Sustainable energy for developing countries

Urban, Frauke

3. Modelling energy systems for developing countries[8]

Abstract

Developing countries' energy use is rapidly increasing, which affects global climate change and global and regional energy settings. Energy models are helpful for exploring the future of developing and industrialised countries. However, energy systems of developing countries differ from those of industrialised countries, which has consequences for energy modelling. New requirements should be met by present-day energy models to adequately explore the future of developing countries' energy systems. This paper aims to assess if the main characteristics of developing countries are adequately incorporated in present-day energy models. These main characteristics will first be discussed; focusing particularly on developing Asia, and then a model comparison will be presented consisting of 12 selected energy models to test their suitability for developing countries. It is concluded that many models tend to be biased towards industrialised countries, neglecting main characteristics of developing countries, e.g. the informal economy, supply shortages, poor performance of the power sector, structural economic change, electrification, traditional biofuels and the urban–rural divide. To more adequately address the energy systems of developing countries, energy models should be adapted and new models should be build. It is therefore indicated how to improve energy models for increasing their suitability for developing countries and it is given advice on modelling techniques and data requirements.

3.1 Introduction

The energy use in developing countries is rapidly growing and affects global climate change and the world's energy resource stocks. Mankind has to acknowledge the increasing influence of developing countries on the global energy setting. One way to do this is through energy models, which explore the future of the global and regional energy setting and the effects of energy use on the human and natural environment.

Most present-day energy models were built and used by industrialised countries, so that the assumptions about energy systems of developing countries were mainly based on experience from the energy systems of industrialised countries. It was therefore assumed that the energy systems of developing countries would behave like those of industrialised countries (Shukla, 1995). It was further assumed, that the present-day development trajectories for developing countries would be similar to the historic development trajectories in industrialised countries, which in reality is not the case. For energy modelling, trends for developing regions were derived from those of industrialised regions and extrapolated to low-income ranges. What seems to be a fair modelling technique may nevertheless result in models biased towards industrialised countries, possibly leading to incorrect interpretations of the energy systems of developing countries. The use of these biased models is therefore questionable for developing countries.

In line with this reasoning, this chapter of the thesis aims to assess to what extent present-day energy models used in developing countries adequately address main characteristics of developing countries' energy systems and economies. Chapter 3.2 first describes briefly these main characteristics: poor performance of the power sector and traditional fuels which implies supply shortages, lack of access to electricity and the predominance of traditional biofuels.

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Afterwards, it is elaborated on the transitions from traditional to modern economies which include the informal economy, non-monetary transactions and structural economic change. Finally, there is a discussion about structural deficiencies in society, economy and energy systems by which is meant the urban-rural divide, inadequate investment decisions and misdirected subsidies. For evaluating these characteristics in Chapter 3.3, secondly 12 present-day energy models are compared to assess their suitability for developing countries' energy systems and their economies. In Chapter 3.4, the results of the energy model comparison are presented and discussed in Chapter 3.5. In Chapter 3.5, it is also indicated how to improve energy models for increasing their suitability for developing countries. In Chapter 3.6, the findings are concluded and recommendations for future research are indicated.

For the description of the energy systems and the model comparison, wide disparities are acknowledged between "developing countries", particularly between smaller and larger, poorer and wealthier countries and the differing modelling approaches required for each individual country. For this study, developing countries are defined as countries with an average income of below $10,065 GNI per capita (representing the lower and middle income countries of the World Development Indicators, World Bank, 2006), an under-developed infrastructure and a poor human development index. Recognising the wide cross-country disparities, the focus is only on developing Asia in this study, because it is the world's largest developing region, hosting the world's largest population, having the highest economic and industrial growth rate and contributing the most to global climate change in absolute terms compared to the contributions of other developing regions. The focus is especially on rapidly developing countries such as China and India.

3.2 Characteristics of the energy systems and economies of developing countries

The energy systems of industrialised countries are characterised by a constant match of supply and demand, low losses of transmission and distribution, universal access to electricity, predominance of modern energy carriers, similar structural premises in urban and rural areas, adequate financing and investment decisions, adequate subsidies and profit-making utility companies in developed economies with a low extent of informal economies. To the contrary, the energy systems of developing countries differ from those of industrialised countries and among each other. A number of issues will be elaborated which are described in scientific literature as the main characteristics of developing countries' energy systems and economies (e.g. Van der Werff and Benders, 1987; Schramm, 1990; IEA, 2002a b; Xu Yi-chong, 2002, Xu Yi-chong, 2005; Urban et al., 2006). These characteristics are also the most important issues for energy modelling. It is therefore evaluated in Chapter 3.4, whether these characteristics have been adequately addressed in present-day energy models. For the description of the main characteristics of developing countries' energy systems and economies, specific examples for Asia are given.

