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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

RESEARCH AND STATISTICS BRANCH

STAFF WORKING PAPER 02/2006

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case study of industrial development in China

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A model approach for analyzing trends in energy supply and demand at country level: case study of industrial development in China

Sérgio Miranda-da-Cruz

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Abstract

Ideally, national energy supply and demand choices would be based on comprehensive models and predictions of the energy sources, energy transformations, energy carriers and energy end-uses expected to play major roles in the foreseeable future (30-40 years). However, in many cases, the necessary detailed, high quality, consistent and timely data is not available, and there is no time to wait until such comprehensive models can be constructed. In those cases, there have been a number of countries, particularly large and complex developing economies expected to be major energy users in the near future, that have been concentrating their attention on two fronts: (a) a dramatic decrease in energy intensity, particularly in activities linked to industrial production and (b) a major increase in the contribution of local renewable energy to limit growth in fossil fuel use as well as resulting local pollution and global greenhouse gas emissions. In line with those changes, national policies need to be oriented towards a strict and strategic monitoring of the respective energy matrices with a focus on the two fronts. A robust assessment of industrial development trends throughout the whole 30-40 year transition phase is needed to achieve both objectives. As part of that assessment, in order to overcome the limited availability of data at country level on most of energy related issues, it is proposed that an energy supply and demand model analysis consisting of three phases be used for identifying future needs and corresponding policy requirements. This model analysis, which is a dynamic exercise in any given economy, consists, first, of an analysis at aggregate level of the current and future national energy matrices; secondly, an analysis of perspectives for decreasing the energy intensity of the most inefficient systems or industrial sectors; and thirdly, an analysis of perspectives for increasing the supply and cost-effectiveness of sustainable energy sources. As an illustration of this model approach, the case of China is analysed with emphasis on the industrial sector, followed by a discussion of some of the structural change policies indicated for China to reach the planned energy supply and demand objectives for 2020.

Keywords: Energy modelling; Structural change; Policy implications, Industrial development

1. Introduction

There are a number of key challenges underway in the global, regional and national energy supply and demand situations. The need to make deep cuts in greenhouse gas (GHG) emissions is gathering force with the coming into force of the Kyoto Protocol, which sets binding targets for most developed countries for 2008-2012, and with discussions underway as to the size and distribution of future GHG cuts. The Clean Development Mechanism (CDM) and European Emission Trading System (EU ETS) are making GHG reductions a growing cash flow component of renewable energy projects worldwide. The EU Energy Efficiency Directive and suitable approved methodologies under CDM will soon give energy efficiency projects a similar extra cash flow component, to help unlock this huge and highly cost effective, but complex, potential.

Constraints on conventional oil supply have driven oil prices to the highest levels in real terms since 1986, partly due to ongoing strong growth in transport energy demand in such key developing countries as China and India. There are growing analyses and predictions that the physical peak in conventional oil supply is approaching in the short term, while some authorities argue that the constraint will come from the huge capital investments required to expand oil supply and refining (IEA, 2005). High recent oil prices are leading to inflationary pressures as well as impacting on developing countries' industries, which use oil for on-site process steam and electricity generation. Growing demand and constraints in regional natural gas supplies is also putting upward price pressure on natural gas in many countries. The impact of higher gas prices is being seen in many industrial petrochemical products such as urea fertiliser. Coal is plentiful and widely distributed, but growing business-as-usual conventional coal use is incompatible with global GHG reduction goals.

There are a number of mature renewable energy technologies now widely available, in particular hydro and wind. Bio-energy and photovoltaic are growing strongly and look likely to make a major energy supply contribution in coming decades. In the longer term, the hydrogen economy, based on renewable energy, shows promise for both mobile and stationary applications (Gielen and Simbolotti, 2005), although some argue that biofuels and advanced internal combustion engines are more promising than hydrogen fuel cells for mobile applications (Doty, 2005).

Energy market monopoly unbundling, corporatization, removal of cross subsidies and anti-monopoly and pro-competition regulation are generally making energy prices more financially cost-reflective and, in some cases, more environmentally cost reflective. Appropriate energy prices and open access to supply and demand energy markets are necessary, but not sufficient in themselves, prerequisites for the radical renewable energy supply and end-use energy efficiency changes needed in the transition period.

A transition to more sustainable global energy supply and demand patterns is clearly required. It is expected that the transition period will be oriented in *two* major directions: (a) decrease in energy intensity, primarily through an increase in energy efficiency, particularly in activities linked to industrial production; and (b) increase of the contribution of renewable energy to limit use of fossil fuels and corresponding local pollution and global GHG emissions. In line with those changes, national policies need to be oriented towards a strict and strategic monitoring of the respective energy matrices with a focus on *two* fronts: (a) radical improvement of the efficiency of energy systems, particularly in manufacturing industries in developing economies, combined with (b) sustainable and cost-efficient use of national energy resources.

UNIDO´s main concern is sustainable industrial development. Energy is perceived as one of the key inputs, or fundamental determinants, for a healthy industrial sector to contribute to economic and social development while preserving and, indeed, reversing some of the damage to the environment from past and present *unsustainable* industrial growth. For UNIDO, energy supply-use is perceived as part of overall industrial production and development, rather than as an end in itself. Therefore, although fundamental, the assessment of the energy status of UNIDO Member States is only one group of variables in the broader assessment necessary to identify the perspectives for sustainable industrial development.

However, when assessing prospects for sustainable industrial development in some of the countries assisted by UNIDO, it became clear that the energy data availability, quality and comparability were generally deficient for the detailed modelling exercises commonly utilized in developed economies using such tools as the MARKAL family of models[1] (IEA, 2006, DeLaquil *et all*, 2003, Goldstein and Greening, 2001). The same was true for econometric forecasting models, sectoral engineering stock models, engineering economic models and

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[1] MARKAL is a long-term and technology-rich energy system optimization model developed during the last two decades, which provides a flexible framework to evaluate alternate technology and policy options. It was developed under the IEA's Energy Technology Systems Analysis Programme and is used by 77 institutions in 37 countries.

optimization and policy analysis “what-if” models. Therefore, probable scenarios at an aggregated level have to be used instead, as this is more aligned with the data that is available with any reasonable level of confidence in many developing economies. UNIDO has, therefore, adopted an *alternative* model approach on how to work with current and future energy supply and demand as well as the corresponding implications in terms of policies when using existing patchy and incomplete energy supply and demand data.

The main reason for working with macro and very aggregated scenarios in UNIDO’s assessments is that developing MARKAL-type detailed energy supply and demand models requires years to gather and involves a considerable number of detailed technology specific current situations, trends and options, in the case of large, complex developing economies. With these economies changing very rapidly, it is arguable if new data can be added faster that existing data as technical and economic relationships become outdated. Otherwise it is possible to end up with a very sophisticated model structure mainly populated with suspect detailed data and guesstimates of elasticities and other defining relationships. This can give a misleading appearance of accuracy and precision to forecasts.

In economies such as China, for example, a new industrial technology can be introduced and, then, superseded or even banned from further use in new plants within the seven-year timescale of a donor-funded project’s development design and implementation (Pool and Wen, 2005). Further, most of the huge rural biomass in China is not counted, as it is not a commercial energy form. Even the historical supply of coal in China is subject to huge uncertainties, between different data sources. The degree of confidence possible is, therefore, questionable using the model results obtained in the interim before the entire model is developed and suitably resourced systems to update continually the huge quantity of data and inter-relationships are fully realized. Consequently, in the interim, UNIDO needs a simpler alternate methodology, which utilizes existing fairly aggregated energy supply and demand data, to provide timely and useful policy advice to the majority of its Member States on issues where energy is likely to be a constraint for achieving their industrial, economic and social development goals.

The case of China is illustrative. Among several initiatives in the country (DeLaquil *et al*, 2003), Tsinghua University is developing a MARKAL framework energy supply and demand model (Chen and Wu, 2001). However, this exercise has already taken some years and seems unlikely to produce comprehensive results until more detailed and reliable input information is obtained and periodically updated. In UNIDO's assessment in China, part of the information available has come from government sources based on similar initiatives as the one at Tsinghua. However, UNIDO, among other institutions, could not wait for such detailed integrated models to become available as it needed to work with the Government on strategic issues related to industrial development, where energy is an essential factor, beginning with the tenth five-year plan (FYP), covering January 2001 to December 2006 and continuing into the eleventh FYP, from January 2006 to December 2010.

This paper describes UNIDO's approach to advising its Member States on energy-related issues and the reasons for doing so, as well as illustrating this approach with a specific example. Although lacking the complex structure of MARKAL and similar frameworks, the importance of this exercise lies in the ability to allow UNIDO to work with Member States that would otherwise be unable to receive *timely* energy-related industrial development advice.

2. Description of UNIDO's approach

UNIDO's energy model analysis is used at country level to identify future needs and corresponding policy requirements for reducing energy intensity as well as increasing the use of renewable energy resources. It is a dynamic exercise that is continuously monitored and that incorporates new information and data originating from technical and non-technical analyses, as elaborated here. The model consists of *three* sequential phases, which can be applied, in principle, to any economy: (i) analysis, at aggregate level, of current and future national energy matrices; (ii) analysis of perspectives for decreasing energy intensity of the most inefficient industrial systems or sectors; and (iii) analysis of perspectives for increasing the supply and cost-efficiency of sustainable (i.e., renewable) energy sources, as illustrated in Fig. 1.

For phases (ii) and (iii), in order to avoid the traditional difficulties of collecting accurate and consistent data in developing countries, the analyses are, in both cases, a *sum* of individual assessments based mostly on expert analysis of the most critical energy systems and industrial sectors, for phase (ii) and of the sustainable energy sources, for phase (iii). That is the main reason for the requirements of dynamism and openness in the overall exercise.

