Energy in the 21st Century : From Resource to Environmental and Lifestyle Constraints

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After more than 15 years of energy global studies it appears that resource limits and volatile prices are no longer the most important determinants of future energy systems. Instead, improved social and environmental compatibility of energy systems is now in the forefront. In view of increasing concerns about energy-related sources of global change, the paper discusses transitional strategies and policy measures towards sustainable energy development. They encompass a wide range of techno-economic adjustments such as efficiency improvements, shift to low and carbon-free fuels and enhancement of carbon sinks on one hand, and social-behavioral responses such as changes in private and leisure energy use on the other.

Energie du 21ème siècle - Des ressources aux contraintes sur l'environnement et sur le mode de vie.

Après plus de dix ans d'études globales sur l'énergie il semble que les limites des ressources et que les prix ne sont plus les facteurs déterminants dans les schémas énergétiques de demain. Au contraire la compatibilité sociale et environnementale accrue des systèmes énergétiques est maintenant sur le devant de la scène. A la vue de l'intérêt accru envers les sources de changement global reliées à l'énergie, l'article explore les stratégies de transition et les mesures politiques pour un développement énergétique. Elles englobent un grand nombre d'ajustements technico-économiques et une amélioration des puits de carbone d'un côté et des réponses socio-comportementales telles que des changements dans l'utilisation de l'énergie privée et de loisir.

Energie im 21. Jahrrhundert : Beeinträchtigung der Umwelt und des Lebensils.

Nach mehr als 15 Jahren globaler Energiestudien scheinen begrenzte Resourcen und steigende Preise nicht mehr die entscheidenden Faktoren zukünftiger Energieszenarien zu spielen. Stattdessen stehen Sozial- und Umweltverträglichkeit der Energiesysteme im Vordergrund. In Anbetracht steigender Beunruhigung bezüglich weltweiter Veränderungen, die im Zusammenhang mit der eingesetzten Energie stehen, untersucht der vorliegende Artikel Übergangsstrategien und politische Maßnahmen hinsichtlich einer erträglichen Energieentwicklung. Sie beinhalten eine große Spannweite techno-ökonomischer Maßnahmen, wie z.B. Verbesserung von Wirkungsgraden, Übergang zu Brennstoffen mit geringem oder keinem Kohlenstoffgehalt sowie Beschleunigung von Kohlenstoffsenken auf der einen Seite und Änderung des sozialan Verhaltens, wie Umstellungen beim privaten Energieverbrauch während der Freizeit auf der anderen Seite.

Energía en el siglo 21 : de las restricciones de recursos a las restricciones ambientales y del estilo de vida.

Después de más de 15 ános de estudios globales de energía parece ser que las limitaciones de recorsas y los precios volátiles vio son ya los determinantes más importantes de los patrones energéticos futuros. En cambio el méjoramiento de la compatibilidad social y ambiental de los istemas energéticos es ahora el objectivo principal. En vista de las preocupaciones crecientes con respecto a recursos energéticos de cambio global, el artículo explora las estrategias transicionales y las medidas políticas para un desarrollo energético sostenido. Estas cubren un amplio rango de ajustes técnico-económicos tales como mejoras en la eficiencia, adopción de combustibles sin carbón o a bajo contenido y el méjoramiento de pozos de carbón por un lado y de respuestas del comportamiento social (cambios en el consumo de energía para usos privados o para placer) por el otro.

Energia no Século XXI: Das Reservas ao Meio Ambiente e às Limitações do Estilo de Vida.

Após mais de quinze anos de estudos globais de energia, parece que os limites das reservas e os preços voláteis deixaram de ser os determinantes mais importantes para os futuros padrões energéticos. Ao contrário, é a melhoria da compatibilidade social e com o meio ambiente que está agora em evidência. Com a finalidade de aumentar o interesse pelas fontes relacionadas à energia de troca global, o trabalho explora as estratégias de transição e as medidas políticas visando um desenvolvimento de energia sustentável a longo termo. Estas englobam um largo espectro de ajustes técnico-econômicos como a melhoria da eficiência, a mudança para combustíveis sem ou com baixo teor de carbono e a valorização das reservas de carbono de um lado, e do outro as respostas do comportamento social como as mudanças dos hábitos de utilização pessoal de energia, tanto na vida privada como no lazer.

mots-clés ● keywords

énergie ● environnement ● compatibilités sociales et environnementales des systèmes énergétiques ● modes de vie

energy efficiency ● environment ● social and environmental compatibility of energy systems ● lifestyles

1. Introduction

Traditional concerns about the physical and economic availability of adequate energy resources have given way to increasing awareness of global and long-term environmental impacts of energy production, conversion and end-use. Today, the predominant question is whether it would actually be possible to continue consuming fossil energy at current or even higher rates in the future. What is new is that instead of energy resources the risks of adverse global change could constitute the ultimate limit of future development in energy systems. Thus, the ultimate global resource could be the environment rather than recoverable energy reserves and resources.

