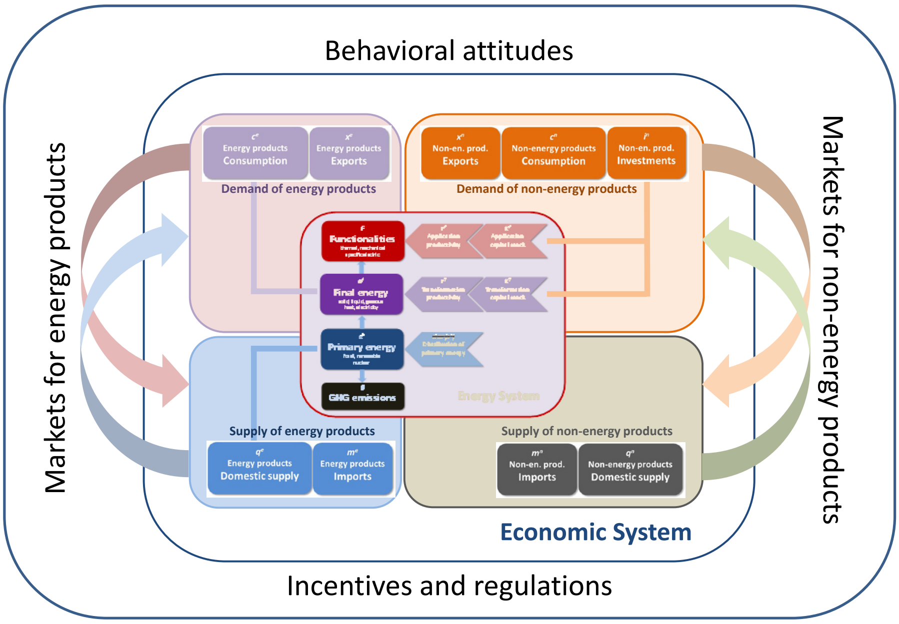
Reducing epistemic uncertainty with deepened structural modeling

The deepened structural modeling approach increases the knowledge on and strengthens the representation of (1) the external interactions of an energy system with the socio-economic and institutional systems as well as (2) the internal structure of an energy system by emphasizing the role of functionalities as the ultimate purpose of an energy system. In doing so it significantly reduces to sources of epistemic uncertainty, *system uncertainty* and *model uncertainty*, and may also contribute to the reduction of a third source, namely *language uncertainty*, by clearly expressing the eventual purpose of an energy system and posing the relevant questions that matter in reality.

3.6 Caring for caveats: The essentials of deepened structural modeling

Based on this exposition of the essential components and design aspects that constitute a deepened structural modeling framework, we are able to draw some conclusions. With them we want to encourage caring for the caveats that have been discovered.

Figure 3-10 Embedding the energy and the economic system into the institutional framework



Discovering the onion-like structure of the overall system

An overall perspective of this modeling framework is summarized in Figure 3-10 which exhibits the embedding of the energy and the economic system into the institutional framework in an onion-like structure.

Extending the exposition of the physical energy system

At the core we identify the energy system, which is represented by the interaction of physical energy flows together with application and transformation technologies for providing the welfare-relevant energy related functionalities.

This tier, however, is almost completely missing in conventional energy models and needs to be developed in much more detail. With reasonable effort this is possible since we are dealing mainly with physical phenomena.

Improving the links from the energy system to the economic system

The tier representing the economic system is measured by monetary units and is mainly linked via energy flows and investment activities with the energy system. Remarkably, conventional models do not adequately distinguish this differentiation between interactions in the operating mode from the investment mode. This differentiation, however, is essential for evaluating the impact of investments in the energy sector on its productivities and on its impacts on the non-energy sector.

Considering the institutional setting

Finally, we realize that the economic system is exposed to a multi-facet institutional setup which ranges from various types of market designs to a portfolio of incentives and a seemingly incomprehensible role of personal attitudes.

Paradoxically it is this tier which is given most implicit weight in conventional modeling, mainly by specifying behavioral assumptions rooted in the neoclassical economic paradigm. Yet, such modeling seems to be of too little differentiation.

It is probably this feature of conventional modeling that deserves to undergo a creative destruction by being replaced with much more sophisticated approaches. This requires, however, major research efforts.

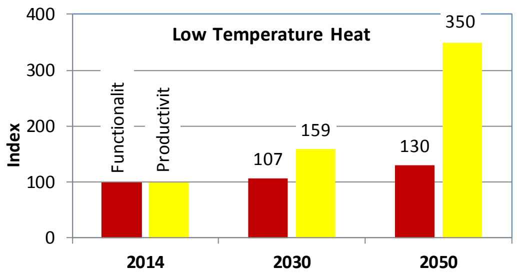
4 Implementation of the modeling tool on different platforms

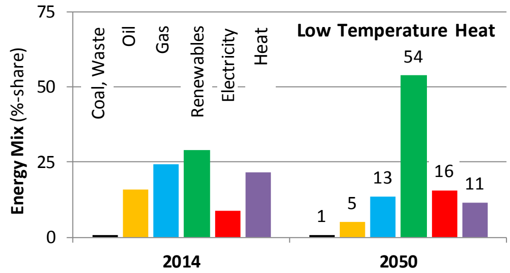
4.1 Implementation in Excel

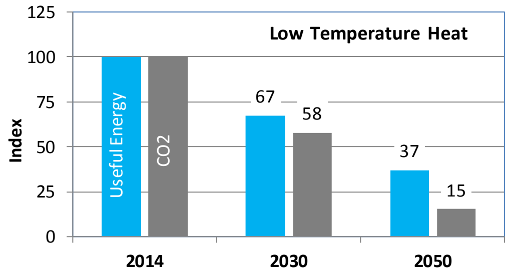
Figure 4-1 Visualization of Low Temperature Heat

Step 1 **LOW TEMPERATURE HEAT** Start Back Next sGAIN Energy Austria

Functionalities and Useful Energy				Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
Low Temperature Heat		2014	TJ	**288,241**	2,031	46,037	70,410	83,032	24,960	61,770
	Functionality	Productivity					Start Period Energy Mix			
2014	*100*	*100*	*Index*	*100*	*1%*	*16%*	*24%*	*29%*	*9%*	*21%*
							Change of Energy Mix			
Change	*30*	*250*	*Index*	*-63*	*0%*	*-11%*	*-11%*	*25%*	*7%*	*-10%*
							End Period Energy Mix			
2050	*130*	*350*	*Index*	*37*	*1%*	*5%*	*13%*	*54%*	*16%*	*11%*
		2050	TJ	**107,061**	754	5,323	14,376	57,606	16,765	12,237







Proceed to the Model Modules	Look up the Summary Tables
Step 1: Low Temperature Heat	Energy Use
Step 2: High Temperature Heat	Energy Supply
Step 3: Stationary Engines	CO2 Emissions
Step 4: Mobile Engines	
Step 5: Lightening and Electronics	**Look up the Data Tables**
Step 6: Non-energetic Use	Energy Use
Step 7: Energy Distribution	Energy Supply
Step 8: Energy Transformation	CO2 Emissions

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4.2 Implementation as web tool

The implementation as a web tool offers the cascade structure of the energy system in an accessible way. The low access barriers allow especially stakeholders, but also other non-modelers, visualization and modification possibilities of all relevant information.

Users can create visions of the future of the Austrian energy system and all decisions are reflected in the composition of Energy Use, Energy Supply and induced CO_2 Emissions. The findings are visualized and can be compared with historic information.

The web tool is implemented as a responsive web application, which can be used on every contemporary computer, tablet and smartphone. All the chosen options are locally stored and remembered over multiple sessions. Two pages of the interface are illustrated in Figure 4-2 and Figure 4-3.