3.2.1 Poor performance of the power sector and traditional fuels

Many Asian developing countries suffer from a poor performance of the power sector for various supply-side, demand-side and economic reasons.

First, from a supply-side perspective, the power system configurations are often sub-optimal: these systems are often not meeting the demand, even though a substantial excess capacity may exist (Schramm, 1990). The reasons for the excess capacity are faulty planning and poorly performed operational and maintenance tasks leading to frequent plant breakdown, outages and voltage fluctuations, resulting in unreliable service causing economic losses (Schramm, 1990).

For the functioning of modern economies, meeting the electricity demand is crucial. Supply shortages are unfortunately characteristic for many Asian developing countries and regions. They are caused by (a) a poor performance of the power sector such as poor conditions of generation and distribution equipment, inadequate operational and maintenance performance and a high level of technical and nontechnical losses. Other reasons are (b) a rapidly growing demand for electricity (c) a low number of power plants (d) technical constraints (e) organisational problems (f) underfinanced power companies (g) restriction on capital available for investments (h) a dependence on import of plants and equipment for power supply and (i) too low consumer prices (Schramm, 1990; Van der Werff and Benders, 1987; IEA, 2002b). A reliable electricity supply can in some situations also be threatened by high electricity losses, such as in India where they account for 27%, ranking world second just after Nigeria (IEA, 2002a). The Philippines have also high losses of about 14% and Indonesia has 12%, compared to an OECD average of about 6% (IEA, 2002a).

Second, a demand-side problem is access to electricity, which is in general rather low in developing Asia, particularly in poorer rural areas. Only 64% of the Asian population had access to electricity in 2000, leaving about one billion inhabitants in the dark (IEA, 2002a). A good example for increased access to electricity is, however, China which managed to achieve an electrification rate of about 99% in the last years, because of wide-spread electrification schemes. The lowest electrification rates in Asia in 2000 were in Afghanistan with only 2% and Myanmar with only 5% (IEA, 2002a). Despite some very low electrification rates, the IEA (2002a) expects that with rising per capita income access to electricity will reach 81% in developing Asia by 2030, thus an increase of 0.57% per year. Critically assessed, however, it appears to be too simplistic to assume a direct link between income and access to electricity for a number of reasons: income is not equally distributed, governments can refuse to invest in electricity infrastructure, also structural problems may occur as described earlier, and technical and geographical limitations exist for grid connections. Further, population growth will also lead to an increase of at least one billion inhabitants in developing Asia until 2030. Consequently, the additional one billion inhabitants need to be provided with electricity, which will decrease the annual rise of electrification rates. Further, stand-alone renewable options or mini-grids are also possibilities to electrify households, but these options are often not included in the national statistics of electrification. Finally, some studies advocate that electrification in developing Asia can only be successful if long-term strategies comprise micro-loans or other forms of financial support for investments for electric equipments (Kanoria, 2006) or create opportunities for a higher income generation (Bhattacharyya, 2005), as experience from India has shown.

Third, concerning the demand side, even though electricity consumption is at the rise, the predominant fuels in developing Asia are still traditional biofuels: fuel wood, fuel roots, dung, agricultural waste, crop residues, and fuel sticks. Traditional biofuels are primarily used domestically for cooking and heating, particularly in poorer rural areas, as indicated by 1.7 billion poor inhabitants in Asia who relied on traditional biofuels in 2000, which is about 53% of the total Asian population (IEA, 2002a; IEA, 2004). The number of people relying on traditional biofuels is expected to increase to 2.6 billion by 2030, mainly because of population growth and unavailability of alternative fuels (IEA, 2002a). Besides population growth and the unavailability of alternative fuels, increased consumption of traditional biofuels is mainly due to three factors: changes in income, the degree of urbanisation and the degree of industrialisation. The share of traditional biofuels declines in general with rising GDP, although differences exist between countries and regions (Victor and Victor, 2002). When income distribution and geographic distribution is taken into account, the relation between income and traditional bio-fuel use, particularly fuel wood use, can be different (Victor and Victor, 2002), because traditional biofuels are mainly used by lower income households and in poorer rural areas.