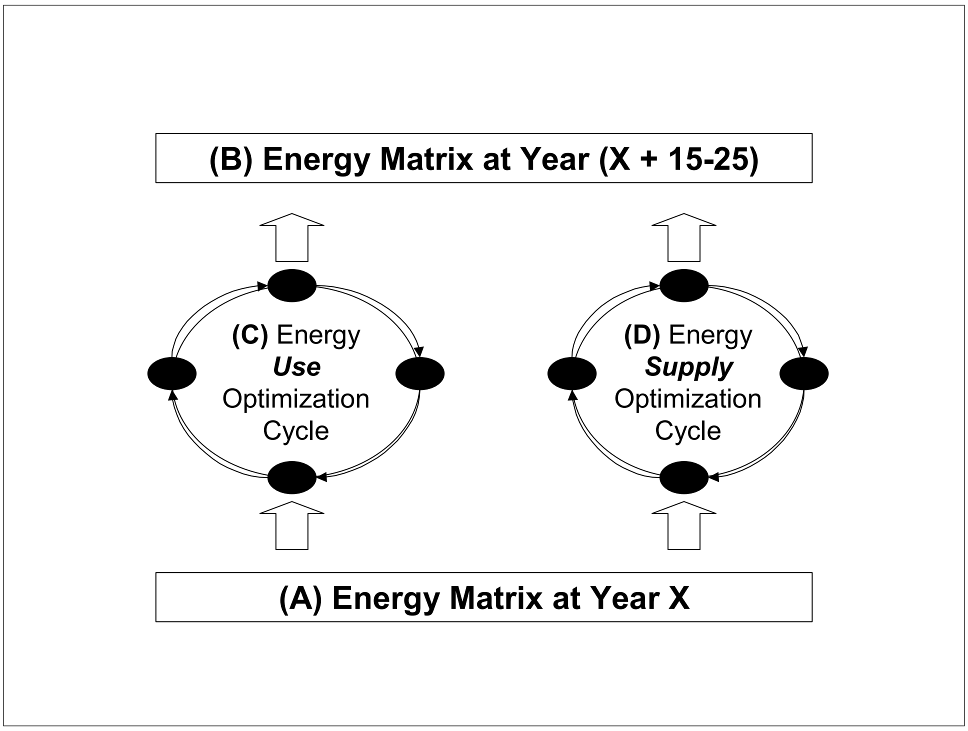

Fig. 1. UNIDO energy model analysis

The analysis of current and future national energy matrices is based on data at aggregate level. The data derive from primary and secondary information of current and future energy supply and use, using initiatives based on well-known techniques, as in the case of the MARKAL family of models and energy intensity decomposition analysis.

In addition to the technical data derived, in general, from these two techniques, this exercise takes into consideration government objectives, particularly when working with the future energy matrix [(B) in Fig. 1]. Therefore, in the analysis of national energy matrices, there is a *political*, or *non-technical*, component whose feasibility needs to be tested against more technical data. This is reflected in the discussion of the policy implications of the structural changes required to reach the national objectives of energy supply and demand.

For analysis of the perspectives for decreasing the energy intensity of the most inefficient energy systems or industrial sectors, a framework called the *energy use optimization cycle* is used (Fig. 1-A). Applied to individual energy systems or industrial sectors, the cycle consists of *four* phases: (1) diagnosis or assessment of the status of energy demand by the most important energy usage systems or industrial sectors in the country; (2) assessment of the managerial and technical knowledge (*tech*-knowledge) required to optimize the energy use of the systems or industrial sectors identified in phase (1), followed by implementation of an experimental programme for absorption and/or development of the required knowledge; (3) policy formulation phase to identify the constraints on dissemination of the knowledge absorbed and/or developed under phase (2), followed by design of the required scaling-up strategy; and (4) policy implementation phase, which brings in the structural changes, at system or sectoral level, required to introduce the energy optimization measures needed to decrease, on national scale, the energy intensity of the most inefficient energy systems or industrial sectors.

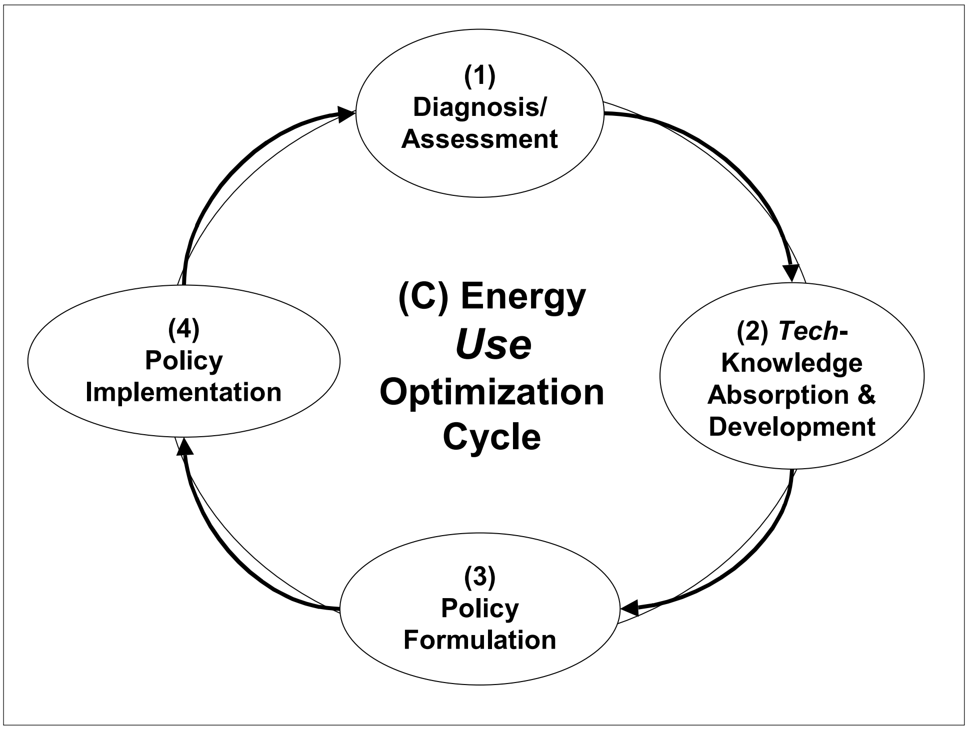

Fig. 1-A. Energy use optimization cycle

For analysis of the perspectives for increasing the supply and cost-efficiency of sustainable energy sources, the framework similar to that applied in the case of the energy use optimization cycle. The framework is called the *energy supply optimization cycle*, as illustrated in Fig. 1-B.

The cycle is also applied to individual energy supply systems and consists, similarly, of *four* phases: (1) diagnosis or assessment of the status of energy supply systems in the country, with particular emphasis on renewable energy sources; (2) assessment of the managerial and technical knowledge required to optimize the supply and cost-effectiveness of energy from the systems identified in phase (1), followed by implementation of an experimental programme for absorption and/or development of required knowledge; (3) policy formulation phase to identify constraints on dissemination of knowledge absorbed and/or developed under phase (2), followed by design of the required scaling-up strategy; and (4) policy implementation phase to carry out the structural changes, at system level, required to introduce energy supply optimization measures to increase the supply of sustainable (i.e., renewable) and cost-efficient energy resources on national scale.

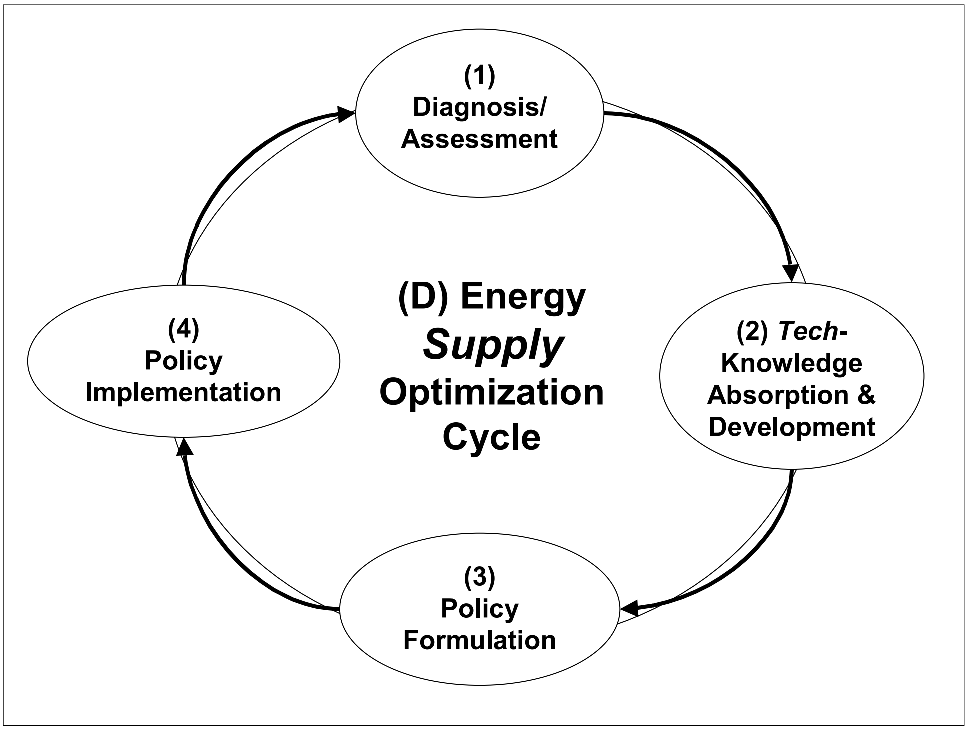

Fig. 1-B. Energy supply optimization cycle

The combination of these three phases leads to a general assessment of the energy status of an economy. As illustrated in the case of China, this is used by UNIDO as an input for assessing perspectives for sustainable industrial development of the wider economy.

3. Application of UNIDO’s approach: China

3.1. Energy matrix in 2002 (A)

The commercial energy supply and demand matrix for China for 2002 amounts (NDRC, 2002, NDRC, 2004, APERC, 2004) to some 44,000 Peta Joules (PJ), equivalent to 12,200 Tera Watt hours (TWh), or some 1.5 billion tonnes of coal equivalent (TCE), as presented in Table 1. In order to be in line with the data usually presented in Chinese government documents and official discussions, the expression TCE is used most frequently throughout the text. In addition, since the focus is on an aggregated scenario, the figures used are approximate.

Primary Energy Source	**Energy *Supply* (*2002*)**			**%**
	PJ	**TWh**	**Mill. TCE**	
Coal	29,000	8,050	990	66
Crude Oil	9,250	2,550	315	21
Hydro + RE	3,550	1,000	**120**	**8**
Natural Gas	1,300	350	45	3
Nuclear	900	250	30	2
Total	**44,000**	**12,200**	**1,500**	**100**

Table 1. China: commercial primary energy supply, 2002

In 2002, there were *five* major sources of commercial primary energy in China, in order of importance: (i) coal (66 per cent); (ii) crude oil (21 per cent); (iii) hydroelectricity and other currently minor sources of renewable energy (8 per cent); (iv) natural gas (3 per cent); and (v) nuclear (2 per cent). Special attention is given to hydroelectricity and other renewable sources of energy, which are highlighted in the text, as the focus of UNIDO's work with national authorities.

Based on primary and secondary sources in the country (NDRC, 2002, APERC, 2004), together with UNIDO analysis for coherence of collected figures, the structure of energy *use* at aggregate level has been compiled for 2002, with the results shown in Fig. 2. Similar to the case of energy supply, the figures are approximate, as the focus is on an aggregated scenario.

