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Long-run energy scenarios for Cambodia and Laos: Building an integrated techno-economic and environmental modelling framework for scenario analyses

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ABSTRACT

This article analyses energy trends in Cambodia and Laos and constructs future scenarios. The target is (i) to compare different scenario methods, (ii) to construct scenarios with these methods, (iii) to analyse the future energy demand and the related CO_2 emissions and (iv) to analyse the potential role of renewable energy sources and their impact on CO_2 emissions.

Decomposition scenarios have been constructed based on the trends of the drivers of the energy consumption and CO_2 emissions. More detailed scenarios have been constructed using combined LEAP/LINDA models to take into account the structural socio-economic and technological changes in the energy system. The paper provides a novel combination of bottom-up modelling and macroeconomic modelling. The constructed scenarios indicate rapid increase in energy consumption and related CO_2 emissions mainly due to the fast economic growth and industrialization. Increase in fossil fuel use in electricity production in the future increases the emissions considerably.

The potential of different renewable agricultural residues is analysed to evaluate the possibilities to reduce the CO_2 emissions and fossil fuel import dependence. The reduction potential is considerably large in both countries.

1. Introduction

The article analyses historical trends of energy production and use in Cambodia and Laos and constructs scenarios for future trends. The target is to examine future energy demand and the development of energy supply dependence on foreign countries and to then assess the potential for domestic renewable energy sources to reduce future import dependency.

The article develops new approaches to energy planning and modelling by combining the use of different approaches and models. The idea is to utilize different approaches for varying informational needs. In addition to energy use, CO_2 emissions are also of interest in this article due to their role in climate change. When the target of a study is to analyse the drivers behind the changes in the CO_2 emissions, decomposition analysis provides a useful method because it does not require a large amount of data. If, however, more detailed analysis is needed for planning purposes, additional energy models can provide alternatives. In this article we have used a combination of two accounting framework models which are utilized in a complementary way to yield needed information. The decomposition analysis and the model construction form the basis for techno-economic and socio-environmental forecasting and scenario building.

In this article, first, a decomposition analysis has been conducted to analyse the drivers of energy consumption and CO_2 emissions in Cambodia and Laos. In the decomposition analysis, the changes in the observed variable are explained by changes in the driving variables. The decomposition analysis is based on the Kaya identity [1]. In the Kaya identity the CO_2 emissions are expressed as a product of four components: (i) population, (ii) GDP per capita,

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(iii) energy intensity of economic production and (iv) carbon intensity of energy use. Finally a future development trend of CO_2 emissions based on the trend analysis of the decomposed drivers has been constructed.

The LEAP and LINDA models that are used in this research are so-called 'Accounting Framework' models. In addition to the energy models, we have constructed a population model to create scenarios for energy use in Laos and Cambodia. The research group has developed these energy planning models to assess the present and future energy supply and demand in more detail. In the modelling process we have used the LEAP and LINDA models in an integrative way to be able to utilise the different properties of these accounting framework models. The complementary use of the models provides new possibilities for gaining deeper insight into different processes and factors affecting energy use. The models have been used to create scenarios for future energy use and CO_2 emissions in the case of varying economic development trends and different electricity production technologies. Typically, energy scenarios are used to help energy planners and decision makers to understand alternatives and to make strategic choices [2–5].

The article also analyses the potential of biomass energy sources in Cambodia and Laos in order to evaluate different energy alternatives that might reduce the import of expensive fossil fuels. The potential role of agricultural waste (such as rice husk and straw) as an energy source is given particular analytical attention. With the use of agricultural residues it is possible to avoid competition for scarce land resources with food production. In addition, the available technologies for conversion and utilisation of agricultural residues are discussed.