Figure 4-2 Visualization of Final Energy Consumption in 2050

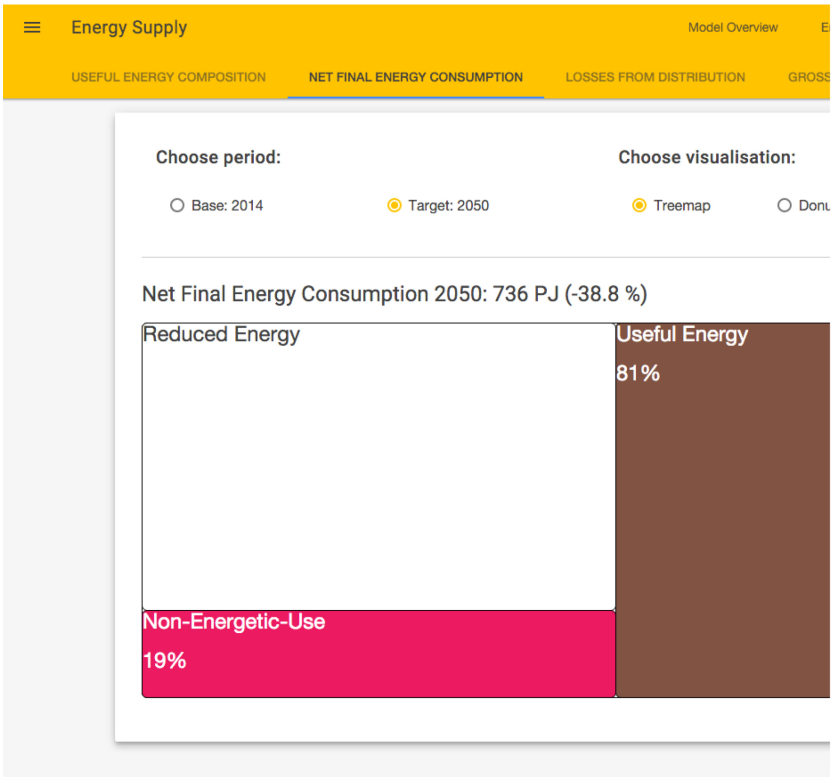
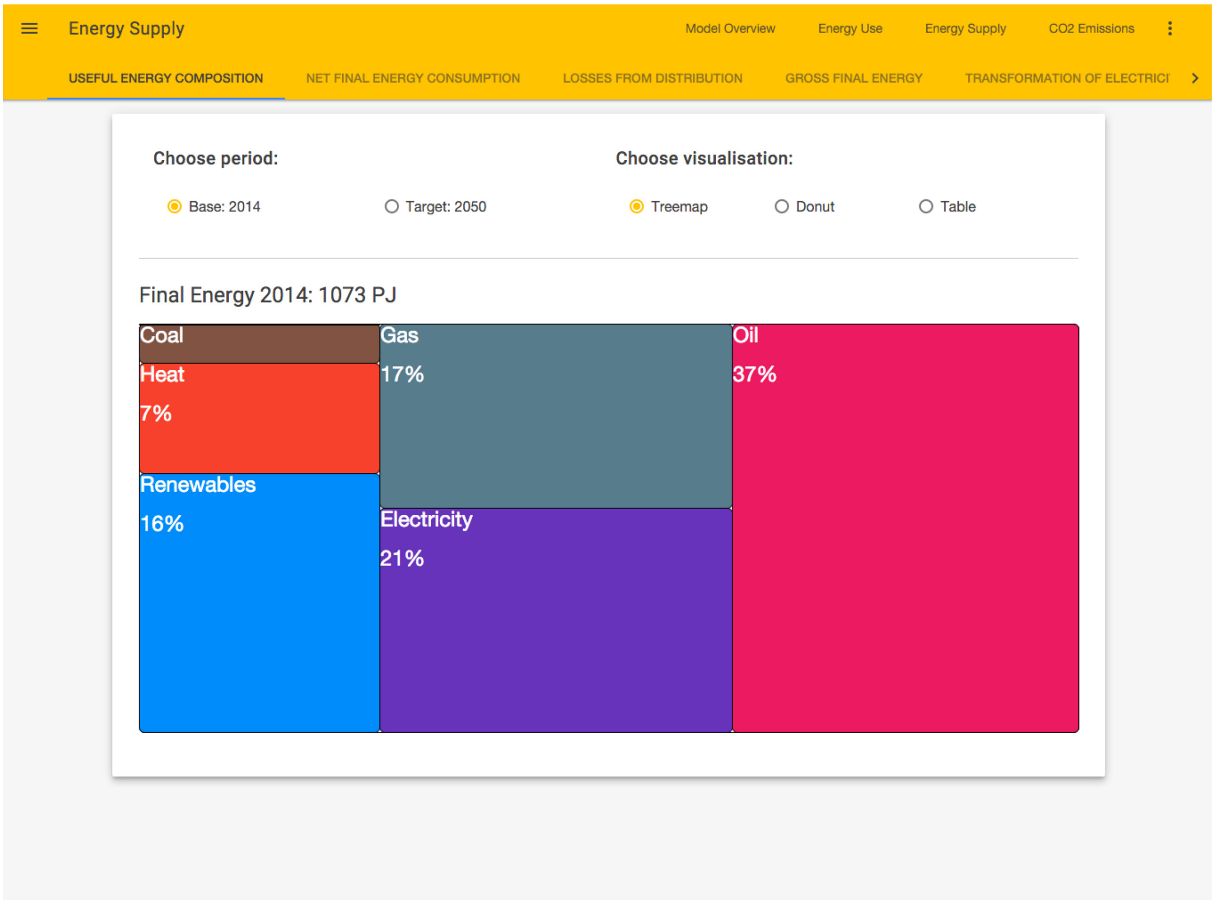


Figure 4-3 Visualization of Final Energy Consumption in 2014



5 A full scale energy model for Austria following the deepened structural modeling approach

5.1 Energy Use

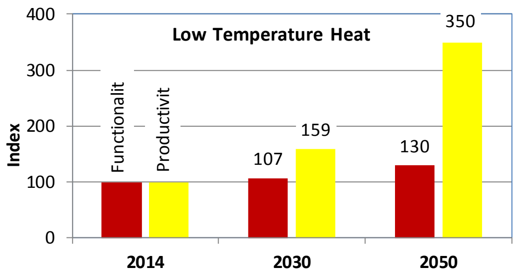
5.1.1 Functionalities and useful energy

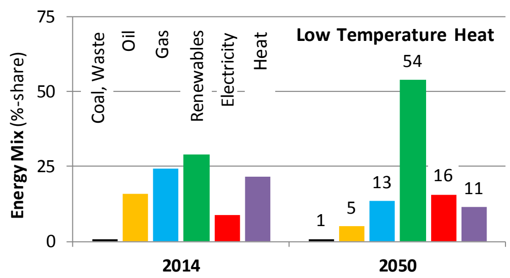
Low temperature heat

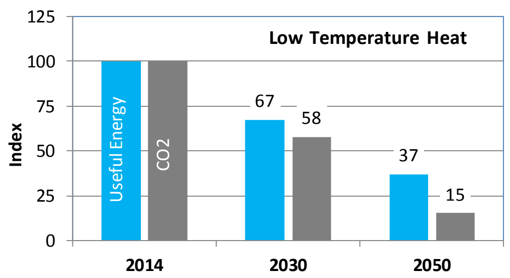
Table 5-1 Low Temperature Heat

Functionalities and Useful Energy				Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
Low Temperature Heat		2014	TJ	**288,241**	2,031	46,037	70,410	83,032	24,960	61,770
	Functionality	Productivity					Start Period Energy Mix			
2014	*100*	*100*	*Index*	*100*	*1%*	*16%*	*24%*	*29%*	*9%*	*21%*
							Change of Energy Mix			
Change	*30*	*250*	*Index*	*-63*	*0%*	*-11%*	*-11%*	*25%*	*7%*	*-10%*
							End Period Energy Mix			
2050	*130*	*350*	*Index*	*37*	*1%*	*5%*	*13%*	*54%*	*16%*	*11%*
		2050	TJ	**107,061**	754	5,323	14,376	57,606	16,765	12,237

Figure 5-1 Low Temperature Heat





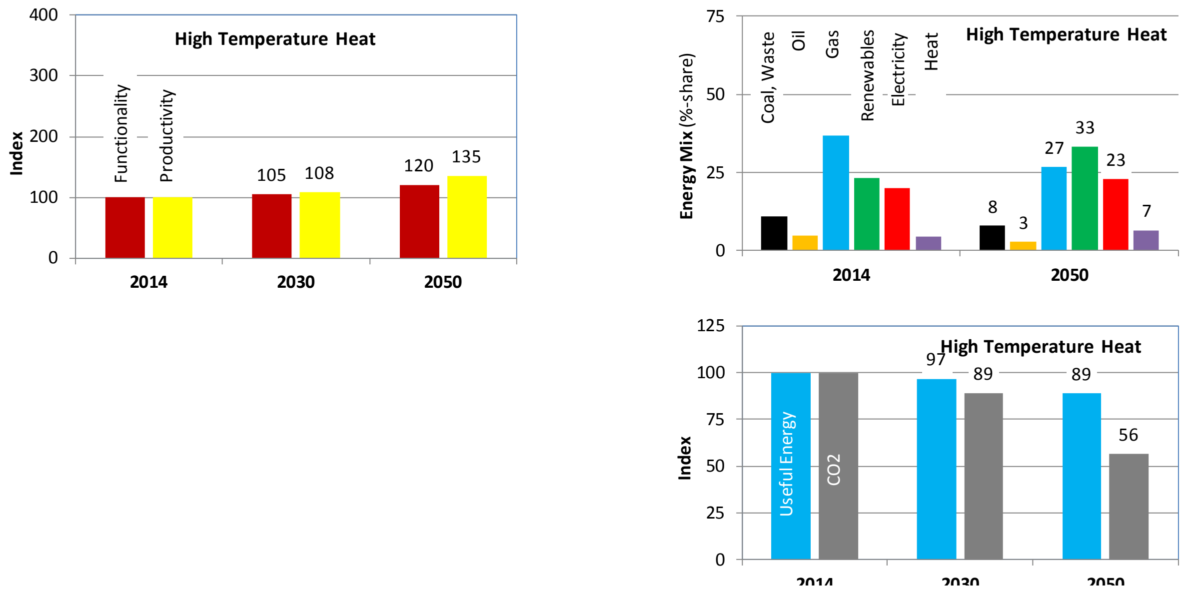


High temperature heat

Table 5-2 High Temperature Heat

Functionalities and Useful Energy				Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
High Temperature Heat 2014			*TJ*	**247,710**	26,940	11,741	90,899	57,707	49,243	11,180
	Functionality	Productivity			Start Period Energy Mix					
2014	*100*	*100*	*Index*	*100*	*11%*	*5%*	*37%*	*23%*	*20%*	*5%*
					Change of Energy Mix					
Change	*20*	*35*	*Index*	*-11*	*-3%*	*-2%*	*-10%*	*10%*	*3%*	*2%*
					End Period Energy Mix					
2050	*120*	*135*	*Index*	*89*	*8%*	*3%*	*27%*	*33%*	*23%*	*7%*
2050			*TJ*	**220,187**	17,341	6,033	58,780	73,314	50,377	14,342