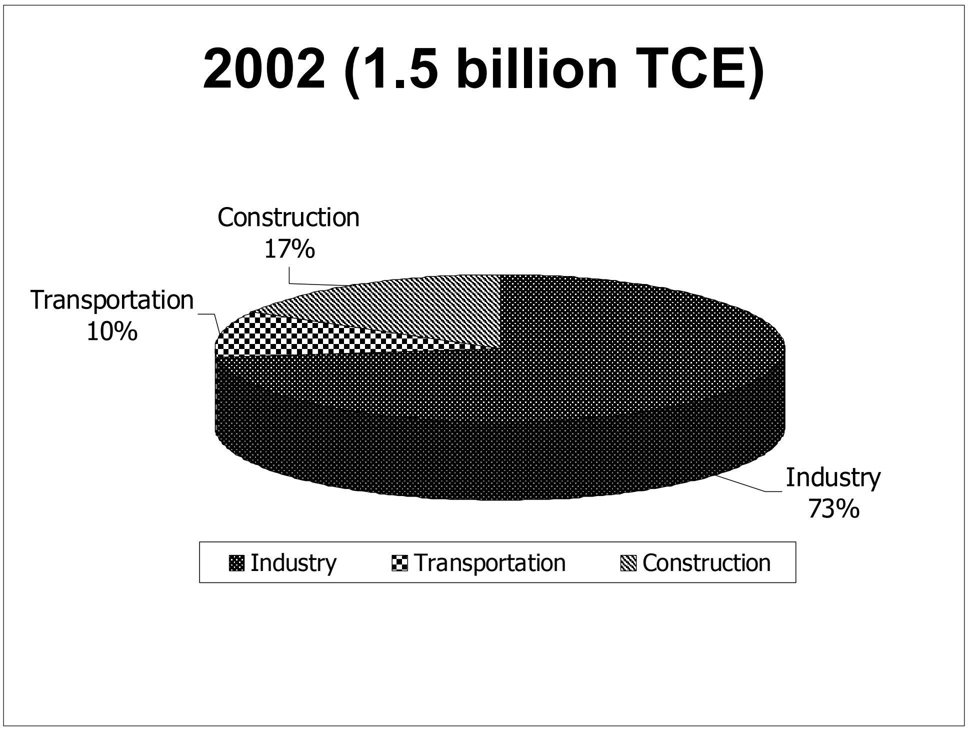

Fig. 2. China: structure of energy use, 2002

In line with the majority of countries with economies where the secondary sector has reached a minimum stage of development, the industrial sector in China accounts, by far, for the largest level of energy use (73 per cent), followed by construction (17 per cent) and transportation (10 per cent).

3.2. Energy matrix in 2020-2025 (B)

Analysis of the future energy matrix for China reflects, as mentioned above, the combination of both sets of figures: *technical*, based on systematic and long-term techniques for energy systems optimization and *non-technical*, based on what the Government foresees as an ideal balance in terms of the supply and use of energy in line with more strategic goals for economic development. The results are presented in Table 2.

Primary Energy Source	**Energy *Supply* (*2020*)**			**%**
	PJ	**TWh**	**Mill. TCE**	
Coal	50,100	13,900	1,710	57
Crude Oil	13,200	3,650	450	15
Hydro + RE	15,850	4,400	**540**	**18**
Natural Gas	5,250	1,450	180	6
Nuclear	3,500	1,000	120	4
Total	**87,900**	**24,400**	**3,000**	**100**

Table 2. China: projected commercial primary energy supply, 2020

The requirements of commercial energy supply for China in 2020 are projected at some 88,000 PJ, equivalent to 24,400 TWh, or some 3 billion TCE.

An overarching objective covering both energy efficiency and commercial renewable energy, established by the Government of China, is to quadruple gross domestic product (GDP) between 2002 and 2020 whilst only doubling the overall supply of commercial energy (NDRC, 2004) and, within this commercial energy supply, increasing the share of commercial renewable energy from some 8 to 18 per cent (NDRC, 2003, APERC, 2005). This implies achieving an extremely ambitious overall *energy:GDP* ratio of 0.5, in a 15-year period and, at the same time, a more than fourfold increase in commercial renewable energy.

In February 2005, the Government promulgated the *Renewable Energy Law*, to be implemented as of January 2006. The law is an important milestone in the direction of implementing the China National Energy Strategy and Policy, which *inter alia*, called for at least 18 per cent of primary commercial energy sources to be renewable by 2020 (NDRC, 2003, APERC, 2005), equivalent to generation of 400-500 million TCE, an over fourfold increase in 15 years.

In Table 3, both matrices (2002-2020) for commercial primary energy supply are compared. For simplification of analysis, only data in TCE is used.

Primary Energy Source	**Energy *Supply* (Mill. TCE)**		**Percentage (%)**	
	2002	**2020**	**2002**	**2020**
Coal	990	1,710	66	57
Crude Oil	315	450	21	15
Hydro + RE	**120**	**540**	**8**	**18**
Natural Gas	45	180	3	6
Nuclear	30	120	2	4
Total	**1,500**	**3,000**	**100**	**100**

Table 3. China: commercial primary energy supply, 2002-2020

Based on primary and secondary sources available in the country (NDRC, 2002, APERC, 2004) as well as data for 2025 projected by China's State Grid Corporation, the structure of energy use at an aggregate level is shown in Fig. 3. The figures are approximate.

In Fig. 4, both matrices (2002-2025) for the structure of energy use are compared. For simplification of analysis, only percentages are used.

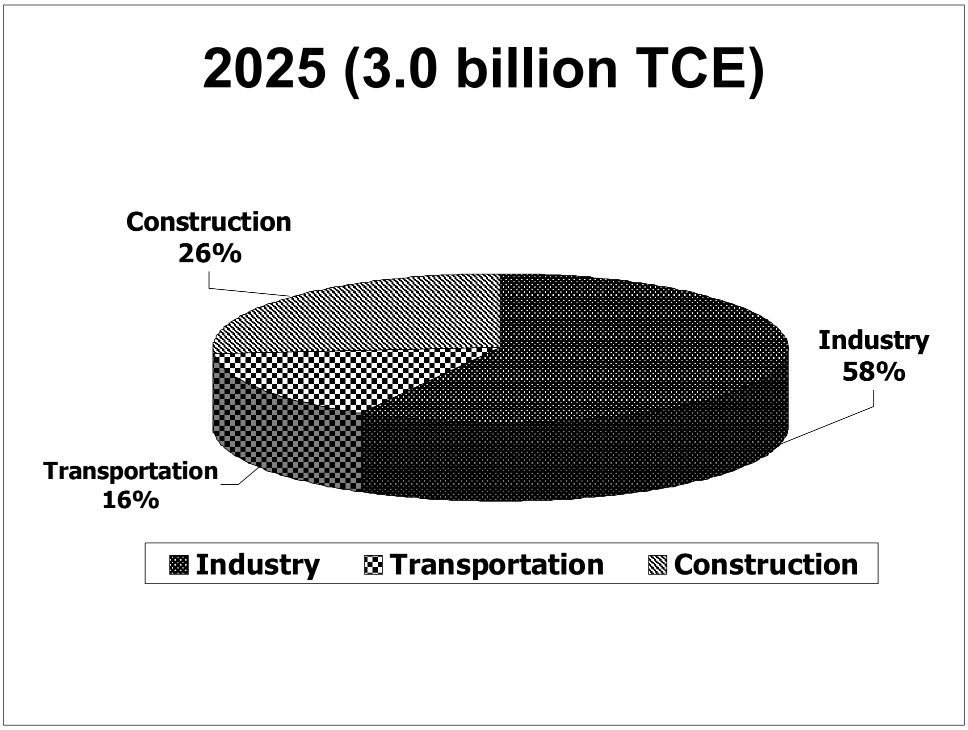

Fig. 3. China: projected structure of energy use, 2025

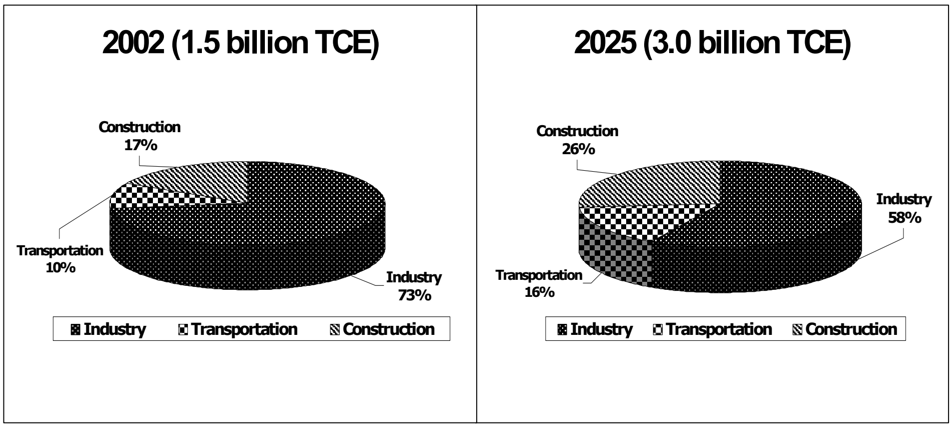

Fig. 4. China: structure of energy use, comparing 2002 and 2025

3.3. Preliminary analysis of energy matrices A and B

Based on current energy use trends in China (ADB, 2006a) the *energy elasticity coefficient* for China from 1981 to 2003 showed an increasingly high unit of commercial energy supply and use per unit of GDP growth. As illustrated in Fig. 5, from an annual average value of 0.8 for the period 1981-1986, the figure shows that, after a reduction, most probably linked to the Asian economic crisis in 1997/1998, the *energy:GDP* elasticity coefficient in China increased to 1.4, in 2003. Therefore, despite the lack of precision, resulting from the aggregated level of figures used in formulation of the energy matrices for China and the slightly different figures shown in various statements and reports, it is possible to conclude, on a preliminary basis, that is unlikely that the Government can reach the current objectives of quadrupling economic growth while only doubling energy supply and use by 2020 (NDRC, 2004).

