English summary:

Sustainable energy for developing countries
- Modelling transitions to renewable and clean energy in rapidly developing countries

1. Background

1.1. Energy and its impacts

Energy is vital. Energy is needed for basic human needs: cooking, heating, lighting, boiling water and for other household-based activities. Energy is also required to sustain and expand economic processes like agriculture, electricity production, industries, services and transport. It is commonly suggested that access to energy is closely linked with development and economic well-being.

Today about 80% of the world’s primary energy comes from polluting fossil fuels such as coal, oil and natural gas. However, fossil energy resources are not endlessly abundant, but can be depleted. Energy has thus become a major geo-political and socio-economic issue. Recent oil price shocks have shown the world’s dependency on a scarce fuel. Fossil energy use is also associated with a number of negative environmental effects like air pollution and global climate change. During the combustion of fossil fuels large amounts of carbon dioxide (CO₂) and other so-called greenhouse gases (GHG) are emitted, which are reported to contribute to global climate change. Global climate change, sometimes also called global warming, is a phenomenon which is indicated to have multiple impacts. The United Nations’ Intergovernmental Panel on Climate Change (IPCC) reports that some of the observed impacts are an increase in global surface temperatures, increases in heavy precipitation events, higher frequency of droughts, changes in the large-scale atmospheric circulation and increases in tropical cyclone activity. This could mean increased water stress, flood risks, drought risks, food insecurity, reduction of living standards and health risks. Developing countries are likely to be most vulnerable to climate change, due to their limited financial and structural means which could hinder quick adaptation and mitigation.

1.2. Energy transitions and the role of renewable and clean energy

These energy-climate implications put pressure on all countries around the world. The pressure on developing countries may be even greater, because they are currently in the process of development which requires substantial energy resources for achieving higher living standards. High population levels and high fossil fuel reliance increase this pressure even more. The share of low-polluting renewable and clean energy should therefore be increased to meet energy security, to reduce pressure on fossil energy resources, to mitigate climate change and to ensure a higher environmental quality. Renewable and clean energy are likely to spur sustainable energy transitions.

Energy transitions can be defined as shifts from a country’s economic activities based on fossil fuels to an economy partially based on renewable and low-polluting clean energy sources. This means that substitutions take place from fossil fuel-based technologies to clean energy technologies. Such transitions can take place in every sector of a country’s or a region’s
economy. For example, electricity can be generated from wind instead of being generated from coal. Sustainable energy transitions could open up new possibilities for developing countries to achieve higher development and higher living standards while at the same time safeguarding energy resources, the environment and human health due to lower pollution levels.

1.3. Energy modelling

Energy models can be important tools for analysing and planning energy transitions. Computer models are simplifications of the real world and can also be useful for energy planning. Complex real-life problems can be observed and analysed by computer models. The future can be simulated with these models to assist the energy planning of years and decades to come. Since most present-day energy models are developed by and for industrialised countries, they often tend to be biased towards the energy systems of these countries and they may thereby overlook that the situation is very different in developing countries. Developing countries usually differ from industrialised countries in terms of energy consumption, production and distribution, energy infrastructure and energy economy. For example, in many developing countries a large part of the rural population uses fuel wood for cooking meals and heating homes. In industrialised countries, the majority of the population uses electricity or natural gas for cooking and heating. These differences in energy systems between developing countries and industrialised countries result in the need to adapt energy modelling approaches for the use in developing countries.

2. Objective of the thesis and research approach

The main objective of this thesis is first to adapt energy models for the use in developing countries and second to model sustainable energy transitions and their effects in rapidly developing countries like China and India.

The focus of this thesis is three-fold: a) to elaborate the differences between energy systems in (rapidly) developing countries and in industrialised countries, b) to adapt energy modelling approaches to improve their suitability for rapidly developing countries and c) to develop scenarios using these adapted models to simulate sustainable energy transitions for rapidly developing countries and to assess the implications of these energy transitions. The core of this research is to develop scenarios for sustainable energy transitions for China and India. China and India are chosen, because they are currently considered the most rapidly developing countries, and thereby also the most energy-consuming, most climate-relevant and most economically-growing developing countries. Their development is expected to have global impacts. Implementing renewable and clean energy sources in these countries is likely to mitigate climate change. Three case studies are chosen for China and India which assess different levels and scales of energy transitions: national/regional, urban/rural and supply/demand. These three case studies are corresponding with current energy policy in China and India. A case study for Beijing was developed based on the local government’s renewable energy target for 2020 and was performed in cooperation with Chinese researchers.