Figure 5-2 High Temperature Heat

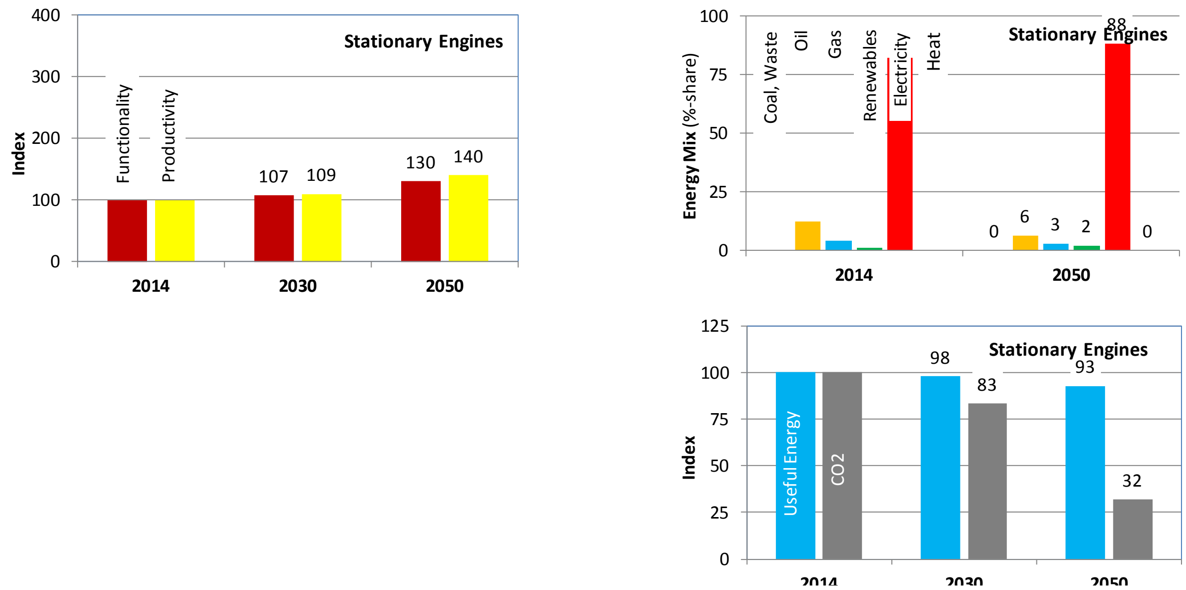


Stationary engines

Table 5-3 Stationary Engines

Functionalities and Useful Energy				Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
Stationary Engines 2014			*TJ*	**119,843**	0	14,900	4,794	1,466	98,684	0
	Functionality	Productivity			Start Period Energy Mix					
2014	*100*	*100*	*Index*	*100*	*0%*	*12%*	*4%*	*1%*	*82%*	*0%*
					Change of Energy Mix					
Change	*30*	*40*	*Index*	*-7*	*0%*	*-6%*	*-1%*	*1%*	*6%*	*0%*
					End Period Energy Mix					
2050	*130*	*140*	*Index*	*93*	*0%*	*6%*	*3%*	*2%*	*88%*	*0%*
2050			*TJ*	**111,283**	0	7,158	3,339	2,474	98,312	0

Figure 5-3 Stationary Engines

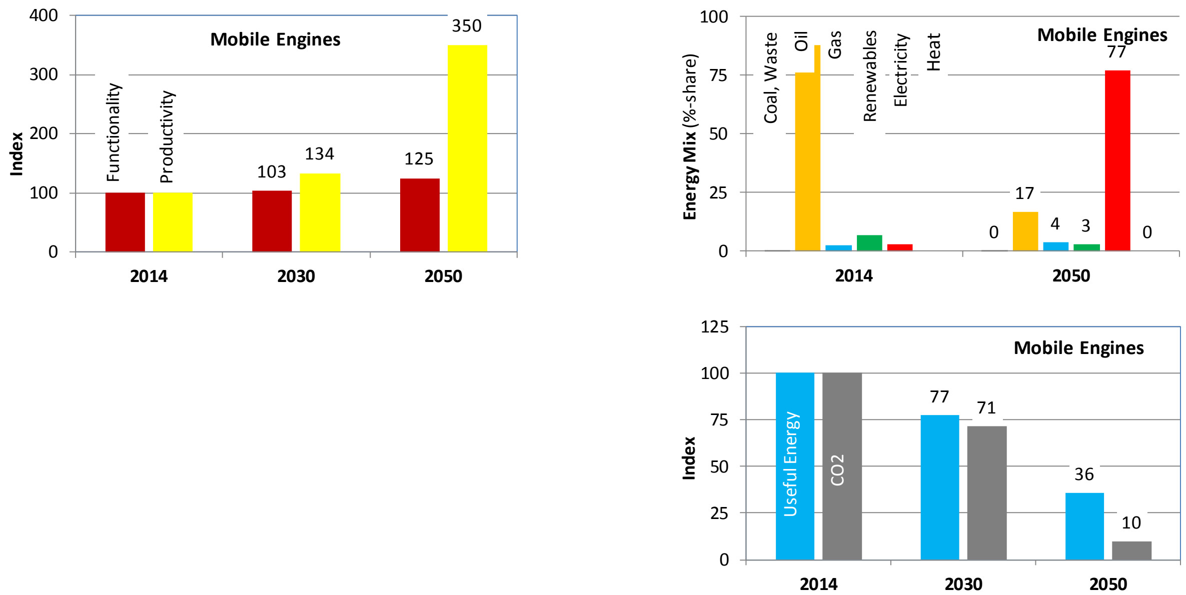


Mobile engines

Table 5-4 Mobile Engines

Functionalities and Useful Energy	Functionality	Productivity		Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
Mobile Engines 2014			*TJ*	**376,036**	6	329,911	9,781	25,473	10,865	0
					Start Period Energy Mix					
2014	*100*	*100*	*Index*	*100*	*0%*	*88%*	*3%*	*7%*	*3%*	*0%*
					Change of Energy Mix					
Change	*25*	*250*	*Index*	*-64*	*0%*	*-71%*	*1%*	*-4%*	*74%*	*0%*
					End Period Energy Mix					
2050	*125*	*350*	*Index*	*36*	*0%*	*17%*	*4%*	*3%*	*77%*	*0%*
2050			*TJ*	**134,299**	2	22,473	4,836	3,726	103,261	0

Figure 5-4 Mobile Engines

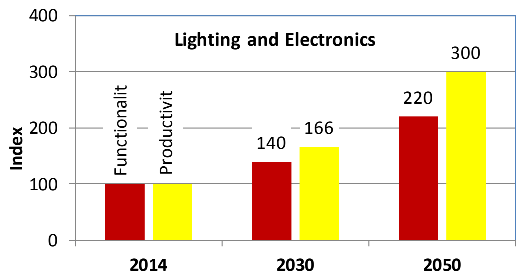


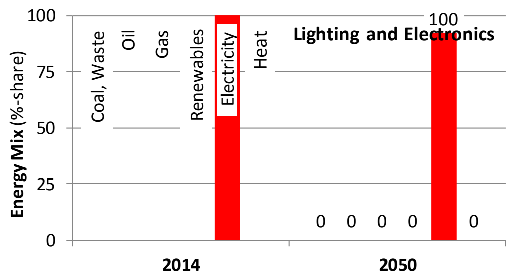
Lighting and electronics

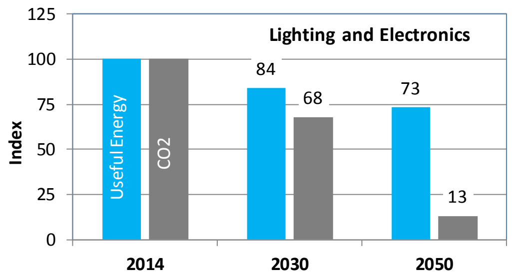
Table 5-5 Lighting and Electronics

Lighting and Electronics		2014	TJ	**31,350**	0	0	0	0	31,350	0
	Functionality	Productivity					Start Period Energy Mix			
2014	*100*	*100*	*Index*	*100*	*0%*	*0%*	*0%*	*0%*	*100%*	*0%*
							Change of Energy Mix			
Change	*120*	*200*	*Index*	*-27*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
							End Period Energy Mix			
2050	*220*	*300*	*Index*	*73*	*0%*	*0%*	*0%*	*0%*	*100%*	*0%*
		2050	TJ	**22,990**	0	0	0	0	22,990	0