Since the onset of the Industrial Revolution, humanity has consumed fossil energy amounting to some 200 Gt carbon and current annual emissions from fossil energy use amount to almost 6 Gt carbon (C). Compared to this, our remaining carbon wealth accumulated over geological times is orders of magnitudes higher. Currently identified, economically recoverable energy reserves amount to 540 Gt C (Table 1). Additional 3026 Gt C are contained in resources (i.e., identified quantities, whose economic recoverability is uncertain at present) and further 5200 Gt C are contained in additional occurrences (quantities inferred by broad geological information but with their economic and technical potentials remaining largely speculative). Remaining fossil energy resources thus range between 3500 to 8700 Gt carbon, compared to a current atmospheric carbon loading of about 760 Gt. This clearly illustrates that already currently known fossil energy resources could be sufficiently large to raise atmospheric CO_2 concentrations by several factors.

	Coal	Oil	Gas	Total
1860-1987	114.9	58.2	24.5	197.6
1987	2.5	2.4	1.0	5.9
Reserves	391.6	92.1	58.5	542.2
Resources	2289	622	115	3026
Additional Occurences	>3500	>1000	>700	>5200

Fossil Energy Consumption, Reserves and Resources (Gt C)

Table 1 Accounting for historical, present and potential future carbon emissions from fossil fuel use in Gigatons carbon. Historical (1860-1987) and present (1987) carbon emissions from fossil fuel use by source and carbon content ; in identified, economically recoverable fossil fuel reserves ; resources (identified quantities with uncertain prospects of economic recoverability) ; and additional occurrences (additional quantities inferred from geological information but with speculative technical and economic potential). Compared to historical fossil fuel use, the remaining resources in the ground represent a (perhaps even far too large) "carbon wealth" which is more than a factor 10 greater than the total carbon pool in the atmosphere of around 760 Gt C (corresponding to a present CO_2 concentration of about 350 ppm).

In order to assess possible and likely future trends in the energy sector, Stanford University and IIASA have been jointly organizing since 1981 the International Energy Workshop (IEW) with the aim to compare energy projections made by different groups in the world and to analyze their differences. The median of global CO_2 emissions calculated from the IEW polls of global energy consumption or, in our interpretation, the current consensus view of the future, corresponds to an annual growth rate of one percent per year, i.e., to an increase from about 6 Gt today to some 9 Gt carbon by the year 2020, with a range between 8 to 10 Gt as shown in Figure 1. Although lower than the business-as-usual scenario of the Intergovernmental Panel on Climate Change (IPCC) for the same year, the IEW poll range gives rise to concerns as to how such a trend could be bent downwards, e.g., along the lines of the Low Emission and Accelerated Policy scenarios of the IPCC. All this suggests that - in the absence of appropriate countermeasures - global carbon emissions will rise, perhaps beyond environmentally acceptable levels.

GLOBAL ENERGY-RELATED CO_2 EMISSIONS

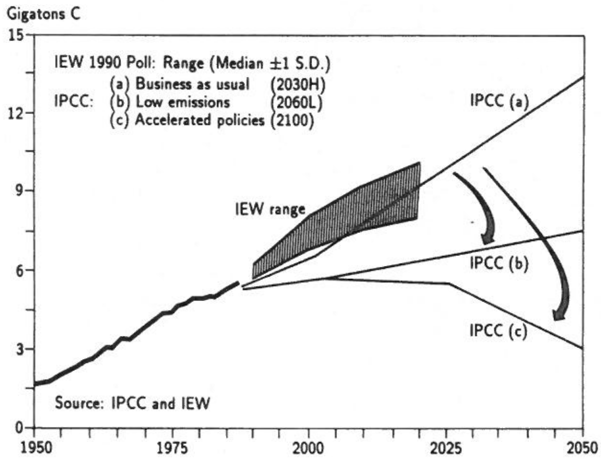

Fig.1 Historical and future global energy-related CO_2 emissions (Gigatons C). From 1950 to present emissions have increased on average at about two percent per year. Possible future global energy-related CO_2 emissions are indicated by the International Energy Workshop (IEW) poll-response range and by three Intergovernmental Panel on Climate Change (IPCC) scenarios. IEW is jointly organized by Stanford University and IIASA with the aim to compare energy projections made by different groups in the world and to analyze their differences.

