Indicator-Based Methodology to Analyse Progress Toward a Sustainable Energy System in a Country: Application to the Spanish Energy Context

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Abstract

The importance of energy to achieve better living conditions for mankind is an undisputable fact. Energy facilitates the provision of essential services, and it has a profound impact not only on the environment, but also on the economy and social conditions of people all around the world.

As a global reference frame, sustainable development is "the development that meets the needs of the people today without compromising the ability of future generations to meet their own needs". Energy sustainability, as a part of this global sustainability, has social, environmental and economical dimensions. Sustainable development needs a long-term perspective, and global strategies should be adopted to achieve this common objective, but then it is left to each country to adopt its own course of action.

This paper proposes an indicator-based methodology to analyse progress in terms of energy sustainability in a particular country. The indicator-based framework developed by the European Environmental Agency to the particular case of energy and environment in the European Union, has been extended to the case of energy production and consumption and its impacts on society, the environment and the economy. It has been also particularized for a specific country. The indicator-based methodology proposed in this paper divides the analysis of the entire energy cycle into five stages: Driving Forces, Pressures, State, Impacts and Responses. The methodology has been applied to the Spanish energy system, and the most important results are presented.

Keywords: Indicator-based methodology, energy sustainability, sustainable development, environment, society, economy, Driving Forces, Pressures, State, Impacts, Responses.

1. Introduction

It is beyond question that energy and the services it provides are essential for human development, that its availability contributes very positively to the progress of all nations world-wide and that it also highly contributes to the well-being of the people. Energy provides essential services for development, such as water, lighting or transport, and it also provides comfort, warmth and mobility, among a variety of other services that are increasingly demanded by all the population.

It is necessary to have a full vision of what development means. According to [1], "development is a comprehensive economic, social, cultural and political process, which aims at the constant improvement of the well-being of the entire population and of all individuals on the basis of their active, free and meaningful participation in development and in the fair distribution of benefits resulting there from". But development has to become sustainable, which means that it should "meet the needs of the people today without compromising the ability of future generations to meet their own needs", as it is defined in [2]. Sustainable development considers that development is possible and necessary; that it must become sustainable, lasting and viable in the long-term, and that sustainability must be social, economical and environmental.

Energy has a major function to perform, in terms of contributing to human development. Energy has deep relations with the three dimensions of sustainability: energy provides many social services and it strongly contributes to economic development, but its transformation and consumption may

also cause serious damage on the natural environment. Energy sustainability means having an energy production and consumption system that supports the human development in its social, environmental and economical dimensions.

Despite the fact that security and quality of supply are legitimate preoccupations of the inhabitants of a country, energy sustainability must be analysed from another perspective. The energy problem should not be considered from just a local and short-term horizon. A realistic and deep analysis of the energy model cannot ignore that 2,000 million people in the world have no-access to electricity and other advanced energy forms; it must consider the security of supply not only for the present generation, but also for the future ones, and it must be conscious of the impacts that energy production and consumption have on the environment, the society and the economy.

Considering this global and long-term perspective, many prestigious organizations world-wide have analysed the evolution of the world energy context, paying special attention to those aspects affecting sustainability. Opinions are overwhelmingly coincident about the lack of sustainability of our present energy model. For example, it is expressed in [3] that "Although there seem to be no physical limits to the world's energy supply for at least the next 50 years, today's energy system is unsustainable because of equity issues as well as environmental, economic, and geopolitical concerns that have implications far into the future". Three main aspects are on the basis of all sustainability problems affecting the world energy system nowadays:

- The availability of resources to meet the needs of future generations.
- The global impact that is caused by energy production and consumption.
- The enormous lack of equity in terms of accessibility to advanced energy forms, which are essential to human development in the XXI century.

As energy sustainability is a global problem affecting the entire world, a global response is necessary to face up to it. However, that global response must start from local actions that give way to ampler ones in the future. In fact, it is very relevant the role to play by any of the countries in the world in order to achieve energy sustainability world-wide: no progress will be done in the future without implying most of the countries of the world.

Considering all the relevant aspects presented before, an indicator-based methodology is exposed next, as a useful tool to evaluate if a particular country is undertaking the necessary efforts to improve the sustainability of our present energy model. As indicated above, local actions are essential to achieve in the future a global sustainable energy system world-wide.

2. Overview of the methodology

The methodology that is proposed in this paper to analyse the sustainability of an energy model is based on an extensive set of indicators. By means of them, the objective of the methodology is to describe the state and evolution of the energy model, in order to identify the existing threats and the progress that has been made here from a sustainable development perspective.

This methodology is based on the DPSIR framework established by the European Environmental Agency, see [4]. In this paper this framework is extended and particularized so that it becomes a useful tool for studying the energy system of a country from the global and long-term perspective that sustainable development requires. For that reason, the European Environmental Agency DPSIR framework is adapted in the following way:

- Energy sustainability, according to the definition of sustainable development, is considered in an ample sense. It covers not only environmental problems, but also social and economical concerns. Those three aspects are strongly interrelated, and all of them must be considered when studying sustainability from a global perspective.
- The energy system of a country is analysed from its contribution to global energy sustainability, but taking into account the particular circumstances of the country and how all of them affect to the energy system.