Figure 5-5 Lighting and Electronics





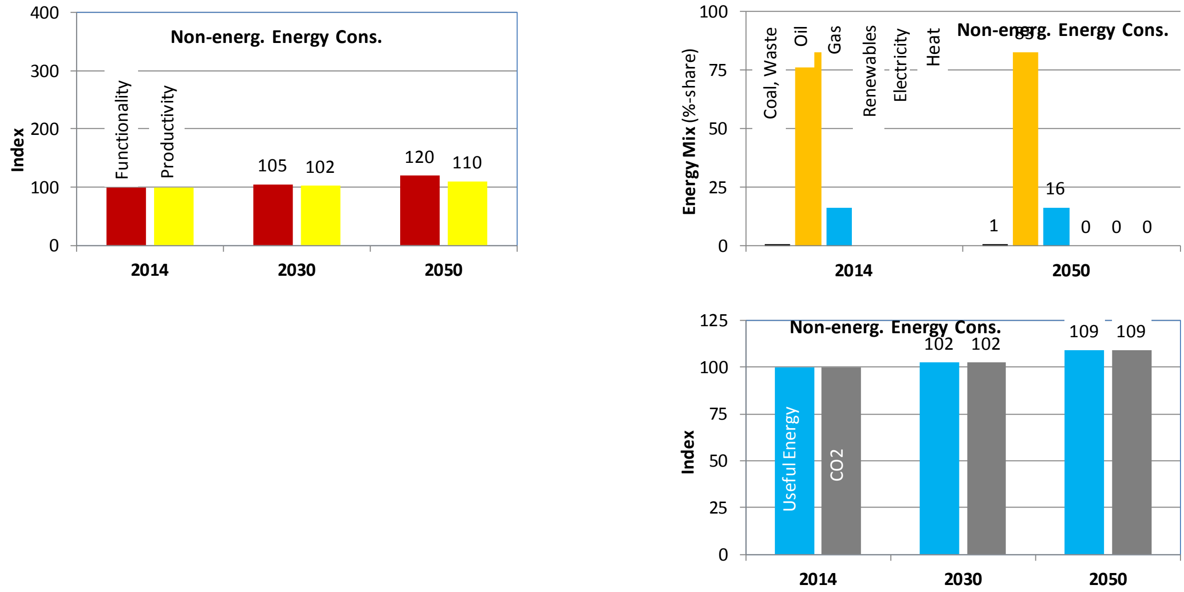


5.1.2 Non-energetic energy use

Table 5-6 Non-energetic Energy Use

Non-energetic Energy Use				**Total**	**Coal, Waste**	**Oil**	**Gas**	**Renewables**	**Electricity**	**Heat**
Non-energetic Energy Use		2014	TJ	**84,944**	609	70,354	13,981	0	0	0
	Functionality	Productivity					*Start Period Energy Mix*			
2014	*100*	*100*	*Index*	*100*	*1%*	*83%*	*16%*	*0%*	*0%*	*0%*
							Change of Energy Mix			
Change	*20*	*10*	*Index*	*9*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*
							End Period Energy Mix			
2050	*120*	*110*	*Index*	*109*	*1%*	*83%*	*16%*	*0%*	*0%*	*0%*
		2050	TJ	**92,666**	664	76,749	15,252	0	0	0

Figure 5-6 Non-energetic Energy Use



5.1.3 Summary Energy Use

Table 5-7 Final Energy Consumption

Final Energy Consumption		Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
2014	TJ	**1,063,181**	28,978	402,588	175,884	167,678	215,102	72,950
	Share		*3%*	*38%*	*17%*	*16%*	*20%*	*7%*
2050	TJ	**595,819**	18,098	40,987	81,331	137,119	291,706	26,579
	Share		*3%*	*7%*	*14%*	*23%*	*49%*	*4%*

Figure 5-7 Final Energy Consumption

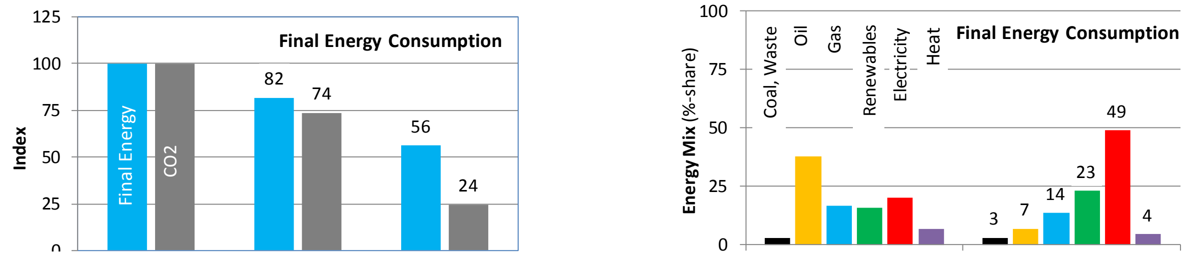


Table 5-8 Net Final Energy Consumption

Net Final Energy Consumption		Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
2014	TJ	**1,148,124**	29,587	472,942	189,865	167,678	215,102	72,950
	Share		*3%*	*41%*	*17%*	*15%*	*19%*	*6%*
2050	TJ	**688,485**	18,762	117,736	96,583	137,119	291,706	26,579
	Share		*3%*	*17%*	*14%*	*20%*	*42%*	*4%*

5.2 Energy supply

5.2.1 Energy distribution

Table 5-9 Losses from Distribution

Energy Distribution			Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
Net Final Energy Cons.	*2014*	*TJ*	**1,148,124**	29,587	472,942	189,865	167,678	215,102	72,950
	2050	*TJ*	**688,485**	18,762	117,736	96,583	137,119	291,706	26,579
Losses from Distribution	*2014*	*TJ*	**148,570**	60,287	22,935	18,416	12	40,028	6,891
	2050	*TJ*	**67,837**	30,716	4,429	7,094	10	24,298	1,291
				Start Period Distribution Losses					
Shares of Disttribution Losses		%		*67%*	*5%*	*9%*	*0%*	*16%*	*9%*
				Change of Distribution Losses					
	Change	%		*-5%*	*-1%*	*-2%*	*0%*	*-8%*	*-4%*
				End Period Distribution Losses					
	2050	%		*62%*	*4%*	*7%*	*0%*	*8%*	*5%*
Gross Final Energy	*2014*	*TJ*	**1,296,695**	89,874	495,877	208,282	167,690	255,130	79,842
	2050	*TJ*	**756,322**	49,478	122,165	103,677	137,129	316,004	27,869

Table 5-10 Untransformed and Transformed Final Energy

Energy Distribution			Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
Gross Final Energy	*2014*	*TJ*	**1,296,695**	89,874	495,877	208,282	167,690	255,130	79,842
	2050	*TJ*	**756,322**	49,478	122,165	103,677	137,129	316,004	27,869
Gross Final Energy Untransf.	*2014*	*TJ*	**522,597**	6,377	118,135	208,282	156,415	33,389	0
	2050	*TJ*	**265,918**	3,016	27,882	103,677	127,909	3,435	0
				Start Period Share of Untransformed Gross Final Energy					
Shares of Untransformed Gross Final Energy	*2014*	%		*7%*	*24%*	*100%*	*93%*	*13%*	*0%*
				Change of Share					
	Change	%		*-1%*	*-1%*	*0%*	*0%*	*-12%*	*0%*
				End Period Share of Untransformed Gross Final Energy					
	2050	%		*6%*	*23%*	*100%*	*93%*	*1%*	*0%*
Gross Final Energy Transf.	*2014*	*TJ*	**774,097**	83,497	377,742	0	11,276	221,741	79,842
	2050	*TJ*	**490,403**	46,462	94,283	0	9,221	312,568	27,869

5.2.2 Energy transformation

Table 5-11 Transformation of Energy - Input Energy

Energy Transformation			Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
			from	Coal, Waste	Oil	Gas	Biomass	Hydro	Wind, PV, …
Output Electricity	2014	TJ	**221,741**	20,157	2,192	19,442	15,619	147,608	16,723
				Start Period Input Shares for Electricity Generation					
Energy Mix for Electricity	*2014*	*Index*	*100*	*9%*	*1%*	*9%*	*7%*	*67%*	*8%*
				Change of Share					
	Change	*Index*	*41*	*-7%*	*-1%*	*-7%*	*-4%*	*-13%*	*32%*
				End Period Input Shares for Electricity Generation					
	2050	*Index*	*141*	*2%*	*0%*	*2%*	*3%*	*54%*	*40%*
	2050	*TJ*	**312,568**	6,534	276	5,213	9,514	167,436	123,595
			from	Coal, Waste	Oil	Gas	Biomass	Hydro	Wind, PV, …
Output Heat	*2014*	*TJ*	**79,842**	9,022	3,920	30,703	35,592	0	604
				Start Period Input Shares for Heat Generation					
Energy Mix for Heat	*2014*	*Index*	*100*	*11%*	*5%*	*38%*	*45%*	*0%*	*1%*
				Change of Share					
	Change	*Index*	*-65*	*-2%*	*-3%*	*-17%*	*11%*	*0%*	*11%*
				End Period Input Shares for Heat Generation					
	2050	*Index*	*35*	*9%*	*2%*	*21%*	*56%*	*0%*	*12%*
	2050	*TJ*	**27,869**	2,592	532	5,979	15,489	0	3,277
			from	Coal, Waste	Oil	Gas	Biomass		
Output Other Transform.	*2014*	*TJ*	**472,515**	83,497	377,742	0	11,276		
	2050	*TJ*	**149,965**	46,462	94,283	0	9,221		

Table 5-12 Transformation of Energy – Transformation Losses

Energy Transformation			Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
			from	Coal, Waste	Oil	Gas	Biomass	Hydro	Wind, PV, …
Losses from E & H Transf.	*2014*	*TJ*	**78,877**	32,422	2,399	11,406	32,651	0	0
	2050	*TJ*	**22,941**	7,356	258	1,903	13,424	0	0
				Start Period Electricity and Heat Transformation Losses					
Share of Transformat. Losse: in Electricity and Heat Processes	*2014*	%		*53%*	*28%*	*19%*	*39%*	*0%*	*0%*
				Change of Distribution Losses					
	Change	%		*-8%*	*-4%*	*-4%*	*-4%*	*0%*	*0%*
				End Period Electricity and Heat Transformation Losses					
	2050	%		*45%*	*24%*	*15%*	*35%*	*0%*	*0%*
Input Electricity and Heat	*2014*	*TJ*	**380,460**	61,601	8,511	61,551	83,861	147,608	17,327
	2050	*TJ*	**363,379**	16,482	1,066	13,096	38,427	167,436	126,871

				Coal, Waste	Oil	Gas	Biomass
Losses from Other Transf.	*2014*	*TJ*	**5,239**	4,203	874	0	162
	2050	*TJ*	**2,323**	2,323	0	0	0
Input Other Transformations	*2014*	*TJ*	**477,754**	87,700	378,616	0	11,438
	2050	*TJ*	**152,288**	48,785	94,283	0	9,221

			Total	Coal, Waste	Oil	Gas	Biomass	Hydro	Wind, PV, …
Input Transformation	*2014*	*TJ*	**858,213**	149,301	387,127	61,551	95,299	147,608	17,327
	2050	*TJ*	**515,668**	65,267	95,349	13,096	47,648	167,436	126,871