The sustainable energy technologies which are assessed in these case studies are renewable energy sources coming from the sun, wind, water, biomass and so-called “clean” energy technologies which emit less greenhouse gases than conventional coal and oil, such as nuclear energy, natural gas and more efficient fossil fuel technology. It has to be noted that the term “clean” energy actually describes less polluting energy, keeping in mind that there is no completely clean energy. Sustainable energy scenarios are compared to business-as-usual
scenarios or baseline scenarios in which unsustainable fossil fuel technologies prevail as it is the case today in China and India. Energy models are specifically adapted in this thesis for the use in developing countries with a focus on the Chinese power sector, Beijing’s economy and rural non-electrified India. These models take into account important characteristics and the level of detail needed to model the energy systems of the developing regions selected.

3. Findings

3.1 Energy systems of developing countries: characteristics and modelling approaches

In chapters 2 and 3, the various characteristics of the energy setting in developing countries are elaborated and it is analysed how energy models address these.

The energy systems of developing countries tend to differ from those of industrialised countries. It is found that the energy systems of developing countries are usually characterised among others by a high dependence on traditional biofuels such as fuel wood and dung, by low electrification rates and limited access to modern energy sources, by supply shortages, poor performance of the power sector and high differences in energy access, supply and demand between urban and rural areas. Some economic issues, like the prevalence of the so-called unofficial or informal (thus non-taxed) economy and changes in the structure of the economy, can also influence the energy setting. These characteristics can generally be observed in developing countries, but the extent to which these characteristics play a role varies between countries and regions. Factors which influence the energy systems and trigger changes are among others population growth, economic growth, fuel switching, technological change and policies. Concepts of energy and development are elaborated in Chapter 2, like the Energy Ladder (which relates increasing income to the use of cleaner and more efficient energy) and the Environmental Kuznets Curve (which relates income levels to pollution levels). These concepts can be observed in the results of the IPCC/Special Report on Emission Scenarios (SRES) models, but improvements can be made in modelling the issues that underlie these concepts.

Most present-day energy models were built by and for industrialised countries and are based on the experience of energy systems in these countries. Although these energy models work usually very well for industrialised countries, it is found that many of them tend to oversee the different energy setting in developing countries. Their results might therefore be imprecise or at worst even misleading, which might in some cases affect policy recommendations. This should be addressed in a time of global climate change, when negotiations about potential emission caps for developing countries are on the global agenda. Hence, there is a need to adapt energy modelling approaches to make them more suitable for the changing energy systems of developing countries, particularly for rapidly developing countries like China and India. Chapter 3 concludes that particularly those characteristics of developing countries’ energy systems need to be modelled for which reliable data are available and the system dynamics are sufficiently understood. As a result of the energy model comparison in Chapter 3, which tests the suitability of models for developing countries, it is suggested that for an improved use in developing countries adapted energy models should preferably follow a bottom-up or hybrid approach and be scenario-simulation models or toolbox models. In Chapters 4 to 6, three existing energy models were adapted for the use in developing countries according to this approach.

3.2 Energy transitions in rapidly developing countries
In chapters 4 to 6, three case studies for China and India are presented in which existing energy modelling approaches are adapted to suit the rapidly changing energy systems of these countries. Some of the main characteristics of developing countries’ energy systems are modelled, like the fossil fuel-based and low efficient power sector, electrification, the prevailing use of traditional biofuels and the urban-rural divide.

The energy models used for this thesis are specifically adapted for China and India. With these models, it is found that sustainable energy transitions could be possible in China and in India for various sectors.

For the Chinese power sector, energy transitions to renewable energy might save between 17-57% of total CO₂ emissions from electricity generation compared to the business-as-usual scenario in 2030, depending on type and share of renewable energy technology installed. 20% renewable energy among the total installed capacity might reduce total CO₂ emissions from electricity generation by up to 27%, while 30% renewable energy installed might save up to 57% CO₂ emissions compared to the business-as-usual scenario in 2030. A combination of biogas and small-hydro power plants is likely to achieve the highest CO₂ emission savings, compared to mixed renewables and a combination of PV and wind power. 20% nuclear energy among the total installed capacity could reduce total CO₂ emissions from electricity generation by up to 38% compared to the business-as-usual scenario in 2030. The electricity system is likely to stay stable in the future also when higher shares of low-carbon energy will be implemented. Fossil resources are expected to be safeguarded, while costs are likely to rise (Chapter 4).