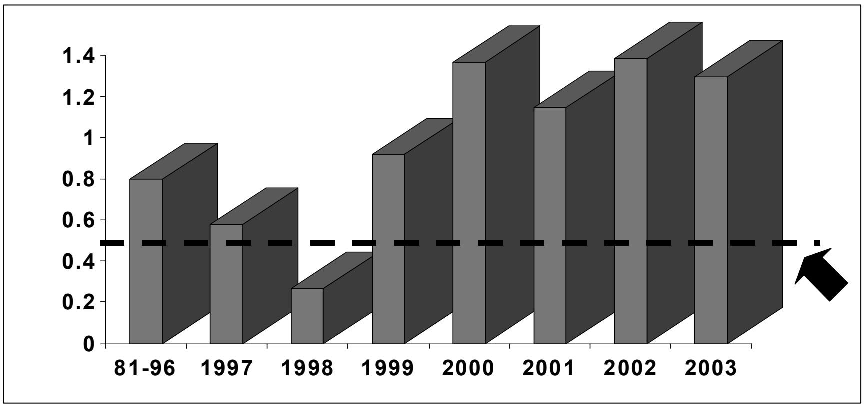

Fig. 5. China: *energy:GDP* elasticity coefficient, 1981-2003

There are, at a first glance, *two* alternatives for reaching the objectives initially established by the Government to reduce the total amount of energy to be used in 2020, which requires a drastic reduction in the *energy:GDP* elasticity coefficient from 1.4 to 0.5, as highlighted at fig.5. The first is economic growth almost exclusively in those sectors that naturally increase GDP with low energy use, such as services and elaborately transformed manufactures, which would have major consequences for a complete restructuring of the Chinese economy, which is unlikely in the immediate future. The second is an extremely ambitious programme of energy savings in heavy industrial and other sectors where gains in GDP are accompanied by high energy use. Most likely, a combination of both will be needed if *energy:GDP* ratios are to fall below 1.0, let alone to 0.5.

Whichever the approach followed, it would lead the corresponding authorities and national energy experts to enter into the *energy use optimization cycle* (Fig. 1-A).

Based on this preliminary analysis, it would seem extremely difficult to reach the goals established by the China National Energy Strategy and Policy for 2020, to be implemented with legal support from the Renewable Energy Law (NDRC, 2003, APERC, 2005). In line with figures presented at Tables 2, and 3, 18 per cent of the primary energy sources would, in fact, correspond to 540 million TCE. In this case and to be compatible with international environmental objectives such as the stabilization of greenhouse gas emissions, under the Kyoto Protocol (UNFCC, 1998), the corresponding authorities and national energy experts would need to enter into the *energy supply optimization cycle* (Fig. 1-B).

3.4. Energy use optimization cycle (C)

To illustrate the *four* phases of the cycle (described in Fig. 1-A), *two* specific examples implemented in China by UNIDO, in cooperation with other international organizations, are given. It is particularly relevant to highlight, at this stage, the observation made above about the dynamics of the overall exercise. As with item (B), the energy matrix in year X + 15-25, the cycle has to be carried out continuously, on individual energy systems or industrial sectors, to identify the ones that need to be considered among the priorities for introduction of the other *three* phases of the cycle.

The two examples provided in this paper are among the most relevant in the country for optimization of energy use. There are, however, other energy systems and industrial sectors that are equally important and that have either already been or that would need to be approached, in the same way as illustrated in these examples, to reach the final objective, i.e., the introduction of the highest number of structural changes, at system or sectoral level, required to decrease, on national scale, the energy intensity of the most inefficient energy systems or industrial sectors in the country. As a consequence, the systematic application of the energy use optimization cycle to the largest number of individual systems or sectors would introduce the managerial and technical knowledge required to reduce the energy elasticity coefficient for moving towards the national goal of quadrupling economic growth while only doubling energy supply and use.

3.4.1. Example 1. Improvement of the energy efficiency of selected industrial sectors in town and village enterprises (TVEs)[2] in China[3].

The first example in this paper illustrates one of several initiatives carried out by the Government with support from different national and international organizations, including the United Nations system. In China, there have been several initiatives similar to those in this paper, as summarized in Box 1. Although not all the initiatives linked to energy saving measures presented in there have been tested against the framework illustrated in Fig. 1-A, preliminary analysis suggests that the four phases of the energy use optimization cycle, which is designed to be applied to individual energy systems or industrial sectors through expert analysis, is also applicable to all similar initiatives listed in this box.

The example illustrates that the application of the energy use optimization cycle to industrial sectors selected from among the most energy inefficient could save, on completion of the cycle, some 50 million TCE annually, with a parallel impact on the reduction of GHG emissions.

(1) Assessment of the status of the energy demand of the most important energy usage systems or industrial sectors

As a government initiative supported by the United Nations, in the early 1990s the World Bank's Energy Sector Management Assistance Programme (ESMAP, 2004) completed a study that resulted in the project Energy Conservation and Greenhouse Gas (GHG) Emissions Reduction in Chinese Township and Village Enterprises, Phase I, implemented in 1998-1999. As a result, detailed information on technology and markets related to energy efficient technologies in TVEs emerged. Expert analysis of energy use within TVEs identified that *four* industrial sectors, all comprised of small- and medium- scale enterprises (SMEs), were of

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[2] China's TVEs were originally established in the 1950s as collectively owned rural entities primarily to absorb surplus rural labour, provide essential low-cost products and contribute to improving local livelihoods. Since 1995, there have been some *22* million TVEs established in China, currently contributing some 30 per cent of GDP and providing some 136 million jobs. Although there are now TVEs that are privately owned and export oriented, the majority face critical problems of low technology, lack of knowledgeable human capital, difficulties in accessing financial resources and the like. Consequently, they are generally highly *energy inefficient* and polluting.

[3] See (TVE, 2000, Pool and Wen, 2005).

particular relevance: (i) *brick making*; (ii) *small foundries for metal-casting*; (iii) *coke-making*; and (iv) *small cement manufacturing plants*.

The above example is one in a programme of energy and environmental management projects supported by the UN. Most of the other initiatives focus on removing barriers to *energy efficiency* and introducing the use of *clean energy*. The most closely related projects, at the time, were:

- *Capacity Building for Rapid Commercialization of Renewable Energy in China*, to build capacity for removing barriers to widespread adoption of renewable energy sources in the country
- *Improving the Performance of Power Plants in China*, to build the capacity of the power industry for using modern management practices, tools and technologies to improve the technical, economic and environmental performance of power plants
- *Capacity Building for the China Green Lights Programme*, to create the capability for introducing market mechanisms for energy efficient lighting, through consumer awareness and confidence in the products
- *Modernized Biomass Energy in China: Jilin*, to: (1) build capacity for designing, installing and operating biomass-based CHP (Combined Heat and Power); (2) demonstrate biomass gasification technology and (3) disseminate information learned throughout China and other developing countries
- *Study on Resources Concessions for Sustainable Development of Renewable Energy*, to establish a framework for doing resources concessions to prepare a set of draft model regulations, power off-take agreements and policy recommendations on renewable energy
- *China: Issues and Options in GHG Emissions Control*, to identify large-scale energy savings and greenhouse gas (GHG) abatement potentials through “no regrets” projects in all key economic sectors, which provided a foundation for a portfolio of energy efficiency projects supported by national and international institutions:
    - (i) The *China Efficient Refrigerators* project focusing on both demand-pull and supply-push activities to promote design, production, and utilization of more energy-efficient refrigerators throughout the country
    - (ii) The *China Efficient Industrial Boilers* project to develop affordable and energy-efficient industrial boiler designs
    - (iii) The *China Energy Conservation* project to achieve sustainable investments and increases in energy efficiency through proliferation of energy performance contracting to a variety of companies in China based on improved access to information on successful experiences with energy efficiency

Box 1. Other initiatives in energy efficiency and clean energy in China during the 1990s

Table 4 presents a summary of the assessment. With the level of technology used at the time, the average relative energy use of the four selected sub-sectors was 30-60 per cent more than their counterparts within China's state-owned enterprises sector (SOEs)[4], noting that the Chinese SOE sector also has a much higher energy use than in developed countries and some developing countries. In addition, the low quality of their final products has lead to additional energy inefficiencies in product use as, for instance, poor building materials with low insulation levels resulting in buildings being constructed with high heat losses (Pool and Wen, 2005).

Sector	**Energy *Use* (million TCE)[5]**	**Projected production growth rate**	**Energy efficiency gap comparison (%)**		**Share of TVE in total sector energy use (% p.a.)**
	1995		**Local State-of-art**	**Int'l State-of-art**	
Brick	**79**	**2-5 %**	**28**	**37[6]**	**58 % across the board**
Cement	**27**	**2-5 %**	**40**	**57**	
Coking	**54**	**2 %**	**28**	**48**	
Metal-casting	**3.4**	**2 %**	**16**	**45**	

Table 4. Summary of energy demand trends in the four TVE sectors

(2) Assessment of the managerial and technical knowledge required to optimize energy use by systems or industrial sectors identified in phase (1), followed by implementation of an experimental programme for absorption and/or development of the required knowledge

The project also identified and detailed barriers to energy efficiency in TVEs and designed a barrier removal framework, together with identifying sites suitable for implementation of other pilot barrier-removal activities. It assessed the national capacity to provide energy efficiency services to TVEs, developed a comprehensive training package and trained trainers in local institutes in order to develop capacity to remove those barriers.

The experimental programme was carried out in a follow-up model project with the basic objectives of: (a) creating institutional mechanisms for barrier removal at national, county and

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[4] State-owned Enterprises refer to non-corporation economic units whose entire assets are state owned and that have registered in accordance with the Regulation of the People's Republic of China on the Management of Registration of Corporate Enterprises. Excluded from this category are solely state-funded corporations in the limited liability corporations (NBS, 2005).

[5] For reference, total energy use in China was some 1300 million TCE in 1995.

[6] In addition, it had been identified that advanced building regulations in other countries, such as the United Kingdom, would reduce energy use to 20-40 per cent of that for comparable rural Chinese buildings. However, UK buildings would be larger per family or per person.

enterprise level; (b) establishing incentives and monitoring systems to strengthen existing regulatory programmes at county level; (c) building technical capacity for energy efficiency and product quality improvement in TVEs; (d) creating access to commercial financing for TVEs in the four industries, with emphasis on energy conservation; and (e) proposing expansion of the application of best practices for local regulatory reform to the national level.

Item (e) of the objectives falls under the third phase of the energy use optimization cycle: *(3) policy formulation phase to identify constraints on dissemination of knowledge absorbed and/or developed under phase (2), followed by design of the required scaling-up strategy*.

Currently, the project is being adjusted for completion of phase (3) of the cycle, in order to proceed with expansion at national scale [phase (4)]. The assessment shows that the project has achieved, as a result of the previous two phases, at least a 20 per cent energy savings compared to the pre-investment period, which represents, at the experimental and pilot phases, savings of more than 120,000 TCE annually. In the nine pilot projects, greenhouse gas (GHG) emissions to date have been reduced by 300,000 tonnes annually of carbon dioxide (CO_2). One hundred and eighteen formal replication projects within the four sub-sectors have been developed with projected reductions of nearly 2 million tonnes of CO_2 emissions annually. This indicates that the necessary knowledge has either been absorbed or developed and that it is now reaching the stage of being disseminated on national level.