Table 5-13 Gross Energy Supply

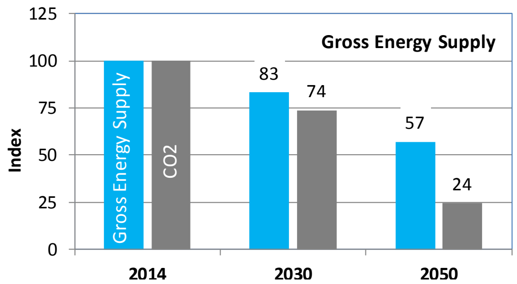
Gross Energy Supply		Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
2014	*TJ*	**1,380,811**	155,678	505,262	269,832	416,649	33,389	0
	Share		*11%*	*37%*	*20%*	*30%*	*2%*	*0%*
2050	*TJ*	**781,586**	68,283	123,232	116,772	469,864	3,435	0
	Share		*9%*	*16%*	*15%*	*60%*	*0%*	*0%*

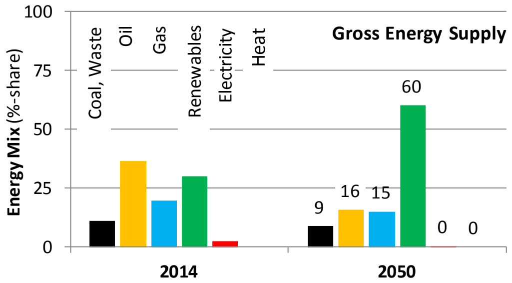
5.2.3 Summary Energy Supply

Table 5-14 Summary Energy Supply

Energy Supply			Total	Coal, Waste	Oil	Gas	Renewables	Electricity	Heat
Net Final Energy Cons.	*2014*	*TJ*	**1,148,124**	29,587	472,942	189,865	167,678	215,102	72,950
	2050	*TJ*	**688,485**	18,762	117,736	96,583	137,119	291,706	26,579
Losses from Distribution	*2014*	*TJ*	**148,570**	60,287	22,935	18,416	12	40,028	6,891
	2050	*TJ*	**67,837**	30,716	4,429	7,094	10	24,298	1,291
Gross Final Energy	*2014*	*TJ*	**1,296,695**	89,874	495,877	208,282	167,690	255,130	79,842
	2050	*TJ*	**756,322**	49,478	122,165	103,677	137,129	316,004	27,869
Gross Final Energy Untransf.	*2014*	*TJ*	**522,597**	6,377	118,135	208,282	156,415	33,389	0
	2050	*TJ*	**265,918**	3,016	27,882	103,677	127,909	3,435	0
Gross Final Energy Transf.	*2014*	*TJ*	**774,097**	83,497	377,742	0	11,276	221,741	79,842
	2050	*TJ*	**490,403**	46,462	94,283	0	9,221	312,568	27,869
Losses from Transformations	*2014*	*TJ*	**84,116**	36,625	3,273	11,406	32,813	0	0
	2050	*TJ*	**25,265**	9,680	258	1,903	13,424	0	0
Gross Energy Supply	2014	*TJ*	**1,380,811**	155,678	505,262	269,832	416,649	33,389	0
		Share		*11%*	*37%*	*20%*	*30%*	*2%*	*0%*
	2050	*TJ*	**781,586**	68,283	123,232	116,772	469,864	3,435	0
		Share		*9%*	*16%*	*15%*	*60%*	*0%*	*0%*

Figure 5-8 Gross Energy Supply



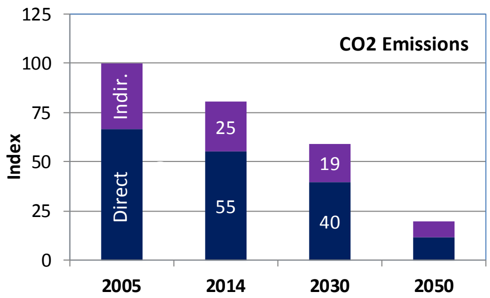


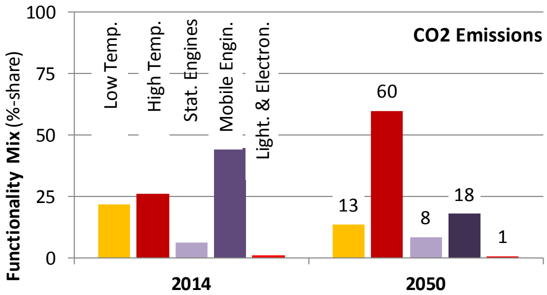
5.3 CO_2 Emissions from Energy Use

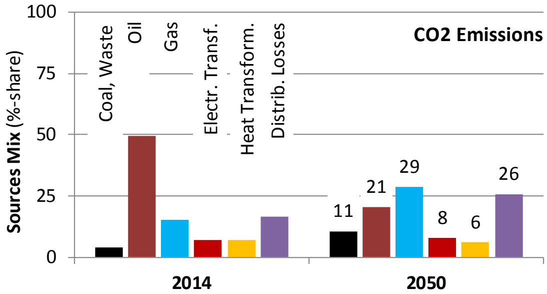
Table 5-15 CO_2 Emissions from Energy Use

				Direct Emissions			Indirect Emissions		
CO2 Emissions			**Total**	**Coal, Waste**	**Oil**	**Gas**	**Electricity**	**Heat**	**Distribution**
Low temperature heat	2014	*thsd t*	**13,796**	187	3,591	3,873	535	3,840	1,771
	2005	*Index*	*100*	Start Period Distribution					
	2014	*Index*	*67*	*1%*	*26%*	*28%*	*4%*	*28%*	*13%*
	2030	*Index*	*42*	End Period Distribution					
	2050	*Index*	*10*	*3%*	*20%*	*38%*	*3%*	*21%*	*15%*
	2050	*thsd t*	**2,098**	69	415	791	71	439	313
High temperature heat	2014	*thsd t*	**16,500**	2,479	916	4,999	1,055	695	6,356
	2005	*Index*	*100*	Start Period Distribution					
	2014	*Index*	*87*	*15%*	*6%*	*30%*	*6%*	*4%*	*39%*
	2030	*Index*	*79*	End Period Distribution					
	2050	*Index*	*49*	*17%*	*5%*	*35%*	*2%*	*6%*	*35%*
	2050	*thsd t*	**9,308**	1,595	471	3,233	213	514	3,282
Stationary Engines	2014	*thsd t*	**4,059**	0	1,162	264	2,115	0	518
	2005	*Index*	*100*	Start Period Distribution					
	2014	*Index*	*69*	*0%*	*29%*	*6%*	*52%*	*0%*	*13%*
	2030	*Index*	*59*	End Period Distribution					
	2050	*Index*	*22*	*0%*	*43%*	*14%*	*32%*	*0%*	*10%*
	2050	*thsd t*	**1,290**	0	558	184	415	0	133
Mobile Engines	2014	*thsd t*	**28,372**	1	25,733	538	233	0	1,868
	2005	*Index*	*100*	Start Period Distribution					
	2014	*Index*	*89*	*0%*	*91%*	*2%*	*1%*	*0%*	*7%*
	2030	*Index*	*67*	End Period Distribution					
	2050	*Index*	*9*	*0%*	*64%*	*10%*	*16%*	*0%*	*11%*
	2050	*thsd t*	**2,754**	0	1,753	266	436	0	299
Lighting and Electronics	2014	*thsd t*	**797**	0	0	0	672	0	125
	2005	*Index*	*100*	Start Period Distribution					
	2014	*Index*	*50*	*0%*	*0%*	*0%*	*84%*	*0%*	*16%*
	2030	*Index*	*36*	End Period Distribution					
	2050	*Index*	*7*	*0%*	*0%*	*0%*	*92%*	*0%*	*8%*
	2050	*thsd t*	**105**	0	0	0	97	0	8
CO2 from Energy Use	2014	*thsd t*	**63,524**	2,666	31,402	9,674	4,610	4,535	10,637
	2005	*Index*	*100*	Start Period Distribution					
	2014	*Index*	*80*	*4%*	*49%*	*15%*	*7%*	*7%*	*17%*
	2030	*Index*	*62*	End Period Distribution					
	2050	*Index*	*20*	*11%*	*21%*	*29%*	*8%*	*6%*	*26%*
	2050	*thsd t*	**15,555**	1,665	3,197	4,473	1,232	953	4,035

Figure 5-9 CO_2 Emissions from Energy Use







6 Lessons that might be worth learning

We summarize now some key issues that were developed in this handbook for a deepened structural approach to energy modeling.

6.1 Mind your mindset

The need for a next generation of energy models

There are many reasons for initiating a major joint research effort to switch to a next generation of energy models, above all the emerging breakthrough-technologies, the promising options for a transition to low-energy and low-carbon energy systems, and the accompanying far reaching changes in the business and institutional environments.

The accompanying keywords: inversion, innovation, and integration

For model-based analyses this means switching to a mindset that can be characterized by three keywords:

- Inversion
  of the reasoning by focusing first on the functionalities expected from an energy system and sequel on the options for providing these functionalities by a careful selection of technologies and energy flows.
- Innovation
  of all facets of the emerging energy systems of the future, ranging from energy-autonomous buildings to new materials and processes for products and the new storage systems for electricity that may not before long change transport and electricity grids.
- Integration
  of all components that constitute the infrastructure and energy flows for providing a specific functionality for thermal, mechanical and specific electric services.