Thus, perceptions about factors ultimately limiting future energy growth have changed, while the driving forces are still the same : population and economic growth. Some of the measures and strategies that seemed to be desirable in the past, however, appear to be invariant to this shift in perceptions. Efficiency improvements and conservation are instrumental in reducing both fossil fuel requirements and emissions. In addition, structural changes in the energy system towards new, environmentally compatible energy carriers and low or even zero emission technologies have been suggested as technological response strategies to the risks of global change.

2. IIASA Research on Energy-Environment Interactions

An IIASA study on Environmentally Compatible Energy Strategies develops an analytical framework to evaluate policy options and future global energy strategies directed at delaying or mitigating global change. In particular, the objective is to assess future potentials and rates of reducing energy and carbon intensities worldwide. Figure 2 shows historical improvements toward improving energy efficiency and decarbonization in a number of selected countries. The aim is to analyze future trajectories that would lead individual countries and the world as a whole further toward the origin of Figure 2. The purpose is to analyze global tradeoffs involved in ecology and climatic change, technology and economic development, social conditions and lifestyles, and international interactions as reflected in negotiations on how to distribute the burdens and benefits.

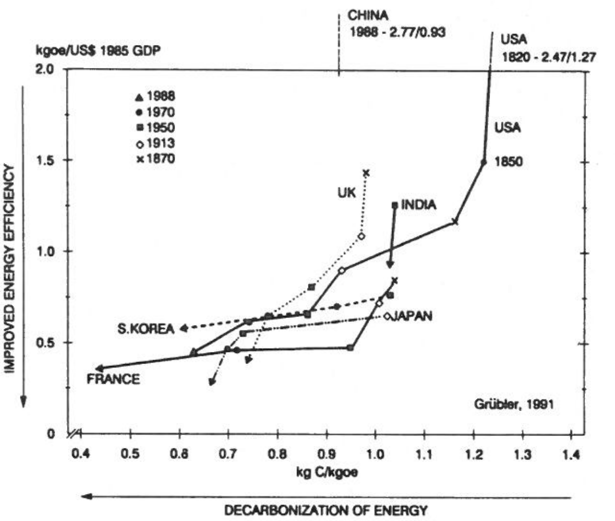

Fig. 2 Historical trends in energy (kgoe per 1000 $ GDP) and carbon intensity (kg C per kgoe) of various countries. Improved energy efficiency (lowering the energy intensity) and interfuel substitution (lowering the carbon intensity of energy use) are two important options for lowering overall carbon emissions. The graph shows the diverse policy mix and strategies followed in different countries over the time horizon considered. France appears to follow a decarbonization strategy, whereas Japan mostly an efficiency improvement strategy. All countries shown achieved improvements in both domains.

The project is developing a comprehensive assessment of a broad range of *options* (technologies, associated economic incentives and institutional frameworks for their implementation) that is needed for evaluating the global potential for stabilizing, ultimately reducing and perhaps even removing carbon dioxide and other greenhouse gases from the atmosphere. Such a system approach in assessing the contribution of individual technologies could lead to a better understanding of the aggregate potential in reducing emissions of greenhouse gases in the future. An important part of that work involves the development of an inventory (a data base) of technologies for reducing carbon dioxide emissions. This inventory provides information about technical characteristics of technologies, their cost structure and economics, and environmental profiles such as specific emissions. A special feature of this inventory is that it will also specify the applicability of mitigation technologies in different technological, economic or cultural settings, and will specify the time horizon of their availability and their forward and backward linkages to other enabling technologies in the energy system.

The second objective of IIASA's research is to identify constraints and boundary conditions of *strategies* for achieving environmentally compatible paths of economic and social development. The development strategies will outline different paths of techno-economic, socio-behavioral and institutional adjustments reflecting differing technological, economic and cultural characteristics of industrial market economies, transforming economies and developing countries. Figure 3 illustrates the high degree of heterogeneity in the world today with respect to the level of energy-related CO_2 emissions. It compares per capita CO_2 emission for different countries indicating varying characteristics of energy systems, structure of the economy and different social and cultural settings. For example, both the USA and the area of former GDR have the highest per capita CO_2 emissions in the world in excess of 5 t carbon per year but for fundamentally different reasons. At similar levels of affluence, some other West European countries and Japan emit much less carbon indicating that decarbonization and development are not mutually exclusive provided an appropriate policy mix is found. Also striking is the strong North-South division in energy related carbon emissions, which becomes even accentuated when considering the differences in historical contributions to atmospheric concentration increases.