As could be expected, phase (3) saw a number of adjustments from problems faced during implementation of the previous two phases, including delays in the project time-frame. Two examples highlight the difficulties faced and how they were overcome. The first, which refers to the financial mechanism required for the introduction of an energy savings programme, involved establishment of an entrustment loan facility, instead of a revolving fund, at one of the main national banks, as originally foreseen. The second involved modifications introduced at the second essential mechanism, or technical arm, of the programme, where originally a non-governmental organization with the function of an engineering consultancy company was planned to be established as the source of technical services on a model basis. Instead, a commercially oriented energy efficiency technical service provider was established as the model for replication[7].

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[7] The availability of independent entrepreneurs (companies) that function based on reasonably established market principles is considered here as the third mechanism required for implementation of a successful energy saving programme on national scale.

(4) Policy implementation phase for structural changes, at the system or sectoral level, required to introduce the use optimization measures that would lead to a decrease, on national scale, of energy intensity of the most inefficient energy systems or industrial sectors

Although in the project design phase, the need to utilize the experimental phase for policy formulation was not explicitly stated, there have been several useful results (Pool and Wen, 2005) that need to be consolidated and expressed in terms of policies in order to be disseminated throughout the whole country. Since *phase (3)* is nearing completion, some points relevant as the basis for policies illustrate how *phase (4)* can be completed:

- The project conducted the first systematic energy survey since 1984 on TVE development in the cement, coking, foundry and brick industries. The survey has proven to be a solid basis for support to the Ministry of Agriculture[8] in its establishment of the ten-year national plan on TVE energy aspects (TVE, 2000).
- For the *cement industry*, the successful pilot project for electricity generation from residual heat in the new rotary kiln process enhanced promotion of this technique in China. A preferential policy to this effect will be issued in Zhejiang Province. In the mid- and long-term national conservation plan, issued by the National Development and Reform Commission (NDRC), in December 2004 (NDRC, 2004), this technique is on the list of encouraged techniques (Pool and Wen, 2005). TVE project experts were involved in developing the relevant part of the national plan. It is expected that some 30 cement enterprises in China will adopt this new technique annually.
- For the *coking industry*, the success of the pilot innovative clean-type coking oven technique has led to its inclusion in a national programme for technology improvement in industrial sectors. The Government of China's dominant coke producing province, Shanxi, has already decided to promote this type of oven and the technique of residual heat power generation in more coking enterprises. This technology has also attracted interest elsewhere in China and in other countries including India.
- For the *brick industry*, the successful hollow shale brick demonstration plant and its subsequent replication have had a considerable impact on enforcement of the national policy prohibiting production and utilization of solid clay bricks, to prevent the loss of

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[8] In China, the four sub-sectors listed are considered as rural industries and, as such, are under the state management of the Ministry of Agriculture.

valuable and strategic farmland. At the urging of the local brick association and project members, the Government of Chengdu, Sichuan, has accelerated enforcement of the ban on production and use of clay bricks in the local brick market.

Based on preliminary estimates, it is expected that, on completion of *phase (4)*, structural changes required to bring savings of the magnitude of 50 million TCE annually will have been introduced into the country, parallel to the knowledge required to partially reduce the energy elasticity coefficient in China.

3.4.2. Example 2. China motor systems energy conservation programme

The second example also illustrates the use of the *energy use optimization cycle* (Fig. 1-A), now applied, through expert analysis in *phase (1)*, followed by the other *three* phases of the cycle, to an individual energy system, instead of industrial sectors, as in Example 1. Similar to the first example, the initiative is far from being isolated. It is, in fact, a consequence of a long-term decision of the Government to improve the efficiency of the country's energy systems through bilateral and multilateral cooperation (UNIDO, 2000, Peter and Nadel, 2005). Several other similar initiatives have been and continue to be implemented in China, to which the *four* phases of the energy use optimization cycle could be similarly applicable, as shown in Box 2.

The example illustrates that application of the *energy use optimization cycle* to an energy system selected from among the most energy inefficient can save, on completion of the cycle, some 60 billion kWh annually, with corresponding implications for reduction of GHG emissions.

(1) Assessment of the status of energy demand of the most important energy usage systems or industrial sectors in the country

This initiative is a consequence of activities undertaken by the National Development and Reform Commission (NDRC)[9] and United States Department of Energy (USDOE) since 1997, as the result of a bilateral cooperation agreement. The energy conservation law, put into place by

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[9] The State Economic and Technical Commission (SETC), which originally undertook the initiative, was merged in 2003 with the State Development and Planning Commission (SDPC), to form the National Development and Reform Commission (NDRC).

the Chinese Government in 1997, includes optimization of motor systems as a specific policy objective.

Several other motor-related activities were already underway in China, at the time that this experimental phase, the *China Motor Systems Energy Conservation Programme* has been initiated. What essentially distinguished this programme from the other initiatives was the use of an integrated approach that used multiple tools to promote motor system optimization across industrial sectors, with the objective of testing programme ideas and materials that would allow for immediate feedback and modifications as needed. This is the essence of the *energy use optimization cycle*. The other main initiatives were:

- *IIEC China Energy Efficiency Programme*, to develop and promote a labelling and certification programme, for motor testing standards, in an effort to promote high-efficiency motors in China;
- *Sino-U.S. Motor Systems Team*, to develop and implement pilot training programmes and informational materials and tools on motor, pump, fan and compressed air systems in order to lay the groundwork for a nationwide China motor systems programme;
- *Technology Cooperation Agreement Pilot Project*, a USEPA (US Environment Protection Agency) funded effort, to demonstrate technology cooperation as called for in the UN Framework Convention on Climate Change, with one of the initial target areas being motor systems, with a focus on technology transfer;
- *SETC/CECA/Energy Foundation*, a multi-year effort focused on policy development, to promote greater industrial-sector efficiency, with motor systems as one planned target area;
- *GTZ/EPRI motor test laboratory and test procedure project*, to establish revised motor efficiency standards in China and establishing a new motor efficiency test laboratory;
- *World Bank/GEF Energy Management Company Project*, a multiyear project to establish multiple energy management companies (EMC's) in China, with motor systems being a selected areas of focus;
- *China Energy Conservation Information Dissemination Centre*, to prepare case studies and good practice manuals on energy-saving measures, including motor systems;
- *China Green Lights Programme*, a major nationwide programme, to promote efficient lighting in China, with starting date in 1996.

Box 2. Other initiatives in energy efficiency in selected energy systems in China during the 1990s

During the assessment, electric motor systems were identified as widely used in China to drive fans, pumps, blowers, air compressors, refrigeration compressors, conveyers, machinery and many other types of equipment. Electric motor-drive systems in China were using more than 600 billion kWh annually, equivalent to half of the total electricity use in the country. Chinese electric motors were found to be 3-5 per cent less efficient than those in the United States and Canada, while pumps and fans were estimated to have an average 8-10 per cent lower efficiency.

Motors, fans, pumps, air compressors and other motor-driven equipment were found to be frequently used in China with little attention to system efficiency, while more optimized design, including appropriate sizing and use of speed control strategies, could reduce energy use by 20 per cent or more in many applications. In addition, improvements in motor operations and maintenance practices could provide significant complementary energy savings of typically 3-7 per cent. Savings of only 5-10 per cent would save an estimated 35-70 billion kWh by 2010, with reductions of 50-100 million tonnes of CO_2 emissions annually.

(2) Assessment of the managerial and technical knowledge required to optimize use of energy of systems or industrial sectors identified in phase (1), followed by implementation of an experimental programme for absorption and/or development of the required knowledge

Based on work carried out in 1993 (USDOE Motor Challenge programme), a conservative estimate of the potential savings from implementing a systems approach for motor-driven equipment showed that they were substantially greater than those derived from replacing individual components with more efficient models. Therefore, the programme in China (UNIDO, 2000) followed the same approach, by upgrading the complete system, rather than focusing on fragmented solutions.

The main objective was removal of multiple barriers to improvement of industrial motor systems in China. These included: (1) lack of system optimization information by enterprises and companies that use motors; (2) limited availability of energy efficiency experts to provide this information; (3) limited availability of printed information and other tools on motor systems benefits and approaches; (4) lack of focus on efficiency by end-users; (5) difficulty in obtaining highly efficient equipment; and (6) lack of project financing. The pilot programme was implemented in two provinces with a strong industrial base, Shanghai and Jiangsu, through two technical centres and focused primarily on barriers 1, 2, 3 and 6.

The transfer of knowledge was completed by the *absorption*, by the corresponding government institutions in the two targeted provinces, of four key elements: (i) information and training on motor system optimization; (ii) information to factory-level managers and engineers on the benefits of motor system optimization; (iii) know-how to reduce operational costs and increase reliability, at plant level, with a motor optimization system; (iv) know-how to provide engineering services offering market-based motor system optimization services.

The first 38 industrial plant assessments, completed by Chinese engineers who received system optimization training, identified nearly 40 million kWh in annual energy savings, equivalent to an average per system saving of 23 per cent. A summary of the activities carried out by the two centres is presented in Table 5. Thus, the required pilot managerial and technical knowledge to redesign energy motor systems in China has been demonstrated, and the Government can now translate the results into policies that would extrapolate them nationwide through *phases (3)* and *(4)* of the cycle.

Goals	**Jiangsu**	**Shanghai**
Train *10* motor system optimization experts (*5* per centre)	**> 10**	**> 10**
Complete plant assessments for *34* factory enterprises (*17* per centre)	**18**	**23**
Implement *8* demonstration projects with case studies (*4* per centre)	**12 completed**	**7 completed**
Train *200* factory enterprise personnel per centre	**> 700**	**> 200**

Table 5. Summary of activities under phase (2) of the China motor systems energy conservation programme

(3) Policy formulation phase to identify constraints on dissemination of knowledge absorbed and/or developed under phase (2), followed by design of the required scaling-up strategy

As part of the activities, the preparation of a plan for a national motor systems energy conservation programme [*phase (3)*], to be implemented as *phase (4)* of the cycle, has been initiated.