Deepened structural modeling frameworks for a better understanding of energy systems

An obvious answer to these new challenges is the opening of the black box of conventional energy models by indulging into a deepened structural modeling framework that explicitly deals the following components:

- The energy system
  is described by an in depth specification of the physical structure, starting with functionalities and continuing with application and transformation technologies that finally determine the volume and the mix of energy flows.
- The economic system
  with the linkages between the energy and non-energy sector and the impacts of innovations on energy flows and capital stocks.
- The institutional system
  which governs the coordination by markets and regulation but is also concerned with incentives for changing behavioral attitudes and innovations for technologies and business models.

Basic virtues of scientific honesty

Also in this innovative modeling framework, some basic virtues of scientific honesty need to be observed:

- Be honest and open about your model's assumptions and how they are driving the results and hence potential policy suggestions
- Make yourself clear that your model is based on normative assumptions and your personal cultural context and worldviews.

Even though economic and energy modelers often perceive their research as purely positivistic, the basic assumptions underlying their models already lead to certain normative conclusions, e.g. regarding distributional justice issues; substitutability of natural capita with human-made capital; the role of labor unions; free market supremacy.

6.2 A checklist for evaluating energy models

This checklist addresses energy models which are intended to serve a better understanding of the long-term transition that has already started in our energy systems.

Given this aim, we want to obtain better insights into the enormous potential for innovation with the help of an analytical modeling framework. Without wanting to be too simplistic we identify three types of intellectual contributions with respect to the modeling designs: essential, experimental and expired.

Essential

If we can agree that for many reasons fundamental transitions of the energy systems are unavoidable and require a deepened understanding of their structures and their driving mechanisms, then we also need to agree on some essential elements in the modeling designs.

Functionalities

The fulfillment of thermal, mechanical and specific electric functionalities or energy services is the ultimate task of any energy system. Although we need better databases about these functionalities, there are operational procedures for dealing with them in a modeling framework.

Technologies

Transitions in our energy systems are closely tied to technological changes, some of them are going to be disruptive for existing structures. A minimal requirement is to deal explicitly with application technologies for providing functionalities and with transformation technologies that convert primary to final energy flows.

Capital stocks

Capital stocks, from buildings to vehicles, from railway tracks to the internet and from heat pumps powered by photovoltaics to micro grids, are the decisive infrastructure that determines the transition to innovative structures of the energy system. Similarly the institutions and societies´ implicit and explicit socio-institutional "capital stock" are the decisive social infrastructure that eases or hinders the transition to innovative structures of the energy system.

Both the quality and the quantity of both physical and institutional capital stock adjustments need to be explicatively modeled.

Separation of system structures from driving mechanisms

Any transitions in our energy systems are reflected in changes of their structures which in turn are described in the way functionalities are provided and energy is transformed. These changes may be driven by different mechanisms, from building standards to energy taxes, from co-design to participatory approaches, and therefore should be separated in the modeling design.

Experimental

Deepened structural modeling approaches reveal the needs for a much better understanding of the linkages between the energy and the economic system, which in turn is governed by the institutional setup for markets, regulations and incentives.

Far from being able to give proven answers, we want to emphasize putting questions that emerge in a deepened structural modeling framework.

What interaction with the socio-economic system

The interactions between the energy and the economic system concern on the one hand the flow of energy for operating and on the other hand the investments in the capital stock for application and transformation technologies that provide the infrastructure of the energy system. This differentiation and its implication for providing the functionalities of the energy system need to be further explored.

What competition

The conventional understanding of competition is mostly limited to single types of energy, as oil and gas or electricity and heat. A comprehensive understanding of the energy system recommends installing markets for providing energy related functionalities, as keeping buildings over the whole year at comfortable temperatures or moving persons and goods over local, regional or transnational distances. Thus limiting competition in energy models to seemingly isolated markets for single types of energy, as for crude oil or electricity, will not be sufficient.

What incentives

There is a lot more to be said about incentives than just recommending monetary transfers. Investments in buildings e.g., can be improved by installing adequate financial vehicles that extend the length of mortgages or switching to public transport can be encouraged to a more sophisticated ticketing system. By emphasizing for the design of incentives a system point of view, recommendations for stimulating transitions of the energy system mainly by a CO_2 tax will turn out to be just too simplistic. Such an analysis, however, needs also an adequate modeling framework.

What innovation

Envisioned transitions of our energy system to low-energy and low-carbon structures recommend targeted innovation policies. There is a unique opportunity to encourage emerging breakthrough-technologies, as a new generation of electricity storage, and to integrate these technologies into the energy system. This is another motivation for a deepened structural modeling specification.

What business models

Closely tied to the emerging transitions of our energy systems are new business models that focus on serving the functionalities than selling energy flows. Similarly we observe for capital goods, like cars, a shift from ownership to use and a corresponding reorientation of the business models. The next generation of model designs should be able to handle also this transition.

Expired

Without wanting to add insult to injury we list some common practices in energy modeling which definitely have reached an expiration date.

Implausible assumptions about causalities

Neither relevant nor predictable are a long list of variables that misleadingly still show up in many models as drivers for long-term energy structures: economic activity as GDP (from which we want decouple energy flows), energy prices as those for oil, gas, coal and carbon allowances (since we are going to deal with disruptive changes) or even exchange rates (because of the volatility of the financial markets).

Specifications based on irreproducible parameters

Closely tied with implausible causalities are the corresponding elasticities for economic activities and prices which either need a lot of prior restrictions in order to match with a historical database or might lack any evidence check with current behavior as elasticities of substitution in nested production functions.

Claims of forecasting capabilities

Economics was caught by surprise to engage in policy issues with time ranges up to the year 2100 and beyond. It will still take some time to obtain a mutual understanding what the contribution of economics could be in long-term issues. For sure it will be not the pretention of being able to provide forecasts, either unconditional or seemingly safer when based on conditions.

Prices resulting from market equilibria

Although prices seem to be the main mechanism that drives day-to-day decisions, this is only partially true for the consumption of energy goods, like electricity and fuels, let alone for investment decisions concerning buildings and cars. Even more debatable is the claim that observed prices reflect market equilibria.

Scenarios based on input-output tables

Input-output tables reveal a lot about the value chains and interactions between economic sectors. Given the emerging changes in the design of products, in the organization of production process and the role of new materials, it is just not reasonable to make sectoral projections based on input-output tables over time spans that are relevant for the transformations of the energy and other sectors of our economies.

Impact analyses based on computable general equilibrium models

Although energy models, which are characterized by computable general equilibrium specifications, have become very appealing from the point of view of economic theory and seemingly useful for answering many policy questions, there is an emerging understanding that these models if used without complementary analysis lack many required capabilities for dealing with long-term transition processes.

Separate strategies for single types of energy

Both on a European and on national scales separate energy strategies, e.g. for electricity, heat and renewables, have emerged. These strategies neglect in an integrated system perspective potential incompatibilities with functionalities and potential innovations in application and transformation technologies.

PRIMES scenarios for Europe

The PRIMES modeling framework should not be used anymore for predictive statements about the future of the European energy system or for impact analyses, e.g. for carbon prices. The main virtue of the current PRIMES model is a comprehensive and coherent database that could be a good starting point for deepened structural specifications of the current modeling framework.

WEM and WAM scenarios for Austria

Energy scenarios with time ranges up to 2050 have become available for Austria under the heading “with existing measures (WEM)” and “with additional measures (WAM)”. Both the pretense of being able to predict and differentiate policy impacts over such time spans without explicitly reporting sensitivity on the crucial assumptions without explicitly reporting sensitivity on the crucial assumptions used not is justified.

6.3 Naming without shaming

The mindset of economists and economics is closely related to modeling as Leijonhufvud (1973) pointed out in his sharp-witted and up to today valid satire. In fact, economics is perhaps more than any other social science model-oriented and there are many reasons for this, e.g. the history of the discipline with ideas coming from the natural sciences (particularly Newtonian physics), the search for universality, mathematical rigor and precision.

We conclude therefore with commenting three familiar modeling approaches which might serve as benchmarks for further discussions about deepened structural modeling in the context of energy.

6.3.1 Hidden and critical assumptions of the PRIMES model

Lack of transparency and debatable assumptions

Over many years if not decades the PRIMES model (E3mlab, 2015) has become a kind of workhorse for evaluating impacts of almost all energy related European policy decisions.

This practice, however, has come under critical attacks, mainly articulating complaints about a lack of transparency regarding the general model structure as well as the choice of critical assumptions.

As an example of such critical assumptions might serve a dispute about the values of GDP up to 2050, which serve as an important exogenous input to the PRIMES model and a key driver of modeling results. It was revealed (European Commission, 2016) that these values were taken from the 2015 Aging Report (European Commission, 2015).

This practice contains at least two major flaws: First, it is absolutely impossible to make statements about GDP with any predictive power just beyond one year, as forecasting performance over recent years confirms; second there are many reasons that GDP will not be a relevant driver for energy use before long if we really want to decouple energy flows from GDP, which will be essential for achieving any low-carbon targets.

Despite these and other similar flaws in the model design for which PRIMES is representative, many policy impact analyses of the European Commission claim using well-founded in economic theory by referring to these type of models. Since opening the black box of e.g. the PRIMES model reveals a kind of emperor's new clothes effect, it is highly recommended to reflect more critically on modeling results and derived policy suggestions that are argued with these models. Finally this might be a good time for phasing out the use of conventional energy models and substituting them with deepened structural modeling approaches in particular when long-term transitions are concerned.

6.3.2 Scrutinizing the energy scenarios of Umweltbundesamt Wien

Renewable energy scenarios for Austria

More details about the modeling of energy scenarios are provided in a research report by Umweltbundesamt Wien (2016) in their analysis of renewable energy scenarios for Austria.

Table 6-1 lists key input parameters used for producing scenarios under the heading WEM ("with existing measures") and WAM "(with additional plus measures").