2. Materials and methods

2.1. Data sources

The data for this research come from numerous sources. The macro level energy data for Cambodia is mainly from IEA Energy Balances for Non-OECD Countries [6]. The macro level energy data for Laos is from the Lao Ministry of Energy and Mines. The economic macro level data is from the Statistical Bureau of Laos [7], the National Institute of Statistics of Cambodia [8] as well as the World Bank [9,10] and the Asian Development Bank [11]. Energy data for Laos has also been collected as part of the INES project of the EEP Mekong Programme [12].

The baseline household level data in the LEAP model is from two household surveys in Cambodia ($n = 1261$) [13] and Laos ($n = 2102$) [14], conducted in 2009 and 2011 respectively. This study provides novel empirical results because it is based on data from new field survey research in Cambodia and Laos. The study provides interesting and insightful results because data problems have been a considerable constraint for empirical research in these LDC countries. Both of the surveys are representative of the countries and their population characteristics. The samples were clustered by a method called PPS (probability proportional to size), and stratified by region. The topics in the questionnaire included livelihoods and energy use. Based on the data, households were categorized into four income groups according to their monthly income and house type. Just under a third of the households in both countries belonged to the low income group, two fifths to the medium income group, one fifth to the high income group. The remaining proportion (6% in Cambodia and 8% in Laos), belonged to the highest income group. The proportions varied greatly in different types of villages. Villages in both countries were classified as being either urban or rural, and according to whether or not they had access to a national electricity grid. Additionally, in Laos, villages were classified based on whether or not they were connected to a road The intensity figures based on the survey data were ultimately scaled to match the official electricity demand estimations of the baseline year 2011. For more detail of the survey methods see Refs. [13,14].

2.2. Decomposition analysis of drivers for energy demand and CO_2 emissions

Decomposition analysis is one method to assess the drivers behind the changes of measured variables. In the following paragraphs a decomposition analysis for CO_2 emissions in Cambodia and Laos is illustrated. This is the first decomposition analysis carried for the energy sector of these LDC countries as far as we are informed. The CO_2 emissions of a country can be expressed with the Extended Kaya Identity [15]. In the Extended form of the Kaya Identity the energy transformation from the TPES (total primary energy supply) to the FEC (final energy consumption) is incorporated in the analysis:

$$CO_2 = \frac{CO_2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP \tag{1}$$

where

CO_2 is carbon dioxide emissions from fuel combustion;
GDP is gross domestic product in real prices;
TPES is total primary energy supply;
FEC is final energy consumption;
POP is the amount of population.

With the equation, five different factors contributing to the change in CO_2 emissions are identified in such a way that their product equals the total change. Using the complete decomposition method (see e.g. Refs. [16–20]) we can express the changes in CO_2 emissions (compared to the selected base year) as a sum of the different components. Complete decomposition means that no residual term is produced when the total change is divided into components.

The first factor CO_2/TPES refers to the contribution of change in CO_2 intensity of the primary energy supply, which is influenced by switching from one energy form to another. Negative values for this factor imply a switch from fuels with high carbon content to energy sources with a lower carbon content (e.g., from coal to natural gas or nuclear power, and vice versa).

The second factor TPES/FEC, refers to the efficiency of the energy transformation system, i.e., the efficiency in transforming primary energy into the different energy carriers such as electricity or heat. This can be influenced by, for example, switching from fuel use to electricity or vice versa, or technological changes in fuel combustion. Positive values for this factor imply increasing use of electricity relative to other energy carriers.

The third factor FEC/GDP, refers to the energy intensity of the whole of economic production. This can be influenced by several factors such as changes in the industrial structure from energy intensive to less energy intensive industrial branches, change from industry towards services in terms of GDP shares, or technological development inside energy consuming parts of the economy. Negative values for this factor imply that countries have decreased their energy intensity due to the reasons provided above.

The fourth factor GDP/POP, refers to the amount of economic activity per capita which can be influenced, foremost, by economic growth. The positive values for this factor imply that continuous economic growth per capita has increased CO_2 emissions.

The fifth factor POP, refers to the change in the size of the population, which is influenced birth and the death rates as well as by the international migration.