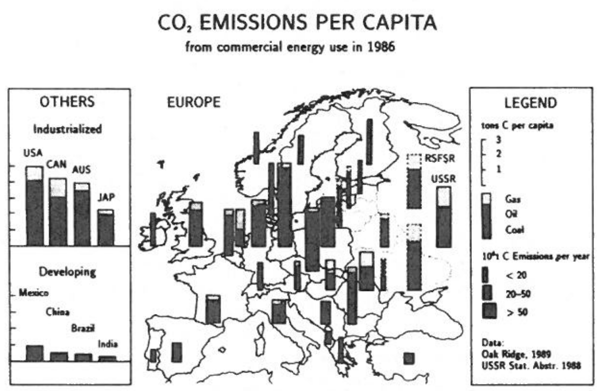

Fig. 3 Per capita CO_2 emissions from commercial energy use, by source and for selected countries (in tons carbon per year per capita). A graphical representation of per capita carbon emissions from energy use reveals extreme disparities and heterogeneity. These are the result of differences in degree of economic development, level and efficiency of energy consumption and the structure of the energy supply system (i.e., its carbon intensity). The figure illustrates vividly the significant North-South divide in energy related CO_2 emissions. Also noticeable are the high per capita emission levels in Eastern Europe, most of them stemming from coal use. Even in cases when per capita emissions are of similar magnitude, they are often so for entirely different reasons. For example, both the USA and the former GDR have per capita CO_2 emissions in excess of 5 tons carbon per year per capita. In the case of the USA this is due to high energy consumption and energy intensive lifestyles, like the high oil consumption for private transportation. In the former GDR it is due to a different level and structure of consumption and supply of energy, stressing the basic material production sector and a high share of brown coal in the energy balance.

3. Improving Energy Efficiency and Decarbonizing the Energy System

With respect to improved energy efficiency, a long-term perspective reveals that the frequently discussed decoupling of energy demand from economic growth is not necessarily confined to periods of high energy prices. The primary energy input per (constant) unit of GDP generated for all OECD countries taken together has fallen at an average rate of two percent per year since 1973. If we take 1960 as a base year, improvement in energy intensity amounts to an average rate of one percent per year. A similar analysis performed for the USA (including non-commercial energy consumption) since 1800 shows a comparable long-term improvement rate which raises the question to what extent historical efficiency improvement rates can be maintained in the future.

A detailed energy/exergy efficiency assessment of the OECD countries shows that the conversion from primary energy to final energy forms required by the consumer is about 70 percent. In contrast, the efficiency with which final energy forms are applied to provide useful energy forms and services is much lower, resulting in an overall conversion efficiency of not much more than 10 percent. In developing countries and reforming economies in Europe, the overall systems energy efficiency is even lower. The efficiency of the system is still lower if different quality characteristics of various energy carriers and delivered forms are taken into account. Figure 4 shows that the overall exergy (second law) efficiency in the OECD countries is at most a few percent compared with the theoretical maximum. This shows that there is large scope for more efficient energy use and in particular for improvement of end-use technologies. The inventory of mitigation measures and the technology data base being developed at IIASA are specifically designed to integrate current and possible future individual conversion, transport, distribution and end-use systems into energy (or exergy) chains giving whole bundles of technologies that define a particular reduction strategy.

The overall energy efficiency of the OECD countries would be nearly doubled by application of the most efficient technologies available today. The rates at which such efficiency improvements can be achieved are to a large extent dependent on the age distribution of the capital stock of our economies, rates of diffusion of new technologies and technology transfer. The long-term improvement in energy intensity of GDP was about one percent per year in the industrialized countries. However, this is a historical average over 200 years containing periods of more rapid improvement (2 to 3 percent per year), but also periods of stagnation and even reversals with increasing energy intensity as is the case today in a number of developing countries. Efficiency improvements have been faster in certain areas than in others. For example, over the past twenty years, aircraft manufacturers have managed to improve energy efficiency of commercial jet transports by 3 to 4 percent annually. In electricity generation, this improvement has been 2.5 to 3 percent per year over the period between 1930 and the early 1970s. These are about the upper boundary values to be expected in efficiency improvements in the medium term. With an improvement in the energy intensity of 3 percent per year, a dollar of GDP could be produced fifty years from now with only 20 percent of current energy requirements ; this figure would be lower in terms of carbon emissions if energy substitution is also taken into account.