Table 6-1 Inputs used for modeling WEM (with existing measures) and WAM (with additional plus measures) scenarios

Inputs for WEM and WAM plus scenarios	2010	2020	2030	2040	2050
GDP (bill € 2010)	285	330	383	441	495
Population (mill persons)	8.382	8.733	9.034	9.277	9.46
Places of residence (mill)	3.62	3.86	4.05	4.17	4.25
Heating degree days	3,252	3,204	3,118	3,013	2,907
Exchange rate USD/€	1.33	1.30	1.30	1.30	1.30
International price for coal (USD 2010 / ton)	99.2	109.0	116.0	156.0	197.0
International price for oil (USD 2010)	78.1	148.0	212.0	267.0	335.0
International price for oil (USD 2010 / bbl)	78.1	118.0	135.0	139.0	143.0
International price for gas (USD 2010 / GJ)	7.1	10.4	11.9	13.1	14.3
Price for CO_2 allowances (€ 2010 / ton CO_2) WEM	13	20	30	78	100
Price for CO_2 allowances (€ 2010 / ton CO_2) WAM plus	13	20	35	87	162

Source: Umweltbundesamt (2016)

Having a detailed look at this table can be quite revealing and might lead to questioning the credibility of the underlying and many similar modeling exercises. First, although the exogenous input parameters listed in this table might be needed in the current mainstream modeling mindset, there is mounting reasoning, as explains in this paper, that this paradigm has limited relevance for developing real-world energy policies for time ranges up to 2050. Secondly, not even for 2020 can the variables in this table claim any predictive power. Third, it is just impossible to discriminate between the specified policies labeled “with existing measures” (WEM) and “with additional plus measures” (WAM plus).

Thus modeling exercises that rely on assumption as listed in Table 6-1 serve as a benchmark for two types of misconceptions: wrong questions that just should not be put and misleading answers that just should not be given. The inertia with respect to changing paradigms will be measured by the time it will take to abandon the WEM and WAM vocabulary.

6.3.3 A ministry’s view on the energy perspectives of WIFO and Wegener Center

Long-term energy perspectives for Austria

The Austrian Federal Ministry of Science, Research and Economy commissioned to the Austrian Institute of Economic Research (WIFO) and the Wegener Center at the University of Graz a research project on a long-term view of the Austrian energy system, which is reported in Köppl and Schleicher (2014). Surprisingly, the Ministry added on its website a remark to this report, stating that the results and the methodology of this work do not correspond with similar projects commissioned by the Ministry and based on that questioned if this is a realistic approach to analyzing energy systems.

Deliberately labelled as energy perspectives and not energy scenarios for Austria, this research project closely follows the deepened structural modeling approach by using the sGAIN modeling family. The fact that the innovative mindset and the related methodological approach did not obtain a supporting echo by the sponsoring Ministry might be interpreted as a kind of Litmus test for institutional barriers that hamper a progressive energy policy.

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8 Appendix 1: Dan Rodik's Ten Commandments for economists and non-economists

These are the recommendations of Dan Rodik (2015) with respect to economic modeling.

Ten Commandments for economists

(1) Economics is a collection of models; cherish their diversity.

(2) It's a model, not the model.

(3) Make your model simple enough to isolate specific causes and how they work, but not so simple that it leaves out key interactions among causes.

(4) Unrealistic assumptions are OK; unrealistic critical assumptions are not OK.

(5) The world is (almost) always second best.

(6) To map a model to the real world you need explicit empirical diagnostics, which is more craft than science.

(7) Do not confuse agreement among economists for certainty about how the world works.

(8) It's OK to say "I don't know" when asked about the economy or policy.

(9) Efficiency is not everything.

(10) Substituting your values for the public's is an abuse of your expertise.

Ten commandments for non-economists

(1) Economics is a collection of models with no predetermined conclusions; reject any arguments otherwise.

(2) Do not criticize an economist's model because of its assumptions; ask how the results would change if certain problematic assumptions were more realistic.

(3) Analysis requires simplicity; beware of incoherence that passes itself off as complexity.

(4) Do not let math scare you; economists use math not because they're smart, but because they're not smart enough.

(5) When an economist makes a recommendation, ask what makes him/her sure the underlying model applies to the case at hand.

(6) When an economist uses the term "economic welfare," ask what he / she means by it.

(7) Beware that an economist may speak differently in public than in the seminar room.

(8) Economists don't (all) worship markets, but they know better how they work than you do.

(9) If you think all economists think alike, attend one of their seminars.

(10) If you think economists are especially rude to noneconomists, attend one of their seminars.

9 Appendix 2: Key data of the Austrian energy system and perspectives up to 2050

9.1 Energy Use

Table 9-1 Functionalities and related Useful Energy

TJ	2005	2014	2020	2030	2040	2050
Useful Energy	**1,102,661**	**1,063,181**	**1,037,759**	**893,307**	**636,860**	**595,819**
Low Temperatur Heat	327,421	288,241	274,981	205,314	115,860	107,061
High Temperature Heat	251,624	247,710	246,897	240,951	223,404	220,187
Stationary Engines	103,494	119,843	119,581	117,683	112,252	111,283
Mobile Engines	389,332	376,036	365,683	302,439	162,083	134,299
Lighting and Electronigs	30,789	31,350	30,618	26,921	23,261	22,990
Low Temperatur Heat	327,421	288,241	274,981	205,314	115,860	107,061
Coal and Waste	*4,856*	*2,031*	*1,938*	*1,447*	*816*	*754*
Oil	*90,729*	*46,037*	*43,252*	*28,404*	*7,692*	*5,323*
Gas	*83,855*	*70,410*	*66,504*	*45,765*	*17,489*	*14,376*
Renewables	*69,858*	*83,032*	*80,729*	*69,117*	*57,950*	*57,606*
Electricity	*30,546*	*24,960*	*24,237*	*20,572*	*16,914*	*16,765*
Heat	*47,577*	*61,770*	*58,321*	*40,009*	*14,999*	*12,237*
High Temperature Heat	251,624	247,710	246,897	240,951	223,404	220,187
Coal and Waste	*29,355*	*26,940*	*26,688*	*24,801*	*18,611*	*17,341*
Oil	*20,792*	*11,741*	*11,594*	*10,484*	*6,798*	*6,033*
Gas	*103,080*	*90,899*	*90,055*	*83,737*	*63,025*	*58,780*
Renewables	*46,696*	*57,707*	*58,062*	*60,814*	*70,999*	*73,314*
Electricity	*45,523*	*49,243*	*49,244*	*49,303*	*50,097*	*50,377*
Heat	*6,177*	*11,180*	*11,253*	*11,811*	*13,874*	*14,342*
Stationary Engines	103,494	119,843	119,581	117,683	112,252	111,283
Coal and Waste	*0*	*0*	*0*	*0*	*0*	*0*
Oil	*16,511*	*14,900*	*14,709*	*13,259*	*8,242*	*7,158*
Gas	*785*	*4,794*	*4,757*	*4,479*	*3,538*	*3,339*
Renewables	*2*	*1,466*	*1,489*	*1,668*	*2,325*	*2,474*
Electricity	*86,196*	*98,684*	*98,627*	*98,277*	*98,147*	*98,312*
Heat	*0*	*0*	*0*	*0*	*0*	*0*
Mobile Engines	389,332	376,036	365,683	302,439	162,083	134,299
Coal and Waste	*10*	*6*	*6*	*5*	*3*	*2*
Oil	*368,097*	*329,911*	*317,550*	*241,471*	*63,082*	*22,473*
Gas	*6,545*	*9,781*	*9,558*	*8,203*	*5,330*	*4,836*
Renewables	*2,317*	*25,473*	*24,587*	*19,143*	*6,522*	*3,726*
Electricity	*12,363*	*10,865*	*13,982*	*33,617*	*87,145*	*103,261*
Heat	*0*	*0*	*0*	*0*	*0*	*0*
Lighting and Electronics	30,789	31,350	30,618	26,921	23,261	22,990
Coal and Waste	*0*	*0*	*0*	*0*	*0*	*0*
Oil	*0*	*0*	*0*	*0*	*0*	*0*
Gas	*0*	*0*	*0*	*0*	*0*	*0*
Renewables	*0*	*0*	*0*	*0*	*0*	*0*
Electricity	*30,789*	*31,350*	*30,618*	*26,921*	*23,261*	*22,990*
Heat	*0*	*0*	*0*	*0*	*0*	*0*

Table 9-2 Final Energy

TJ	2005	2014	2020	2030	2040	2050
Final Energy Consumption	**1,102,661**	**1,063,181**	**1,037,759**	**893,307**	**636,860**	**595,819**
Coal and Waste	34,222	28,978	28,632	26,253	19,430	18,098
Oil	496,129	402,588	387,104	293,619	85,814	40,987
Gas	194,265	175,884	170,874	142,184	89,382	81,331
Renewables	118,873	167,678	164,868	150,742	137,796	137,119
Electricity	205,418	215,102	216,707	228,690	275,564	291,706
Heat	53,754	72,950	69,574	51,821	28,873	26,579
Non-energetic Energy Consumption	**73,859**	**84,944**	**85,131**	**86,562**	**91,587**	**92,666**
Coal and Waste	496	609	610	620	656	664
Oil	60,162	70,354	70,508	71,694	75,856	76,749
Gas	13,200	13,981	14,012	14,248	15,075	15,252
Renewables	0	0	0	0	0	0
Electricity	0	0	0	0	0	0
Heat	0	0	0	0	0	0
Net Final Energy	**1,176,520**	**1,148,124**	**1,122,890**	**979,870**	**728,447**	**688,485**
Coal and Waste	34,718	29,587	29,242	26,873	20,086	18,762
Oil	556,291	472,942	457,612	365,313	161,670	117,736
Gas	207,466	189,865	184,886	156,431	104,457	96,583
Renewables	118,873	167,678	164,868	150,742	137,796	137,119
Electricity	205,418	215,102	216,707	228,690	275,564	291,706
Heat	53,754	72,950	69,574	51,821	28,873	26,579