Fourth, from an economic perspective, poor sector financing is common with tariffs below long-term marginal costs of production or even below average operating costs and a poor revenue collection performance by the utilities where a large share of the non-paid bills will never be collected (Schramm, 1990; Van der Werff and Benders, 1987). This is mainly because governmental departments and government-owned companies are under government protection and do therefore frequently not pay their electricity bills or because customers are simply to poor to pay their bills (Schramm, 1990). Another reason for the financial deficiencies is that theft of electricity is common. India’s power sector, for instance, is facing a serious risk of bankruptcy, mainly because of unpaid bills and high transmission and distribution losses (IEA, 2002b). For such cases, installing a theft-proof system would be helpful, as experience has shown in Haiti (Schramm, 1990).

3.2.2 Transitions from traditional to modern economies

There are currently transitions ongoing in many Asian countries from a traditional mainly rural-based economy to a modern mainly industry- or service-based economy. One important part of these economic transitions is the concept of the informal economy and non-monetary transactions. The informal economy (also often referred to as the shadow-economy) and non-monetary transactions take into account the unofficial transactions which occur in reality, but which are not accounted for in official economic descriptions, like GDP or value added (Chapter 2). The informal economy is a broad concept based on varying definitions associated with illegal activities, tax evasion or avoidance and (non-)monetary transactions (Schneider, 2005; Chapter 2). The main drivers for the informal economy are estimated to be the burdens from tax and social security contributions, the intensity of regulations, social transfer systems, overregulation and high costs on the official labour market (Schneider and Enste, 2000; Chapter 2). All around the world, informal economies and non-monetary transactions occur, but it has been observed that they are usually larger in developing countries (Kahn and Pfaff, 2000; Chapter 2). The informal economy had the size of 41% of the total official GDP in developing countries in 1999–2000 in average. Although OECD countries also show a share of 17%, the issue is clearly more present in developing countries (Schneider, 2005; Chapter 2). A major problem with the informal economy and non-monetary transactions is that data are rare which causes difficulties for representing developing countries’ economies and their energy systems.

Besides the informal economy, the economies in developing Asia are characterised by different structural economic changes than in industrialised countries. For developing countries, it is often assumed that they will follow the same development trajectory as today’s industrialised countries did in the past: first a decline of the agricultural sector, then a heavily growing industry and later a shift towards the service sector (Jung et al., 2000). It has been observed, however, that structural economic change in many Asian developing countries takes place as an early shift towards energy-extensive services in the economy of a country, which results in low energy intensity. The trends for India, for example, indicate that the country first developed a modest industrial sector, but then shifted towards the service sector which is flourishing nowadays (Urban et al., 2006; Chapter 2). There are large differences between countries in Asia, such as between the mainly service-based India and the mainly industry-based China. These differences can partially be explained by differences in culture (e.g. it is often stated by Indians that "India's biggest asset is people" which can most cost-effectively be employed in the service sector) and politics (as a communist country China needed a large industry for producing raw materials, such as steel, for being independent from Western imports and for competing in the global arms race).

3.2.3 Structural deficiencies in society, economy and energy systems

Many Asian countries suffer from structural problems which affect society, economy and energy systems. One of these structural problems is the urban–rural divide which describes differences between urban and rural areas affecting access to energy, fuel use, access to education, safe drinking water, health services and sanitation. The urban–rural divide is more common in the developing world than in the industrialised world, usually with rural areas being worse off than urban areas (WEC, 2005). China, as an example, is expected to have to deal with rural poverty for another decade as Yao et al. (2004) report, mainly because of the growing inequality between urban and rural areas as a consequence of policy-makers who tend to favour urban areas. On the other hand, it has to be noted that national and international policy-makers regularly stress the importance of increasing basic human needs, infrastructure and economy in rural areas. Many Asian countries therefore have rural development schemes and/or rural electrification schemes in place since years or even decades, such as Bangladesh, China, India, Nepal, the Philippines and Sri Lanka. The existence of rural development schemes is an indication that the situation might become better in the coming decades.