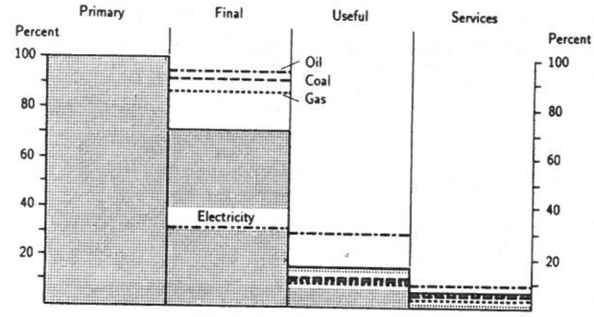

Fig. 4 Exergy balances for the OECD countries in 1986 (in percent of primary exergy). A second-law analysis of the exergetic efficiency of the exergy (and energy) system in the OECD countries, shows that while the efficiency in the provision of final exergy is already quite high, efficiencies at the end-use side, and in particular in the provision of services are low. The overall exergetic efficiency of the OECD countries is estimated to amount only to a few percent. Figures for the USSR and developing countries are probably even lower. This indicates the large theoretical potential for efficiency improvements of between a factor 20 to 100. Realization of this potential depends on the implementation of many technological options and organizational innovations. Their different tradeoffs, the cost and timing involved need detailed study.

While efficiency improvements are a fundamental measure for reducing carbon emissions especially in the near to medium term, in the long-run there is a clear need to shift to energy sources with low carbon content such as natural gas, and ultimately to those without carbon whatsoever, such as hydro, solar, and nuclear energy, and the sustainable use of biomass. Increased reliance on natural gas is a particular interesting transitional option, especially in combination with active CO_2 recovery (e.g., from steam reforming). Thus, both technological and economic structural change will be of fundamental importance for efficiency improvement and for lowering carbon emissions in order to achieve environmentally compatible pathways of socio-economic development.

4. Energy for Work or Pleasure ?

In industrialized countries today about two thirds of final energy demand are consumed outside the productive sphere (agriculture, industry and manufacturing) proper. Furthermore, energy use for private households, transportation and leisure activities is steadily increasing, illustrating a progressive shift from a producer to a consumer society also in energy and environmental terms. At the same time, it is precisely these end-use applications, where energy efficiency, especially in the conversion of final and useful energy to the ultimate services rendered to the consumers continues to be extremely low (Figure 4), indicating a large theoretical potential for lowering energy consumption and thus emission levels, whilest maintaining or even increasing the actual services rendered.

Whereas traditional energy models and policy instruments focusing on availability, quality and relative prices of competing energy carriers are useful in capturing the evolving patterns of energy use in the productive sector, for instance towards higher energy efficiency per unit of value added, new approaches are needed to analyze energy consumption patterns outside the industrial sector proper. This, because energy demand in these applications appears much less determined by traditional influencing variables and policy measures in the final energy market (like energy prices), but instead by (changing) social values and preferences, and behavioral and lifestyle variables. It is also these soft variables, which increasingly influence the efficiency by which energy is converted to the services required. For instance, whereas fuel efficiency of passenger cars have increased noticeably over the last two decades, these technological efficiency gains have been largely offset by increases in service demand (more km traveled by car), and lower usage efficiency (less passenger-km per vehicle-km driven).

For the analysis of the complex connective tissue linking individual, micro-economic decisions with observed macro-economic phenomena, new analytical approaches are needed. For instance, the use of time budget analysis appears to emerge as an important conceptual and empirical tool. Empirical research into actual activity patterns tries to derive a typology of social behavior from various combinations of human activities, as reflected in the time allocation of different people.