The most remarkable characteristic of the DPSIR framework that was established by the European Environmental Agency is that it reproduces the sequence in which the events take place in the

energy process. This characteristic has been maintained in the methodology presented in this paper, because it allows identifying clearly at what stages there is a sustainability problem, in order to adopt the necessary actions to correct it in the future.
The process of analysis of sustainability of the energy sector starts with the demands that it receives from society, in terms of products and services requiring energy (Driving Forces). Both energy production and consumption have several effects (Pressures) on the society, the environment and the economy. Pressures contribute to modify those three aspects, changing their conditions (State). The accumulative effect of all those Pressures on the society, the environment and the economy, produces a global impact on it (Impact). Finally, the different participants in this process react to those consequences adopting a set of actions (Responses) that may change the Driving Forces, Pressures, State and Impacts. The methodology presented in this paper allows to analyse the energy system sustainability of a country in a particular moment or to study its evolution throughout a period of time (a year, several years, etc.). The interrelations of the full energy process are shown in Figure 1.

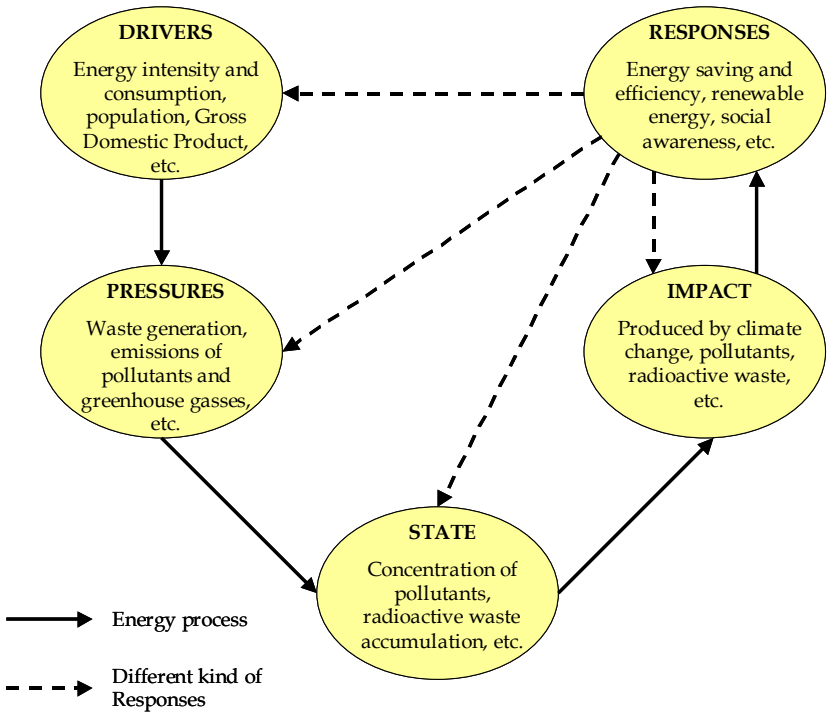

Figure 1. The full energy process: Driving Forces, Pressures, State, Impacts and Responses

Factors conditioning energy demand in a country and its implications are analysed in the four first steps. Regarding the last one (Responses), the actions that are adopted by all the participants in the process are examined. The methodology proposed here, links the causes of the problems with their impacts and society's responses to them. Each step of this energy process is detailed next and some examples are presented.

2.1. Driving Forces

Satisfying the requirements of society is the final objective of an energy system of a country. Electrical power stations, vehicles or heating systems are necessary because of the final consumers, who demand products and services that need energy. Therefore, the entire society is participating in the energy process and, of course, the entire society is responsible for its problems.

Driving Forces (Drivers) are the measures of the volume of demands that the energy sector receives from the society in terms of products and services requiring energy. Driving Forces are the causes underlying the problem, because they are the factors affecting energy use.
The main Driver is the final energy demand of the country, which aggregates the total consumption of final energy. But other indicators should be included among Driving Forces, because they are conditioning the volume of this final energy demand as, for example, energy efficiency of the equipment, industrial processes or transport. As a result, in addition to the total final energy demand, another interesting indicator is the final energy consumption by unit of Gross Domestic Product (final energy intensity). This ratio gives an interesting relation between final energy consumption and economic growth, to observe progresses on energy efficiency in a country. Moreover, this ratio, corrected by the particular economical circumstances of each one of the countries (Purchasing Power Parity, PPP), allows one to compare energy efficiency among different ones.
A similar study can be developed with primary energy consumption and its relations with final energy consumption or Gross Domestic Product, to obtain ratios of energy efficiency, etc.
Other indicators such as population, temperatures, etc. are also the causes underlying energy consumption, so they must be also included as Driving Forces.
The application of the proposed methodology to the particular case of Spain will be exposed in detail ahead. Here, the Driving Forces indicators considered for this particular analysis are presented next:

- Energy consumption: primary and final energy consumption.
- Primary and final energy intensity: energy efficiency.
- Gross Domestic Product: rate of variation and economic structure.
- Population and homes.
- Urban and interurban mobility: passenger and goods transport.
- Energy prices.
- Local temperature and rainfall.