Another major structural problem of developing Asia's power sector is inadequate planning which results in inadequate investment decisions. In developing countries, actual investment costs often turn out to be much higher than the initial appraisal estimate, because forecasting techniques are poor and/or uncertainty ranges were neglected (Schramm, 1990). This often results in exceeded private and governmental funds, difficulties to attract foreign investors and incomplete or sub-standard power projects.

Another structural problem can be the abuse or inadequate use of subsidies. Subsidies were a way of ensuring state regulation of the power industry in many Asian countries in which the power industry was formerly often dominated by state regulation, monopolies and inefficient legislative and policy frameworks (IEA, 2002a; Xu Yichong, 2002; Xu Yi-chong, 2005). Subsidies which are purpose-bound, such as subsidies for rural development and irrigation, e.g. providing free electricity to farmers, may be helpful for the individual consumer and are a way to reduce poverty and enhance rural development, but may lead to market distortion, discarded prices, limited competition between utility companies, and the favouring of government-owned utility companies.

Conclusively, the energy systems of developing countries are complex and face serious challenges. To solve these challenges, good energy planning is required. Good energy planning can, however, only take place when good energy models are used. The issue of energy modelling is discussed in the following chapter.

3.3 Energy model comparison

The above discussed characteristics of the energy systems of developing countries need to be addressed in energy models to ensure an adequate representation of developing countries. This is crucial for an adequate modelling and scenario-making of the regional and global energy future which adequately tackles issues such as climate change, energy security, local air pollution and energy resource use. Due to technical limitations and possibly also due to biases from industrialised countries, these characteristics may be missing in present-day energy models. In this chapter, present-day energy models are compared for their use in developing countries, to assess to what extent these models adequately address the discussed main characteristics.

Energy models have been used to analyse a wide range of issues, serving different purposes and employing a variety of different techniques. Because of the complexity of energy models it is helpful to make a model comparison to analyse their purposes and performances. In line of this reasoning, Beaujean et al. (1977) developed the first survey of global and international energy models based on earlier reviews of energy models by Charpentier (1974–1976), followed by Meier (1984) who compared energy models for developing countries and developed a classification typology describing a variety of modelling techniques and their usefulness for developing regions. Shukla (1995) compared greenhouse gas models for developing nations and assessed the advantages and disadvantages of top-down and bottom-up models for this purpose, whereas Bhattacharyya (1996) compared applied general equilibrium models for energy studies.

Today, a wide range of present-day energy models exist which has not been evaluated for use in developing countries. An energy model comparison is performed here to assess to what extent present-day energy models used in developing countries adequately address main characteristics of developing countries' energy systems and their economies. The models are evaluated according to the main characteristics discussed in Chapter 3.2: performance of the power sector, supply shortages, electrification, traditional biofuels, urban–rural divide, informal economy, structural economic change, investment decisions and subsidies.

First, for the energy model comparison a pre-study was done to select the models on the basis of three criteria: (a) the model specifically takes into account developing countries; (b) the model is widely used by institutions in developing regions or widely used by institutions cooperating with developing regions; (c) the model is cited in scientific literature. The models had to fulfill all three criteria for being selected. For the selection process, 40 present-day energy models were identified, which are all the well-known or medium-well-known models currently used at institutions in developing countries and the OECD. These 40 models were then scrutinized according to the selection criteria, which lead to a selection of 12 models. The selection was restraint to energy and electricity models only and excluded models which entirely focused on climate change, carbon management and its impacts or addressed economic issues such as energy markets, investments and regulation.

Second, after the pre-study to select the energy models, the model comparison was done, which was based on a methodology composed of three steps: (1) literature review of model documentation: analysed material were model documentation guides, user manuals, articles in scientific journals, research reports, technical reports, websites, press releases etc.; (2) model runs: analysed material were input data, output data and model structure; (3) expert questionnaire: analysed material were answers by model developers. For each step, it was assessed to what extent the main characteristics of developing countries' energy systems were addressed. For the evaluation, a difference was made between explicitly and implicitly modelled characteristics. Explicitly means that the characteristics were adequately modelled e.g. that electrification is an input parameter, whereas implicitly means that the characteristics were partially modelled, e.g. electrification is embedded in the energy equation. Implicit modelling is problematic, because even after thorough scrutinisation it often remains unclear how certain characteristics have exactly been modelled. The model codes were not analysed, because of restricted access. The selection of models and applied methods can be seen in Table 2.