(4) Policy implementation phase, for the structural changes, at system or sectoral level, required to introduce the energy end-use optimization measures that would lead to a decrease, on national scale, of the energy intensity of the most inefficient energy systems or industrial sectors

The policy implementation phase is part of the larger China End-Use Energy Efficiency Programme (EUEEP), which began development in 2001 in cooperation with international organizations. It is (Miao *et al*, 2001, EUEEP, 2005) a four-phase 12-year duration cross-sectoral programme, with the goal of improving the efficiency of energy utilization in China's key end-use sectors, industry and building. The complete programme, of which the motor system energy efficiency component is a key part, was originally envisaged to be implemented as follows:

(i) Phase One (tenth five-year plan, 2001-2005)

- Policy and regulatory framework sub-programme initiated
- Information dissemination sub-programme initiated

(ii) Phase Two (eleventh five-year plan, 2006-2010)

- Policy and regulatory framework sub-programme completed
- Financing sub-programme and technology extension sub-programme initiated

(iii) Phase Three (twelfth five-year plan, 2011-2015)

- Financing sub-programme completed
- Technology sub-programme completed
- Information dissemination sub-programme completed

Despite possible discrepancies between the original scaling-up plan and actual implementation, which is usual in large scale operations, on completion of *phase (4)* of the *energy use optimization cycle*, which coincides with completion, by the end of the twelfth five-year plan of the China End-Use Energy Efficiency Programme, savings of some 60 billion KWh annually are expected from nationwide dissemination of the China motor systems energy conservation programme, together with the knowledge required to partially reduce the energy elasticity coefficient.

3.5. Energy supply optimization cycle (D)

An example of an assessment carried out in China by UNIDO is used to illustrate the four phases of the cycle (described in Fig. 1-B). As with items (B) and (C), the cycle has to be applied *continuously* to individual energy supply systems in order to identify those that need to be considered as the priorities for introduction of the other three phases of the cycle.

The example provided in this article illustrates in particular *phases (1)* and *(2)*. Much has been done in China by different national and international institutions to introduce energy supply optimization measures to increase the use of sustainable and cost-efficient renewable energy resources. This example illustrates that the complete cycle need *not* be carried out under the guidance or supervision of a single institution or a given initiative. Phases 3 and 4 are already being partially implemented by different institutions and initiatives within the country, not necessarily following the recommendations in phases 1 and 2 of this example. Special attention, however, needs be given to the fact that the cycle provides a framework for analysis of the different initiatives that are known in the country to optimize renewable energy supply systems. The ultimate objective of both the energy end-use and supply-side cycles is a strict and strategic monitoring of the energy matrices.

Parallel to the system highlighted in this example, there are other equally important sustainable energy supply systems that either have already been or would need to be considered in the same way as illustrated here. The ultimate objective would be the introduction of the largest number of structural changes possible, within energy supply systems, required to introduce the managerial and technical knowledge that would lead to increased use of sustainable (i.e., renewable) and cost-efficient energy resources.

3.5.1. Example 3. Renewable energy in China: the potential of biomass

The third example provided in this paper illustrates the use of the energy supply optimization cycle (Fig. 1-B) applied to an individual energy supply system.

In an internal study by UNIDO's Beijing Office, in 2005, to assess the potential for fuller use of biomass as an enhanced source of *commercial* energy in the country, it was concluded that, although further development was possible, the Chinese bio-energy industry would need to rely, essentially, on gains in productivity in agriculture and industry, rather than expanding agricultural production by exploiting new land. Since the required managerial and technical knowledge are already available in other parts of the world, the Chinese authorities could draw on experience and models from other countries, particularly Brazil and the United States, to increase productivity and generate commercially feasible bio-energy.

The assessment concluded, on a preliminary basis, that the bio-energy industry in China could generate some 27 million TCE annually, which would correspond to nearly 1per cent of the energy supply matrix of the country planned for 2020 (Table 3). Complementary policies, to be implemented in parallel with those proposed for the bio-energy industry, would be required in order to increase the probability of reaching the desired objective of 18 per cent of the energy supply matrix originating from renewable sources by 2020.

(1) Assessment of the status of energy supply systems in the country, with particular emphasis on renewable sources

As shown in Tables 2 and 3, China's energy supply for 2020 is projected to amount to some three billion TCE. The objective of the China National Energy Strategy and Policy-Renewable Energy Law is that at least 18 per cent of the primary energy sources (NDRC, 2003, APERC, 2005), or some 540 million TCE, should be renewable.

UNIDO estimates, which are broadly consistent with secondary information (ADB, 2006a, Li *et al*, 2001), show that, in 2002, some 0.5 per cent, or 6 million TCE, of the 120 million TCE supplied from renewable sources (Table 3) originated from those other than hydroelectric power. As illustrated in Fig. 6, the other sources were: (i) solar water heating systems (72 per cent); industry and farm biomass (10 per cent); geothermal (10 per cent); and grid-connected wind energy (8 per cent).

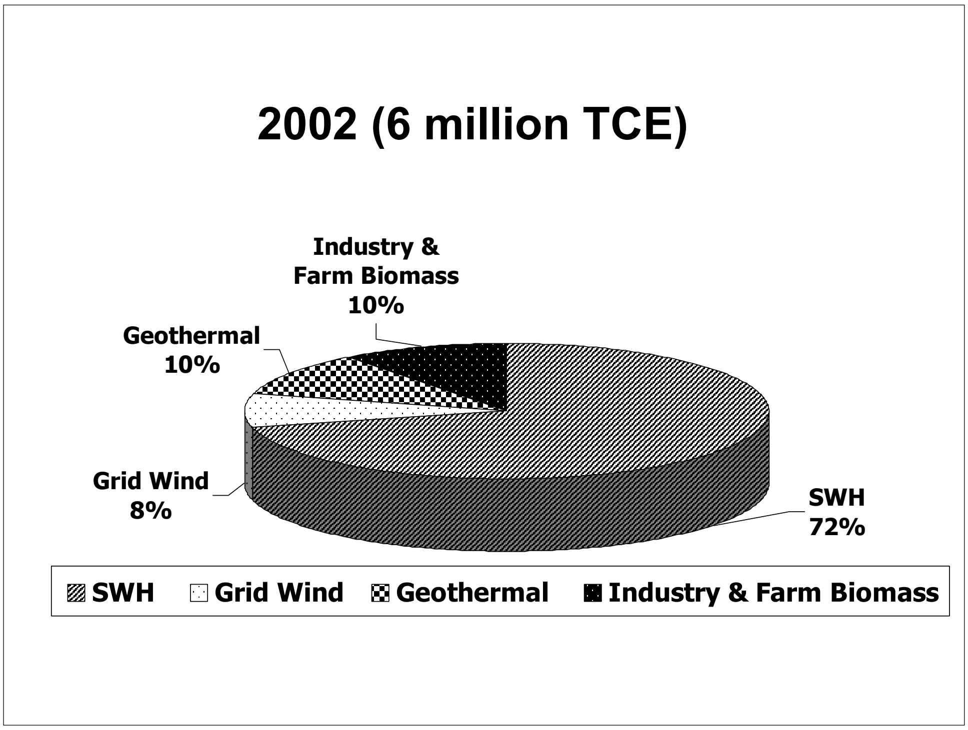

Fig. 6. China: structure of renewable energy supply other than hydroelectric power, 2002

To increase the contribution of renewable energy sources from 120 to 540 million TCE by 2020 is likely to be extremely challenging. Therefore, all potential alternatives, including, in particular, those using currently inefficient or under-utilized industrial and farm biomass, need to be considered.

The assessment has identified *five* specific opportunities: (1) increased use and efficient utilization of municipal solid wastes (MSW) as a source of biogas; (2) increased use and efficient utilization of agricultural residues by gasification; (3) increased agricultural yield and use for ethanol produced from corn, without ignoring diversification in the corn energy supply industry; (4) utilization of oil-seeds for generation of bio-diesel; and (5) increased yield and efficiency of the sugar-cane industry for ethanol production combined with enhancement of export of electricity from bagasse and increased yields of sugar-beet, as highlighted in Fig. 7.

(2) Assessment of managerial and technical knowledge required to optimize energy supply systems identified in phase (1), followed by implementation of an experimental programme for absorption and/or development of the required knowledge

There have been a number of studies and publications on production of agricultural and livestock products, including wastes and the corresponding potential for biomass energy supply in China. The data used in this example are essentially from the National Bureau of Statistics (NBS, 2004), Li *et al*, 2001, Department of Energy (DOE) at the Ministry of Agriculture (MOA, 1998) and UNIDO estimates.

Fig. 7 summarizes potential sources, with the corresponding amounts expressed in PJ. In the case of municipal solid wastes (MSW), the figure used is based on UNIDO's estimates of 2002, in line with project US/CPR/96/150, MSW Management Systems (UNIDO, 2005), of a resource of some 385 million tonnes annually. The figure is considerably higher than estimates released by the Ministry of Agriculture in 1998, which were for some 100 million tonnes annually. The other potential sources of expanded bio-energy—agricultural wastes, grains, oilseeds, sugar-beet and sugar cane—are all dependent on the very limited supply of arable land in China, which is, currently, some 130 million hectares. For bio-energy in China, availability of land is, therefore, an important limitation.

Of a total estimated biomass potential of more than 15,100 PJ annually, UNIDO has concluded from this preliminary assessment that the actual potential for supply of *commercial* energy is only some 3,600 PJ. Utilization of agricultural wastes such as animal wastes, rice husks, and straw for commercial thermal energy and electricity still faces many barriers, while the availability of oilseeds is also essentially limited to direct consumption, China being a net importer. In the last few years, use of rural *non-commercial* biomass energy has, in fact, decreased (Li *et all*, 2001). Of the total agricultural waste potential of 11,500 PJ, it is estimated that the actual use for rural non-commercial activities, through direct combustion for cooking and heating, is 5,600 PJ annually (Li *et all*, 2001). However, this non-commercial energy is typically used at very low efficiency (IEA 2004), since the fuel is free or low cost, and simple and inexpensive combustion devices are used. With the dispersed nature of this energy and the equipment to exploit it, progress will be slow in unlocking this potential.