9.2 Energy Supply

9.2.1 Energy Distribution

Table 9-3 Gross Final Energy

TJ	2005	2014	2020	2030	2040	2050
Net Final Energy	**1,176,520**	**1,148,124**	**1,122,890**	**979,870**	**728,447**	**688,485**
Coal and Waste	*34,718*	*29,587*	*29,242*	*26,873*	*20,086*	*18,762*
Oil	*556,291*	*472,942*	*457,612*	*365,313*	*161,670*	*117,736*
Gas	*207,466*	*189,865*	*184,886*	*156,431*	*104,457*	*96,583*
Renewables	*118,873*	*167,678*	*164,868*	*150,742*	*137,796*	*137,119*
Electricity	*205,418*	*215,102*	*216,707*	*228,690*	*275,564*	*291,706*
Heat	*53,754*	*72,950*	*69,574*	*51,821*	*28,873*	*26,579*
Distribution losses	153,040	148,570	145,983	129,785	83,292	67,837
Coal and Waste	*61,438*	*60,287*	*59,416*	*53,403*	*35,160*	*30,716*
Oil	*31,564*	*22,935*	*22,129*	*17,270*	*6,627*	*4,429*
Gas	*19,970*	*18,416*	*17,877*	*14,756*	*8,429*	*7,094*
Renewables	*0*	*12*	*12*	*11*	*10*	*10*
Electricity	*34,814*	*40,028*	*40,019*	*39,725*	*31,263*	*24,298*
Heat	*5,253*	*6,891*	*6,530*	*4,621*	*1,804*	*1,291*
Gross Final Energy	**1,329,560**	**1,296,695**	**1,268,873**	**1,109,655**	**811,739**	**756,322**
Coal and Waste	96,156	89,874	88,658	80,275	55,246	49,478
Oil	587,855	495,877	479,741	382,583	168,297	122,165
Gas	227,436	208,282	202,764	171,187	112,887	103,677
Renewables	118,873	167,690	164,880	150,752	137,806	137,129
Electricity	240,232	255,130	256,726	268,414	306,827	316,004
Heat	59,007	79,842	76,104	56,442	30,677	27,869

9.2.2 Energy Transformation

Table 9-4 Gross Energy Supply

TJ	2005	2014	2020	2030	2040	2050
Untransformed Final Energy	677,653	679,012	663,398	574,329	418,654	393,827
Coal and Waste	13,087	6,377	6,263	5,477	3,418	3,016
Oil	191,816	118,135	114,142	90,100	38,565	27,882
Gas	227,436	208,282	202,764	171,187	112,887	103,677
Renewables	117,859	156,415	153,793	140,616	128,540	127,909
Biomass	*117,859*	*156,415*	*153,793*	*140,616*	*128,540*	*127,909*
Electricity	9,595	33,389	32,643	26,334	6,704	3,435
Heat	0	0	0	0	0	0
Transformed Final Energy	769,766	774,097	759,268	675,941	521,625	490,403
Coal and Waste	83,069	83,497	82,395	74,799	51,828	46,462
Oil	396,039	377,742	365,599	292,483	129,732	94,283
Gas	0	0	0	0	0	0
Renewables	1,014	11,276	11,087	10,137	9,266	9,221
Electricity	230,637	221,741	224,083	242,080	300,122	312,568
Heat	59,007	79,842	76,104	56,442	30,677	27,869
Input Transformation	886,317	858,213	839,705	741,087	553,121	515,668
Coal and Waste	172,866	149,301	146,648	129,379	77,324	65,267
Oil	418,965	387,127	373,745	298,561	131,594	95,349
Gas	114,172	61,551	59,193	45,870	18,392	13,096
Renewables	180,313	260,234	260,119	267,277	325,812	341,955
Biomass	*42,943*	*95,299*	*92,351*	*77,302*	*51,917*	*47,648*
Hydro	*132,035*	*147,608*	*148,525*	*155,033*	*166,683*	*167,436*
Wind, PV, …	*5,335*	*17,327*	*19,242*	*34,941*	*107,211*	*126,871*
Gross Energy Supply	**1,446,110**	**1,380,811**	**1,349,310**	**1,174,800**	**843,235**	**781,586**
Coal and Waste	185,954	155,678	152,912	134,856	80,742	68,283
Oil	610,781	505,262	487,886	388,661	170,159	123,232
Gas	341,608	269,832	261,957	217,057	131,279	116,772
Renewables	298,172	416,649	413,912	407,893	454,351	469,864
Biomass	*160,803*	*251,714*	*246,145*	*217,918*	*180,457*	*175,556*
Hydro	*132,035*	*147,608*	*148,525*	*155,033*	*166,683*	*167,436*
Wind, PV, …	*5,335*	*17,327*	*19,242*	*34,941*	*107,211*	*126,871*
Electricity	9,595	33,389	32,643	26,334	6,704	3,435
Heat	0	0	0	0	0	0

9.3 CO_2 Emissions

Table 9-5 CO_2 Emissions related to Functionalities

CO2 Thousand tons	2005	2014	2020	2030	2040	2050
Functionalities and related energy	**79,063**	**63,524**	**61,485**	**49,152**	**21,327**	**15,555**
Low Temperatur Heat	20,734	13,796	12,990	8,682	2,744	2,098
Coal and Waste	*447*	*187*	*178*	*133*	*75*	*69*
Oil	*7,077*	*3,591*	*3,374*	*2,216*	*600*	*415*
Gas	*4,612*	*3,873*	*3,658*	*2,517*	*962*	*791*
Renewables	0	0	0	0	0	0
Electricty	1,349	535	511	375	115	71
Heat	4,459	3,840	3,599	2,309	599	439
Distribution Losses	2,791	1,771	1,670	1,133	393	313
High Temperature Heat	18,923	16,500	16,326	15,001	10,370	9,308
Coal and Waste	*2,701*	*2,479*	*2,455*	*2,282*	*1,712*	*1,595*
Oil	*1,622*	*916*	*904*	*818*	*530*	*471*
Gas	*5,669*	*4,999*	*4,953*	*4,606*	*3,466*	*3,233*
Renewables	0	0	0	0	0	0
Electricty	2,010	1,055	1,039	900	340	213
Heat	579	695	694	682	554	514
Distribution Losses	6,342	6,356	6,280	5,715	3,767	3,282
Stationary Engines	5,886	4,059	3,996	3,500	1,669	1,290
Coal and Waste	*0*	*0*	*0*	*0*	*0*	*0*
Oil	*1,288*	*1,162*	*1,147*	*1,034*	*643*	*558*
Gas	*43*	*264*	*262*	*246*	*195*	*184*
Renewables	0	0	0	0	0	0
Electricty	3,806	2,115	2,080	1,793	667	415
Heat	0	0	0	0	0	0
Distribution Losses	749	518	507	426	165	133
Mobile Engines	31,929	28,372	27,408	21,392	6,368	2,754
Coal and Waste	*1*	*1*	*1*	*0*	*0*	*0*
Oil	*28,712*	*25,733*	*24,769*	*18,835*	*4,920*	*1,753*
Gas	*360*	*538*	*526*	*451*	*293*	*266*
Renewables	0	0	0	0	0	0
Electricty	546	233	295	613	592	436
Heat	0	0	0	0	0	0
Distribution Losses	2,311	1,868	1,818	1,493	562	299
Lighting and Electronics	1,590	797	765	577	176	105
Coal and Waste	*0*	*0*	*0*	*0*	*0*	*0*
Oil	*0*	*0*	*0*	*0*	*0*	*0*
Gas	*0*	*0*	*0*	*0*	*0*	*0*
Renewables	0	0	0	0	0	0
Electricty	1,360	672	646	491	158	97
Heat	0	0	0	0	0	0
Distribution Losses	230	125	119	85	18	8

Table 9-6 CO_2 Emissions related to Energy Types

CO2 Thousand tons	2005	2014	2020	2030	2040	2050
Functionalities and related energy	**79,063**	**63,524**	**61,485**	**49,152**	**21,327**	**15,555**
Coal and Waste	3,148	2,666	2,634	2,415	1,788	1,665
Oil	38,698	31,402	30,194	22,902	6,694	3,197
Gas	10,685	9,674	9,398	7,820	4,916	4,473
Renewables	0	0	0	0	0	0
Electricty	9,070	4,610	4,571	4,173	1,872	1,232
Heat	5,038	4,535	4,294	2,991	1,153	953
Distribution Losses	12,423	10,637	10,394	8,851	4,904	4,035
Losses from Distribution	**12,423**	**10,637**	**10,394**	**8,851**	**4,904**	**4,035**
Coal and Waste	5,652	5,546	5,466	4,913	3,235	2,826
Oil	2,904	2,110	2,036	1,589	610	407
Gas	1,837	1,694	1,645	1,358	775	653
Renewables	0	0	0	0	0	0
Electricty	1,537	858	844	725	212	103
Heat	492	428	403	267	72	46
CO2 Emissions from Energy Use	**79,063**	**63,524**	**61,485**	**49,152**	**21,327**	**15,555**
Coal and Waste	8,801	8,212	8,100	7,328	5,022	4,491
Oil	41,602	33,512	32,230	24,491	7,303	3,604
Gas	12,522	11,368	11,043	9,178	5,692	5,126
Renewables	0	0	0	0	0	0
Electricity	10,608	5,468	5,415	4,898	2,084	1,335
Heat	5,531	4,964	4,697	3,257	1,226	1,000