Third, for reasons of comparability, the selected models were classified by using a typology, because the models differ widely among each other in terms of modelling techniques and purposes. For this purpose, an adapted version of Van Beeck's classification typology (1999, 2003) was used, which was specifically meant for use in developing countries. Van Beeck classifies a few present-day energy models, but does not assess the suitability of the models for developing countries. Therefore, this is done in this paper. Van Beeck classifies energy models according to their purposes, model structure, analytical approach, underlying methodology, mathematical approach, geographical coverage, time horizon and data requirements. This typology was restricted to those classification criteria in which models differed the most: the underlying methodology: simulation, optimisation, economic equilibrium and toolbox models; the analytical approach: top-down, bottom-up, hybrid and the purpose. A hybrid approach combines top-down and bottom-up approaches.

Model abbreviation and full name	**Method**		
	Documentation	Model run	Questionnaire
AIM (Asian-Pacific Integrated Model)	X	X	
ASF (Atmospheric Stabilization Framework)	X		X
IMAGE/TIMER (TARGETS-IMAGE Energy Regional model)	X	X	X
LEAP (Long-range Energy Alternatives Planning System)	X	X	X
MARIA (Multiregional Approach for Resources & Industry Allocation model)	X		
MARKAL (MARKet ALlocation model)	X		X
MESSAGE (Model for Energy Supply Strategy Alternatives & their General Environmental impact)	X		X
MiniCAM (Mini Climate Assessment Model)	X		X
PowerPlan	X	X	X
RETScreen (Renewable Energy Technology Screening model)	X	X	X
SGM (Second Generation Model)	X	X	X
WEM (World Energy Model)	X		X

Table 2: Selection of models and applied methods. Applied methods are indicated by a X.
General information about the models can be found at: Kainuma et al. (2005 and 2003) for AIM; EPA (1990) and SEDAC (1996a) for ASF; De Vries et al. (2001) and RIVM (2001) for IMAGE/TIMER; SEIB (2006a and 2006b) for LEAP; Mori (2000) and IPCC (2005) for MARIA; Seebregts et al. (2001) and ETSAP (2002) for MARKAL; IIASA (2005) and Nakicenovic and Riahi (2003) for MESSAGE; SEDAC (1996b) and Edmonds et al. (1997) for MiniCAM; Benders (1996) and IVEM (2006) for PowerPlan; RETScreen International (2005a and 2005b) for RETScreen; JGCRI (2006) and Edmonds et al. (2004) for SGM; IEA (2004 and 2005) for WEM.

3.4 Results of the energy model comparison

For the energy model comparison, the models were evaluated according to the main characteristics of developing countries' energy systems and economies mentioned earlier. As a result, the model comparison of the main characteristics of developing countries can be seen in Table 3. Table 3 shows that only few of the main characteristics are addressed by the compared energy models.

Table 3 also shows that characteristics which have been addressed by the majority of models are electrification, traditional biofuels and the urban–rural divide. A range of models however modelled electrification, the urban–rural divide and traditional biofuels only implicitly, and despite substantial efforts it often remains unclear what exactly has been/what has not been modelled and what purposes the implicit modelling serves. All models further incorporate other features such as greenhouse gas emission trading and the Clean Development Mechanism which are rather popular, whereas individual modelling input assumptions per country, a wide assessment of renewable energy, off-grid renewable energy, rural energy programmes and a special focus on energy and poverty are rare.

Despite some characteristics being often addressed, other important characteristics have not received much attention, such as supply shortages, performance of the power sector, structural economic change, investment decisions, subsidies and especially the informal economy and non-monetary transactions. This is also due to the purposes of the models, since many models are specifically build for certain tasks and are not made for dealing with issues out of their scope.

Model	**Main characteristics of developing country´s energy systems and economies**									
	Performance of power sector	Supply shortages	Electrification	Traditional biofuels	Urban-rural divide / urbanisation	Informal economy	Structural economic change	Investment decisions	Subsidies	Others features*	* Specification of other features
AIM			(X)	X	X					X	Individual assumptions per country, emission trading (ET)
ASF			(X)							X	Clean Development Mechanism (CDM)
IMAGE/TIMER			(X)	X	(X)					X	CDM, ET, wide assessment of renewable energies (RE)
LEAP	(X)		X	X	X				(X)	X	Indiv. ass. p.country, ET, CDM, RE, rural energy programmes
MARIA			(X)				X			X	CDM
MARKAL			X	X	X				(X)	X	ET, CDM, RE
MESSAGE			X	X	(X)		X		(X)	X	ET, CDM, RE
MiniCAM			X	(X)	(X)				(X)	X	ET, CDM, RE
PowerPlan	X	X	(X)							X	CDM, RE
RETScreen			X	X	X			(X)	(X)	X	ET, CDM, RE, off-grid RE systems
SGM			X	X					(X)	X	ET, CDM, RE
WEM			X	X	X			(X)	(X)	X	Indiv. ass. p. country, ET, CDM, RE, focus on energy & poverty