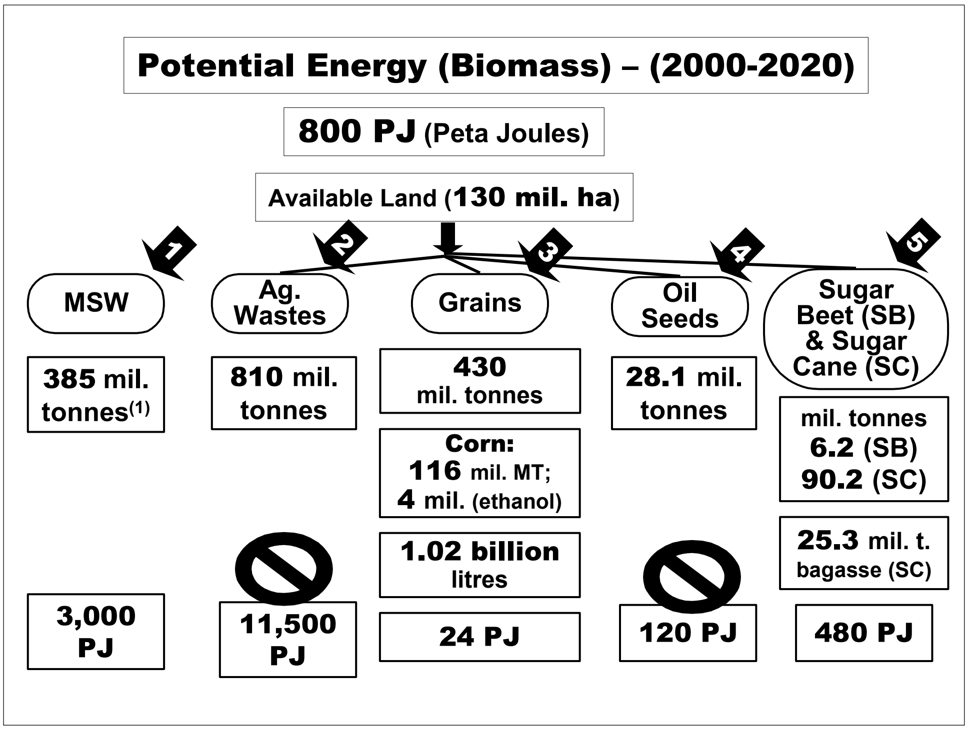

Fig. 7. China: potential sources and amounts of bio-energy estimated for 2020

The potential for enhanced commercial biomass energy supply by 2020 will, therefore, need to mainly rely on *three* other potential commercial energy sources that UNIDO has assessed can be utilized quickly: *MSW*, *grains*, particularly *corn*, and *sugar-cane/sugar-beet*.

In addition to development of its own technology in collecting and processing MSW, China has been cooperating with the international community to acquire knowledge, particularly from Europe. This includes activities in cooperation with UNIDO, through two sequential technology-transfer projects initiated in 1999 and completed in 2005 (UNIDO, 2005). Based on the current status of development of the MSW industry in the country, it is unlikely that the full potential of 3000 PJ annually can be reached by 2020. In fact, UNIDO estimates that not more than 15 per cent of the potential, equivalent to 450 PJ, would be able to be produced on a commercial basis from MSW.

China already has a corn ethanol industry where attempts to absorb and develop the requisite technology are underway. From an analysis of agricultural yields for production of corn and estimated output from the production of the four corn ethanol units installed in China[10], UNIDO has estimated that there is a potential 30-40 per cent efficiency gain compared with the leading corn ethanol country in the world, the United States. Therefore, it has been suggested that the model available there be carefully analysed and applied, to the extent possible, to the Chinese production structure.

China has a large sugar industry that has shown signs of systematic productivity growth within the last few years. Analysis of sugar-cane production in China, combined with a preliminary assessment of corresponding industrial outputs, indicates that there is a potential efficiency gain of as much as 30 per cent, compared with the world's leading country in this field, Brazil. Worldwide, the industry accounts for very considerable consumption of the energy generated on site, as it essentially incinerates the sugar cane bagasse in low temperature boilers to meet only site electrical and process steam loads (WADE, 2004). This holds true, as well, for China. Some 70 per cent of the total generating potential, 650 PJ annually, is estimated to be consumed on site. Therefore, the net generation of commercial energy would currently correspond to some 200 PJ annually[11].

Once the managerial and technical knowledge, which is partially available already in the country, is properly absorbed or further developed, MSW, corn ethanol and sugar cane bagasse/ethanol have an estimated potential for generating a net amount of 700 PJ of commercial energy annually. If combined with the manufacturing of the equivalent of 100 PJ annually of fuel ethanol in other producing countries, possibly through joint ventures, China could generate nearly 1 per cent of its commercial energy supply from farm and industry biomass by 2020, equivalent to 27 million TCE.

(3) Policy formulation phase to identify constraints on dissemination of knowledge absorbed and/or developed under phase (2), followed by design of the required scaling-up strategy

The Government has adopted several policies to accelerate absorption and development of knowledge that would allow establishment of a massive programme for production of bio-

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[10] According to UNIDO's assessment, there are *four* plants producing fuel ethanol from corn in China, with a total output of more than *1 billion litres annually*: one each in Henan and Jilin producing, individually, 300 million litres; one in Anhui producing 320 million litres; and one in Heilongjiang producing 100 million litres.

[11] However, with prices for surplus sugar cane bagasse co-generation-derived electricity exports of above US$ 0.04 per kWh, new, higher temperature-pressure boilers and steam turbines can be installed. With reductions in sugar processing energy use, they could provide an extra 9,390 GWh annually of electricity supply, or 0.72 per cent of China's electricity supply in 2001 (WADE, 2004 and ADB, 2006b) from the same bagasse supply.

energy within the country, with particular emphasis on liquid bio-fuels, by expansion of the corn ethanol industry through increasing the volume processed from four to some 20 million tonnes of corn annually. However, to increase from the current 0.6 to 27 million TCE generated from biomass in less than 20 years seems a daunting, if not impossible, task.

The required policies, in addition to absorption, in the shortest possible period of time, of the experiences of Brazil and the United States in the field of bio-fuels, would have to include a comprehensive set of measures:

- acceleration of programme for dissemination of knowledge already developed in the country and partially absorbed from Europe for management of municipal solid wastes, with particular emphasis on recovery operations for generation of biogas for commercial purposes
- intensification of commercial use of agricultural residues for generation of biogas
- production of bio-diesel through joint-ventures from outside China
- increasing yields of sugar beet to release a larger portion of the sugar cane production for energy generation

(4) Policy implementation phase for structural changes, at system level, required to introduce energy supply optimization measures to increase the use of sustainable (i.e., renewable) and cost-efficient energy resources on national scale

Parallel to the policy formulation phase in some areas of knowledge in the renewable energy industry, the Government is already implementing policies in others. As in other parts of the world, in China, not all policies have been implemented immediately after being designed and, within different areas of knowledge, are not being designed and subsequently implemented. However, considering the magnitude of the challenges being faced to reach 18 per cent of the Chinese energy matrix originating from renewable sources in 15 years, there are some general principles that need to be considered when implementing different policies for dissemination of the required managerial and technical knowledge for different sources of renewable energy. The first is related to the stage and speed of technological development and the second with availability of financial resources at enterprise level to introduce the knowledge acquired or developed during *phase (2)* of the cycle.

The remaining sources of renewable energy for China to reach the goal of 18 per cent of the national energy supply matrix have been identified by UNIDO as: hydroelectric power (11.5 per cent); solar water heating systems (SWH) and photovoltaic (PV) panels (4.5 per cent); grid wind power (0.8 per cent); and geothermal energy (0.2 per cent). As discussed throughout the text, these are approximate figures.

Based on the level and speed of development of technology in various parts of the world for all potential sources described in this example, it is unlikely that China can reach its objective without fully utilising all potential sources without delay. China cannot afford to wait for the rest of the world to develop the technology required for large-scale commercial utilization of renewable energy and, then, acquire and fully implement these technologies by 2020. Either alone or through strategic alliances with other leading institutions in the world, the Chinese research institutions and corresponding authorities would need to take the *lead* in their development if the 18 per cent target is to be met.

An observation similar to the one made in Example 1 can be made here regarding financing as the other essential mechanism to assure adoption of renewable energy by the major groups of end-users, particularly among small- and medium-scale manufacturers. Based on analysis of Chinese TVEs (TVE, 2000 and TVE, 2005), restructuring of the banking system to facilitate access to financial resources from SMEs, in parallel to the corresponding technological development, seems essential. This would also have an impact on all potential sources of renewable energy.

With application of the *energy supply optimization cycle* (Fig. 1-B) to an individual energy supply system, it is possible to draw some revealing conclusions.

To ensure an adequate supply of commercial energy it is essential that China carries out, on an ongoing basis, a strategic monitoring of the energy matrix.

The Renewable Energy Law of 2005 represents a major step in this direction. In line with Stage 2 of the China National Energy Strategy and Policy, to be implemented with the support of the Law, by 2020 at least 18 per cent of primary energy sources (NDRC, 2003, APERC, 2005) need to be renewable. This corresponds to an installed capacity of 90-100 million kW and supply of some 400-500 million TCE. Although feasible, it seems impossible to reach this target without taking the worldwide lead in technology development of renewable energy as well as restructuring the banking system to accelerate introduction of renewable energy technologies within small- and medium-scale enterprises, particularly in the manufacturing sector.

Although the potential for bio-energy in China is considerable, the amount of commercial bio-energy is currently limited, particularly from agricultural wastes. Because agricultural wastes are dispersed and seasonal, reliable and affordable appropriate small-scale technologies need to be developed, electrical energy fed into the grid or thermal energy produced able to obtain suitable export prices and expertise and finance made available at rural level. With China's limited amount of arable land, the country's large-scale bio-energy industry needs to rely, at the current stage, essentially on gains of productivity in both the agricultural and industrial sectors. To increase their productivity, China needs to draw on successful models and knowledge from other countries.

4. Conclusions

UNIDO's main concern is sustainable industrial development, with energy as one of the key inputs, for healthy industrial and, ultimately, economic development. For UNIDO, energy supply and use are perceived as part of overall industrial development, rather than as ends in themselves. Therefore, although fundamental, the assessment of the energy status of UNIDO Member States is considered only as one group of variables in a broader assessment of the perspectives for sustainable industrial development.

The next 30-40 years will have to be a global transition period to more sustainable energy supply and demand patterns. This demands pursuing two major courses: a considerable decrease in energy intensity, particularly in activities linked to industrial production and a major increase in the contribution of renewable energy to limit use of fossil fuels and corresponding emissions of GHG and local pollution. In line with these, national policies need to be oriented towards a strict and strategic monitoring of energy matrices, with a focus on radical improvement in the efficiency of energy systems, particularly in manufacturing, in key developing economies, combined with sustainable and cost-efficient use of national energy resources.

Thorough assessments of likely industrial trends and corresponding indications of energy supply and use throughout this transition phase are necessary to achieve both objectives. A number of national and international institutions are involved in this. As a component, UNIDO has adopted a model approach on how to work with current and future energy supply and use as well as the corresponding implications in terms of policy. UNIDO proposes that an energy supply and use model analysis, which is dynamic and consisting of three phases, be applied for identifying future needs and corresponding policy requirements to reduce energy intensity while promoting cost-efficient use of renewable energy sources.

The three sequential phases can be applied to any economy: (i) analysis, at aggregate level, of current and future energy matrices; (ii) analysis of perspectives for decreasing energy intensity of the most inefficient systems or industrial sectors; and (iii) analysis of perspectives for increasing supply and cost-efficiency of sustainable (i.e., renewable) energy sources. To overcome the traditional difficulties of collecting high quality and consistent data in developing countries, the analyses are, for phases (ii) and (iii), a sum of individual assessments based mostly on expert analysis of the most critical energy systems and industrial sectors for phase (ii) and of sustainable energy sources for phase (iii). This requires dynamism and openness in the modelling exercise.