Possible energy transitions are elaborated for the economic sectors of Beijing, including agriculture, industry, residences, services and transport. The Government of Beijing’s targets to implement 6% of renewable energy among the total energy demand in 2020 could save 23% of total GHG emissions in 2020. The fossil resource use saving is expected to be 16% in the renewable energy scenario compared to the business-as-usual scenario in 2020. Local air pollution, which is a serious problem in Beijing, is likely to decline modestly due to renewable energy transitions in Beijing. Costs are assumed to increase by about 10% due to renewable energy transitions compared to the business-as-usual scenario in 2020. Even in 2020, it is expected that there will be significant differences between urban and rural areas in the municipality of Beijing in terms of income, life style and energy consumption (Chapter 5).

Electrifying India’s rural households could be achieved by three major strategies: grid extensions, decentral diesel systems and decentral renewable energy systems. If grid extensions and diesel systems were to be used for rural electrification, CO₂ emissions and resource use could increase significantly, exceeding the business-as-usual scenario several-fold. A decentral renewable energy-based electrification might save about 99% of total CO₂ emissions and up to 35% of total primary energy use in 2030 compared to the business-as-usual scenario. Rural electrification with decentral diesel systems is likely to be the most expensive option, due to high oil dependence. Concerning whole system costs, rural electrification with decentral renewable energy could be the most cost-effective option when renewable energy-based devices are predominantly used, but could be more costly than grid extensions when electric devices are predominantly used. Rural electrification may have positive effects on social issues like providing access to electricity, improving the living conditions of the rural population and reducing urban-rural differences (Chapter 6).

In summary, it is found that CO₂ emissions could be substantially reduced due to sustainable energy transitions. This thesis shows that natural resources could be safeguarded and fossil energy use could be reduced when renewable energy is used. The electricity system is
likely to stay stable in the future even if a higher share of sustainable energy will be installed. Sustainable energy transitions might reduce social disparities such as urban-rural differences. Concerning costs, the research outcomes suggest a rather mixed picture: In the Chinese power sector, energy transitions to sustainable energy tend to be (much) more expensive than continued reliance on fossil fuels. In Beijing’s economy, energy transitions to sustainable energy tend to increase costs only moderately, with households, agriculture, services and heating, enabling the most cost-effective energy transitions. In the non-electrified residential sector of rural India, rural electrification with decentral renewable energy could be several times cheaper than electrification with grid extensions or decentral diesel systems. This is however only the case when renewable energy-based devices are predominantly used like solar cookers, biogas stoves and solar water heaters. When electricity is generated from decentral renewable energy and predominantly drives electric devices, like electric stoves, electric geysers or other electronics, costs increase to a greater extent than for grid extensions. This may lead to the conclusion that for low-energy requiring processes and small-scale processes sustainable energy could be more cost-effective than other energy sources. For high-energy requiring processes and large-scale processes, sustainable energy tends to be more costly than other energy sources. However, costs for fossil fuels would increase if subsidies were reduced, in return making sustainable energy more competitive. High oil price increases also recently showed that fossil fuel prices tend to be volatile and are likely to increase even more, potentially making sustainable non-fossil energy more attractive in the future. Moreover, the system is highly complex, high uncertainties exist and regional differences prevail, with India differing from China and rural areas differing from urban areas.

4. Conclusion

This thesis aims a) at elaborating the differences between energy systems in (rapidly) developing countries and in industrialised countries, b) at adapting energy modelling approaches to increase their suitability for rapidly developing countries and c) at developing scenarios using these adapted models to simulate sustainable energy transitions for rapidly developing countries and to assess the impacts of these energy transitions. The focus of this thesis is on China and India.

As an overall conclusion, the thesis shows a) that energy modelling needs to take into account the growing importance of rapidly developing countries. This can be done by adapting energy modelling approaches to suit the energy systems of developing countries as was done in the thesis. This thesis also shows b) that renewable and clean energy could be viable options of climate change mitigation for rapidly developing countries like China and India and c) that these energy transitions to a sustainable economy could also have other positive effects on the environment and society. Hence, sustainable energy transitions are likely to have positive effects in rapidly developing countries. To ensure an adequate planning of these energy transitions adequate energy modelling is needed which is suited for developing countries.

Since climate change is a global problem, it is the responsibility of both developing and industrialised countries to cooperate to achieve a sustainable energy future. Such cooperation could be crucial for the success of international climate policy negotiations. Energy models which are adapted to the needs of developing countries are likely to increase the success of climate policy negotiations, as they can be useful tools to support the energy planning of developing countries.