Table 3: Comparison of the main characteristics of developing countries' energy systems and their economies per energy model.
X: explicitly modelled characteristics, (X): implicitly modelled characteristics.

There are also wide differences between how many main characteristics of developing countries are addressed per model. Models which address a large number of characteristics are LEAP, MESSAGE, RETScreen and WEM. Models which address a medium number of characteristics are MARKAL, MiniCAM, AIM, IMAGE/TIMER, PowerPlan and SGM. Models which address a small number of characteristics are MARIA and ASF.

Reasons for these different results are mainly the model structure, as indicated in Table 4 which evaluates the models according to Van Beeck's (1999, 2003) adapted classification typology, and also the different purposes of the models which are specialised for solving certain tasks.

Table 4 shows that models which address larger numbers of main characteristics like LEAP, MESSAGE, RETScreen and WEM are bottom-up or hybrid models, whereas models which address smaller numbers of main characteristics like ASF and MARIA are top-down optimisation models.

Model	Method				Approach			Type of model / purpose
	Simulation	Optimis.*	Eco. Equi.*	Toolbox	Top-down	Bottom-up	Hybrid	
AIM	X						X	Energy-economy-climate
ASF		X			X			Energy-economy-climate
IMAGE/TIMER	X						X	Energy-economy-climate
LEAP	X					X		Energy-economy-environment tool
MARIA		X			X			Energy-economy-climate
MARKAL		X				X		Energy-economy-climate
MESSAGE		X					X	Energy supply-economy-climate
MiniCAM			X				X	Energy-economy-climate
PowerPlan	X				X			Electricity-supply-environment
RETScreen				X		X		Renewable energy-climate decision support
SGM			X		X			Energy-economy-climate
WEM			X				X	Energy-economy-climate, poverty & development

Table 4: Typology of selected energy models, specifying the underlying methodology, analytical approach and purpose. Adapted from Van Beeck´s energy model classification (1999; 2003).
*: Optimisation and Economic Equilibrium Model.

3.5 Discussion

3.5.1 Discussion of model comparison and model groups

In Chapter 3.2, the main characteristics of the energy systems and economies of developing countries are first discussed. Modelling these main characteristics is crucial for an adequate representation of developing countries and therewith also crucial for an adequate modelling and scenario-making of the energy future and environmental problems. In line of this reasoning, present-day energy models were compared to assess whether the main characteristics of the energy systems and economies of developing countries are incorporated in the models.

Differing results were found, both positive and negative, which can mainly be explained by the differing underlying methodology, analytical approach and purpose of the models. These model classification differences will be discussed in detail at this point referring to top-down, bottom-up and hybrid models as well as to simulation, optimisation, economic equilibrium and toolbox models.

Top-down models use aggregated data for predicting purposes, they do not explicitly represent technologies and the most efficient technologies are given by the production frontier, which is set by market behaviour. Top-down models also determine energy demand through aggregate economic indices like GNP and price elasticities, but vary in addressing energy supply. They endogenise behavioural relationships and assume there are no discontinuities in historical trends (Van Beeck, 1999). One reason why a top- down approach is not realistic for developing countries is that market behaviour is only a limited driver of energy consumption and production frontiers are less clear defined than in industrialised countries (e.g. the production frontier of fuel wood). Also, a large part of the economy is non-monetary and aggregate economic indices are not in relation to income distribution, living standards, energy supply and demand. Technologies can further not be determined by market behaviour, because predominant technologies are often based on traditional biofuels, which are not part of the commercial market. Also, assuming no discontinuities in historical trends is not realistic, because rapid population and economic growth affect energy use much more today than a few decades ago, as can be observed in China and India. Another weakness is that top-down models externalise major structural changes such as lifestyles, urbanisation in developing countries and technological changes. The strengths of the top-down approach are its consistency, its links to historic references and economic frameworks, equilibrating prices and quantities and its data availability. Especially data availability is a crucial issue for energy modelling in developing countries.