The analysis of current and future national energy matrices is based on data at aggregate level. The data derives from primary and secondary information of current and future energy supply and demand. Some data is also based on well-known techniques, as in the case of the MARKAL family of models and decomposition analysis, among others. In addition to technical data derived in general from these two techniques, the exercise takes into consideration government objectives, particularly when working with the future energy matrix. Therefore, in the analysis of national energy matrices, there is a political, or non-technical, component whose feasibility needs to be tested against more technical data.

For analysis of the perspectives for decreasing the energy intensity of the most inefficient systems or industrial sectors, the framework energy use optimization cycle is used. The cycle is applied to individual energy systems or industrial sectors and consists of four phases: (1) diagnosis, or assessment, of the status of energy use in the most important energy-utilization systems or industrial sectors in the country; (2) assessment of managerial and technical knowledge required to optimize use of energy by systems or industrial sectors identified in phase (1), followed by implementation of an experimental programme for absorption and/or development of the required knowledge; (3) policy formulation to identify constraints on dissemination of knowledge absorbed and/or developed under phase (2), followed by design of the required scale-up strategy; and (4) policy implementation, which brings in structural changes, at system or sectoral level, to introduce end-use optimization measures needed to decrease, on national scale, the energy intensity of the most inefficient energy systems or industrial sectors.

For analysis of perspectives for increasing the supply and cost-efficiency of sustainable energy sources, the framework energy supply optimization cycle, similar to the one applied in the case of the energy use optimization cycle, is used. This is, likewise, applied to individual energy supply systems and consists, similarly, of four phases: (1) diagnosis or assessment of the status of energy supply systems in the country, with particular emphasis on renewable energy sources; (2) assessment of managerial and technical knowledge to optimize energy supply from systems identified in phase (1), followed by implementation of an experimental programme for absorption and/or development of the required knowledge; (3) policy formulation to identify constraints on dissemination of knowledge absorbed and/or developed under phase (2), followed by design of the required scale-up strategy; and (4) policy implementation, which carries out structural changes, at system level, required to introduce energy supply optimization measures for increasing the supply of sustainable (i.e., renewable) and cost-efficient energy resources.

The combination of these three phases, which is proposed to be carried out continuously and involving the sum of the analysis of individual systems in the country, leads to a general assessment of the energy status of an economy. As an illustration of the model approach, the case of China is analysed, followed by a discussion of some of the policies required to introduce structural changes to move towards the extremely challenging national objectives of improved energy efficiency and enhanced renewable energy supply planned for 2020.

Three specific examples are given. Two illustrate the energy use optimization cycle and one the energy supply optimization cycle. The three examples illustrate that continuous application of the cycles to either individual energy use systems, industrial sectors or individual energy supply systems can lead to a reasonable indication of the likelihood of moving successfully from current to future matrices, facilitating its monitoring by the corresponding national authorities. In addition, it is shown that the complete cycle does not need to be carried out under the guidance or control of a single institution or initiative. The example of application of the energy supply cycle illustrates that it provides a framework for analysis of different initiatives available in the country to optimize renewable energy supply systems. The same can be said of the energy use cycle, which illustrates the openness and flexibility of the analytical methodology used.

The main reason for working with macro and aggregated scenarios in UNIDO's assessments is that a prior detailed energy supply and use modelling exercise in the case of large and complex developing economies would lead to years of delay. Furthermore, there would be a questionable degree of confidence in the results, including the difficulty of obtaining consistent energy supply and demand data and keeping up with the rapidly developing economic structure and energy systems. Consequently, it would be much more difficult, for UNIDO, to provide accurate and timely policy advice in the absence of such reliable, detailed and up-to-date energy supply and use figures to the majority of its Member States on issues where energy is likely to be a constraint for their industrial and overall economic development. It is believed that the model analysis described in this paper, after being reviewed within the technical community dealing specifically with analysis of energy systems, can be upgraded and applied when assessing prospects for sustainable industrial development of assisted countries, as an attempt to overcome, at least partially, the prevalent problem of the limited amount and quality of energy supply, energy end-use and technology data.

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References

ADB, 2006a. Country Report and Overview of Renewable Energy, Energy Efficiency and Technologies for Reducing GHG Emissions in China, TA 5972 PREGA Project, Asian Development Bank, Manila. (http://www.adb.org/Clean- Energy/documents/PRC-Country-Report.pdf).

ADB, 2006b. Clean Energy Applications in Asia and the Pacific: Promotion of Renewable Energy, Energy Efficiency and Greenhouse Gas Abatement Project Results, TA 5972, Discussion Draft, Asian Development Bank, Manila. (http://www.adb.org/Clean-Energy/documents/PREGA-book.pdf).

APERC, 2004. Energy in China: Transportation, Electric Power and Fuel Markets 2004. Asia Pacific Energy Research Centre. Institute of Energy Economics. Tokyo, Japan. http://www.apec.org/apec/publications/all_publications/energy_working_group.html).

APERC, 2005. APEC Energy Overview, Asia Pacific Energy Research Centre. Institute of Energy Economics. Tokyo, Japan. (http://www.apec.org/apec/publications/all_publications/energy_working_group.html).

Chen, W. and Wu, Z., 2001. Study of China's Future Sustainable Energy Development Strategy with Application of MARKAL Model. Journal of Tsinghua University (Science and Technology), Beijing.

DeLaquil, P., Chen, W. and Larson, E., 2003. Modeling China's Energy Future. Energy for Sustainable Development. Volume VII. No 4., December 2003. (http://www.ieiglobal.org/ESDv7n4/modeling.pdf).

Doty F. D., 2005. Practical Clean Energy for Transportation, Doty Scientific, Columbia, SC, USA, March 2005. (http://evworld.com/view.cfm?section=article&storyid=660).

EUEEP, 2004. China End Use Energy Efficiency Project, Final ProDoc, United Nations Development Programme - Global Environment Facility.

WB, 1994. ESMAP, China – Energy efficiency and pollution control in township and village enterprises (TVE) industry: Vol. 1. World Bank, 1994. http://wwwwds.worldbank.org/external/default/main?pagePK=64193027&piPK=64187937&theSitePK=523679&menuPK=64187510&searchMenuPK=64187283&theSitePK=523679&entityID=000009265_3961007220226&searchMenuPK=64187283&theSitePK=523679).

Gielen, D. and Simbolotti, G., 2005. Prospects for Hydrogen and Fuel Cells. International Energy Agency, Paris. (http://www.etsap.org/reports/markal-irg.pdf).

Goldstein, G. and Greening, L., 2001. Energy Planning and the Development of Carbon Mitigation Strategies: Using the MARKAL Family of Models. The Partners in the International Energy Agency – Energy Technology Systems Analysis Programme. International Resources Group. (http://www.etsap.org/reports/markal-irg.pdf).

International Energy Agency, 2002. World Energy Outlook, OECD, Paris. (http://www.iea.org/Textbase/nppdf/free/2000/weo2002.pdf).

International Energy Agency, 2005. World Energy Outlook, OECD, Paris.

International Energy Agency, 2006. Energy Technology Systems Analysis Programme, International Energy Agency (www.etsap.org).

Li, J.; Xing, Z.; DeLaquil, P., and Larson, E., 2001. Biomass Energy in China and Its Potential Energy for Sustainable Development. Energy for Sustainable Development. Volume V. No 4., December 2001. (http://www.princeton.edu/~energy/publications/pdf/2001/Li_01_ESD_China_biomass_energy.pdf).

Miao, H., Li, R. and Ping, H., 2001. End Use Energy Efficiency Programme. United Nations Development Programme. (http://www.undp.org/energy/prodocs/rbap/chinaenduse.htm).

Li, J., Bai, J., and Overend, R., 1998. MOA/DOE Project Expert Team (MOA/DOE), Assessment of Biomass Resource Availability in China, China Environmental Science Press, Beijing, 1998. (http://www.nrel.gov/international/china/pdfs/assessment_of_biomass_resource_availability_in_china.pdf).

NBS, 2004. China Statistical Yearbook, National Bureau of Statistics, China Statistics Press.

NBS, 2005. China Statistical Yearbook, National Bureau of Statistics, China Statistics Press.

NDRC, 2004. China Medium and Long Term Energy Conservation Plan. National Development and Reform Commission. Peoples Republic of China. Beijing. (http://www.beconchina.org/energy_saving.htm).

NDRC, 2002. China Energy Statistical Yearbook 2000-2002. Department of Industry and Transport Statistics, National Bureau of Statistics, Energy Bureau, National Development and Reform Commission. Peoples Republic of China. Beijing. China Statistics Press.

NDRC, 2003. China National Energy Strategy and Policy 2020 - Chapter VII: Renewable Energy Strategy and Policy. National Development and Reform Commission. Peoples Republic of China. Beijing. (http://www.efchina.org/documents/8_Renewable_energy.pdf).

Peters, J. and Nadel, S., 2005. China Motor Systems Energy Conservation Programme, Second Process Evaluation Report, FI/CPR/00/122, United Nations Industrial Development Organization, Vienna, Austria.

Pool, F. and Wen G., 2005. Phase II Mid-Term Evaluation, Energy Conservation and GHG Emissions Reduction in Chinese Township and Village Enterprises, United Nations Industrial Development Organization and United Nations Development Programme, Beijing.

TVE, 2000. Energy Conservation and GHG Emissions Reduction in Chinese TVEs – Phase II. Project number: CPR/99/G31/A/1G/37. Global Environment Facility and United Nations Industrial Development Organization. (www.gefweb.org/Documents/Project_Proposals_for_Endorsem/China_TVE.doc).

UNFCC, 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. United Nations Framework Convention on Climate Change. (http://unfccc.int/resource/docs/convkp/kpeng.pdf.United Nations).

UNIDO, 2000. Project FI/CPR/00/122 – China Motor System Energy Conservation Programme. United Nations Industrial Development Organization. (http://www.unido.org/doc/4263).

UNIDO, 2005. Projects US/CPR/04/150, US/CPR/96/150 – Municipal Solid Waste Management Systems, Technical Standards, Treatment and Disposal, Capacity-Building (China's Agenda 21). United Nations Industrial Development Organization. (http://www.unido.org/data/Project/Project.cfm?c=7467).

WADE, 2004. Bagasse Cogeneration – Global Review and Potential, World Alliance for Distributed Energy. (http://www.localpower.org/documents_pub/report_bagasse_cogeneration.pdf).

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Telephone: (+43-1) 26026-0, Fax: (+43-1) 26926-69
E-mail: unido@unido.org, Internet: http://www.unido.org