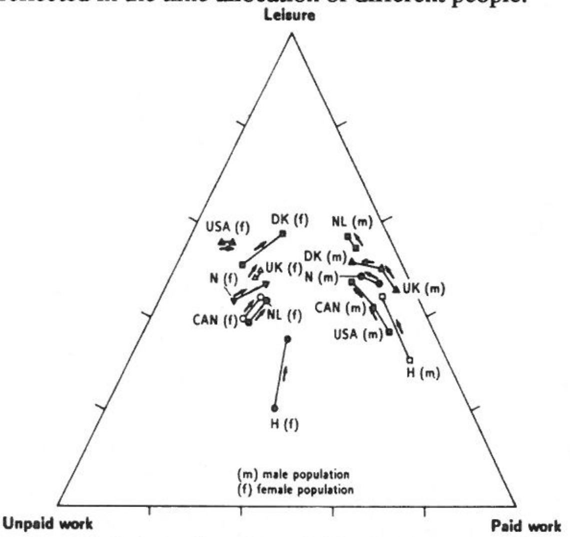

Fig. 5 Relative allocation of time budgets to different activities, male and female population of seven countries 1960s to 1980s [4]. Note in particular the international and gender convergence away from formal, contracted work to unpaid work (e.g., family care) and leisure activities. This transition from work to pleasure in activity patterns of people can be clearly discerned also in energy demand statistics. In industrialized countries today about two-thirds of final energy is consumed outside the productive sphere (i.e., industry) for services and leisure uses of energy.

Time is a convenient way to compare the valuation which people in different settings attach to various activities. As an example, time budget studies in developing countries show that people start attaching value to time only after they are allowed to join the formal economy. Indian women will spend uncounted hours gathering firewood only until they are allowed to put their time to more valuable use in the paid economy, at which point they use their income to purchase (more efficient) commercial fuel. International and intertemporal time-budget series facilitate understanding of the linkages between broad categories of social activity and associated energy use. The reported cross-cultural data on the increase of leisure time relative to paid work (for men) and to unpaid work (for women) confirm the trend towards increasing leisure time, even as women continue to enter the workforce (Figure 5). Whether such changes lead to further increases in energy use can then be inferred from the types of leisure activities selected.

Perhaps the most important lesson provided by time budget research is to acknowledge the complexity of criteria underlying consumer choices and preferences. Efficient use of capital and energy are important, but if indeed time is the ultimate scarce resource for consumers, policies to reorient technological solutions and consumer preferences in particularly energy intensive activities such as transportation (Figure 6) will have to go well beyond traditional intervention instruments, such as changes in the relative price structure of transport modes.

	Time* 10^9 hrs	Final Energy 10^9 kgoe	Density kgoe/hr
At Home*	835.5 *	236.6	0.28
At Work	291.1	660.0‡	2.27
Services	183.5	152.0	0.83
Travel #	107.6	279.0 #	2.59
Total	1417.7	1328.4	0.94
		10^9 kg C	kg C/hr
Carbon Emissions		1201.6	0.85

* Excluding sleep
‡ Including industry transportation, industrial energy use, agriculture, feedstocks
# Only passenger travel

Fig.6 Energy and carbon intensiveness of different activities for the US population. Excluding physiological time (i.e., time required for eating and sleeping) each US citizen consumes on average about one kg of oil equivalent energy per hour and emits roughly the same amount of carbon. Average energy related carbon emissions per capita per year in the US is in excess of 5000 kg per capita. The carbon intensiveness per unit time of transportation is particularly high.

An additional finding emerging from a variety of social science perspectives is the realization of the difficulty to understand the factors and conditions for ultimately lowering energy services demand. The persistent trends in direction of higher levels of affluence, increased leisure and ever higher levels of mobility have all led to substantial increases in energy services demand. That the actual primary energy demand in industrialized countries has not increased significantly over the last two decades is only due to technology stimulated efficiency improvements in the energy sector and economic restructuring in industry.

Thus, the key question remains how to affect the lifestyle and behavioral dimensions of energy demand in the North, eventually causing a trend reversal, and whether alternative development trajectories will emerge in developing countries assuring high levels of personal well-being with low energy consumption. In the future, as in the past, traditions, institutions, norms, and beliefs will constitute the framework within which specific lifestyles and habits will evolve. These need not necessarily be inconsistent with long-term environmental sustainability, but neither can they be expected to change rapidly enough to lead to a substantial decrease of energy services.

Therefore the fundamental problem facing most studies on energy and environment interactions is the discrepancy between the large theoretical potential for conservation and the lack of implementation by private consumers. Energy conservation and less energy and resource intensive lifestyles remain of paramount importance as one of the most effective measures in decreasing adverse environmental impacts of energy use. This is more so important because technological "fixes" such as efficiency improvements and economic structural changes may ultimately not be sufficient to encounter the risks of global change.

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