Bottom-up models use disaggregated data for exploring purposes; include a detailed description of technologies where efficient technologies can lie beyond the economic production frontier suggested by market behaviour. They represent supply technologies in detail, but vary in addressing energy demand. They assess costs of technological options directly and assume interactions between the energy sector and other sectors as negligible (Van Beeck, 1999). A bottom-up approach for developing countries can be useful, mainly because the model is independent of market behaviour and production frontiers and because technologies are explicitly modelled. The weaknesses of bottom-up models are that main drivers remain exogenous such as demand, technology change and resources. Also, quality does not matter e.g. the quality of a given policy.

Hybrid models combine the advantages (and disadvantages) of both bottom-up and top-down approaches. Top-down and bottom-up models can be combined in a tailor-made hybrid approach, depending on purpose, data requirements and desired output. The tailor-made approach leads to flexible models, as needed especially for developing countries. For example, IMAGE/TIMER uses a top-down approach for its energy demand model and a bottom-up approach for its energy supply model.

Optimisation models are used to optimise energy investment decisions by finding best solutions. Optimisation models assume perfect markets and optimal consumer behaviour which do not exist in real life. The use of optimisation models for developing countries might be limited, first because the attempt to optimise investments, which can also be inadequate investments, can lead to suboptimal instead of best solutions. Second, the assumption of perfect markets and optimal consumer behaviour is only of limited use in developing countries where large parts of the economy are non-market-based and where consumer behaviour accounts only for a (small) part of the population. Another (large) part of the population in developing countries consists of inhabitants who do not reflect consumer behaviour such as those without access to modern energy, subsistence farmers, slum dwellers etc.

Economic equilibrium models, on the other hand, either assume partial or general market equilibriums. Shukla (1995) criticises that economic equilibrium models are of limited use in developing countries, because developing countries suffer from constant disequilibrium of markets and because excessive non-market influences determine the situation.

Another option are toolbox models which are mainly bottom-up accounting type models, having the advantage that they are easy to use even by untrained users, which increases their usefulness for developing countries where users do often not have the same financial and training possibilities as in industrialised countries. The main disadvantage of toolbox models is that many important variables are indicated exogenously as parameters in future scenarios.

Finally, simulation models are mostly bottom-up or hybrid descriptive models which aim at reproducing a simplified task of a system. They tend to be rather useful for developing countries, because they do neither assume perfect markets nor optimal consumer behaviour, but allow scenario analysis for future pathways. The disadvantage of simulation models is their complexity, because they may require excessive data inputs and advanced user skills.

Despite certain flaws, present-day energy models can be improved to make them more suitable for the energy systems of developing countries. Table 5 indicates how certain groups of models can be improved for use in developing countries by incorporating suitable characteristics.

Applicable characteristic	Method			Approach			
	Simulation	Optimis.*	Eco. Equi.*	Toolbox	Top-down	Bottom-up	Hybrid
Performance of power sector	(X)			(X)		X	(X)
Supply shortages	(X)			(X)		X	(X)
Electrification	X	(X)	(X)	(X)	(X)	X	(X)
Traditional bio-fuels	(X)	(X)	(X)	(X)	(X)	(X)	(X)
Urban-rural divide / urbanisation	(X)	(X)	(X)	(X)	(X)	(X)	(X)
Informal economy		**	**		**		**
Structural economic change	(X)	X	X	(X)	X	(X)	(X)
Investment decisions		X	X	(X)	X		(X)
Subsidies		X	X	(X)	X		(X)

Table 5: Applicable characteristics of developing countries' energy systems and their economies per model group. X: Modelling this characteristic is applicable regarding model structure and purpose. (X): Modelling this characteristic is applicable regarding model structure, if the purpose allows. *: Optimisation and Economic Equilibrium Model. **: Modelling this characteristic would improve the model, but currently the modelling methods and data are insufficient.

Table 6 gives an indication of modelling methods and data requirements for the described characteristcs.

Applicable characteristics	Modelling method	Data
Performance of power sector	Explicitely (loss-of-load-probability)	Available for some dev. countries
Supply shortages	Explicitely (capacity required/installed)	Available for some dev. countries
Electrification	Explicitely * / Implicitely (energy equation)	Available for all dev. countries (IEA)
Traditional bio-fuels	Explicitely (fuel choices)**	Estimates for all dev. countries
Urban-rural divide / urbanis.	Explicitely (urban/rural energy consumers)	Available for most dev. countries
Informal economy	Unknown	No official data, only rough estimates
Structural economic change	Explicitely (changing value-added/sector)	Available for most dev. countries
Investment decisions	Explicitely / Implicitely	Available for most dev. countries
Subsidies	Explicitely / Implicitely	Available for most dev. countries

Table 6: Modelling methods and data requirements for the applicable characteristics of developing countries' energy systems and economies.
*: Increasing number of people having access to electricity, can be linked to decreasing traditional bio-fuel use over time. **: Can be linked to electrification over time.

3.5.2 Discussion of methodology

The method was composed of three parts, thus three different kinds of sources were examined (documentation, model runs, and questionnaire). Problems with the method were that quality and quantity of the sources differed for each model, because not every model was documented in the same way or to the same extent, not every model developer gave us access to the model, not every developer answered the questionnaire.

There is full awareness that the results of the questionnaire tend to be subjective as they tend to reflect the personal opinion of each more or less biased model developer. It was checked whether the results of the questionnaires were consistent with the results of other methods, which was the case for all models. Finally, there could not be found any correlation between differing results and the availability or unavailability of certain method parts.

A wide range of models were tested, from economic models like MARKAL and MiniCAM to user-support modelling tools such as LEAP and RETScreen. The differences in modelling approaches are acknowledged and there is full awareness that these differences lead to different outcomes, just as much as different scenario inputs lead to different scenario outputs. These results are therefore not standardised, but can still be considered relevant, because they indicate for each model in specific to what extent the main characteristics of developing countries' energy systems are addressed, as discussed in Chapter 3.4.

3.6 Conclusions

In conclusion, this results show that present-day energy models tend to be biased towards experience from the energy systems and economies of industrialised countries as experience from these systems has a long and successful tradition. However, the energy systems and economies of developing countries are different and therefore also need to be modelled differently. None of the present-day energy models fulfills all requirements for adequately addressing the energy systems and economies of developing countries. A "universal" model which will solve all tasks equally well and which will represent all main characteristics of developing countries is also illusory, because of technical restrictions, data inconsistencies, limited purposes of the models and the complexity of the system.

Nevertheless, a poor characterisation of the energy systems and economies of developing countries can lead to incorrect modelling of the future energy and climate settings. This could affect the results of optimisation models, meaning that their modelled best solutions might be only sub-optimal, because the economy and energy systems of developing countries might not have been modelled correctly. There could be similar effects for economic equilibrium models, which might neglect the disequilibrium of markets and overestimate market influences which might lead to distorted results. The consequences of a poor characterisation of developing countries' features for simulation models could be that unreliable scenarios might be developed based on inconsistent or incomplete data and assumptions computing unrealistic results for the global and regional energy future. Toolbox models could be affected by using incomplete or incorrect data and relationships in their accounting scheme which might lead to distorted results. Similarly, bottom-up models could primarily be affected by incomplete or incorrect technological data which might result in incorrect outputs while top-down models could primarily be affected by their link to incorrect or incomplete economic frameworks, which might result in incorrect computed outputs. The effects of a poor characterisation of developing countries' features in hybrid models could lead to distorted results due to incorrect economic and technological data. As indicated before, present-day energy models can be improved to make them more suitable for the energy systems of developing countries. It is suggested that models take more into account those characteristics of developing countries, which are the most relevant for the purpose and scope of the models (as indicated in Table 5).

For further research, new or improved existing energy models need to be developed which adequately address the characteristics of developing countries' energy systems and economies such as indicated in Tables 5 and 6. Particularly those characteristics need to be modelled for which reliable data are available and where the system dynamics are understood, e.g. for the performance of the power sector, electrification, investment decisions and subsidies. For a better representation of developing countries, these new or improved models should preferably follow a bottom-up or hybrid approach and be simulation or toolbox models.

Such research is performed for this thesis by developing an improved version of the electricity model PowerPlan for China in specific, which, besides the performance of the power sector and supply shortages, explicitly models electrification and the urban–rural divide (see Chapters 4). It is also intended to develop a new version of one of the simulation energy models discussed earlier to assess a.o. the use of traditional biofuels and the urban–rural divide for specific developing countries (see Chapter 5 and 6).

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