2.2. Pressures

Energy production and consumption place considerable pressures not only on the environment, but also on society and the economy. Environmental pressures are easier to quantify that social or economical ones. However, these ones should not be omitted, according to the influence they have to reach sustainability.
The Pressures of the Driving Forces on the environment, society and economy (Pressures) are the measures of the effects of the Driving Forces on the natural environment, on the social setting and on the economical scene, for the transitory considered scope.
Greenhouse gas emissions, waste resulting from energy production and consumption or emissions of pollutants are examples of Pressures on the environment. However, the problem exceeds the environmental aspect and affects the socioeconomic context. Thus, for example, production of radioactive waste, that is an environmental Pressure, also constitutes an economical Pressure because of the high costs of management and storage of this type of waste. Similarly, for example, greenhouse gas emissions are produced by refineries are environmental Pressures, but there is also a social Pressure on them, because of the accidents that may occur.
The Pressures are directly related to the Driving Forces, because they are direct consequences of them. The Pressure placed on the environment, society or economy by any activity using energy depends on:

- Driver: the volume of activity that generates demand for an energy-related service (e.g. Gross Domestic Product, industrial value added, demand for road freight delivery or passenger transportation, etc.).
- Energy intensity: the amount of energy required per unit of Driver.

- Pressure intensity: the level of the Pressure per unit of energy use. In the Spanish case, The Pressure indicators that have been considered, are:
- Greenhouse gas emissions by energy uses.
- Pollutant emissions by energy uses.
- Production of radioactive waste.
- Accidents as a result of energy uses.

2.3. State

As shown, the different phases of the energy production and consumption process place Pressures on the society, the environment and the economy.

The State of the society, the environment and the economy (State) is the set of measures that represent the conditions characterizing the social, environmental and economical context, for the transitory considered scope.

The State is very relevant in the energy process. For example, in the particular case of an environmental State, concentration of pollutants is essential to estimate the impacts that Pressures may have. The State determines if the Pressure placed is leading to surpluses of tolerable levels or if it not. Other indicators affecting environmental State, for example, are the accumulation of radioactive waste or the fossil resources availability in the planet.

Universal access to electricity and other advanced energy forms, as a State indicator, is included on the social State of the world. In the same way, energy security of supply is a characteristic of the social State, but it also indicates the situation of the economical State, because of the implications that energy security of supply has on energy prices, both locally and globally.

For the analysis of the Spanish energy context, the considered State indicators, are:

- Greenhouse gas concentration in the atmosphere.
- Pollutants concentration in the atmosphere.
- Accumulation of radioactive waste.
- Fossil fuels resources and its duration.
- Energy security of supply: installed capacity and energy dependency.
- World-wide accessibility to electricity and other advanced energy forms.

2.4. Impact

Global effects occur as a direct consequence of the two previous steps (Pressures and State), that have been caused in the origin by Driving Forces. As a consequence of the many local Pressures in different points of the planet and a specific situation of the social, environmental and economical State, a larger effect that may affect the world may occur.

The global impacts on the society, environment and economy (Impacts) because of the Drivers, Pressures and State, are the measures characterizing all the consequences on the social setting, the natural environment and economical scene, produced by those global effects.

Climate change, i.e., the rise of the global temperature in the world, is a clear example of the environmental Impact. This Impact is caused by the combination of several local Pressures (local greenhouse gas emissions) and a specific environmental State (greenhouse gas concentration in the atmosphere) and it implies many Impacts. The change in the way of life of people living near to the sea in developing countries, to whom an increase on the sea level as a consequence of the global temperature rise will affect seriously, is an example of social Impact. But it also implies economical Impacts because of the high cost of the measures that will be necessary to adopt, in order to reduce its consequences.

According to [5], global Impacts occurring in the future as a consequence of higher level of temperatures in the planet will be: increasing of the sea level, regression of the polar caps and changes in the polar ecosystem, changes in forests distribution, acceleration of the rate of

disappearance of species, variations in precipitations, diminution of the global agrarian yield, changes in water resources and greater probability of transmission of diseases.
For the analysis of the Spanish case, Impact indicators that have been considered, are:

- Climate change and their impacts.
- Impact of the atmospheric pollution.
- Impact of the radioactive waste.

2.5. Responses

Finally, to reduce the Drivers and Pressures on the environment, society or economy, or to mitigate their Impact on the State, the agents participating in the energy process have to adopt diverse actions.
The Responses against this global Impact by the different agents participating in the energy process (Responses) are the measures taken by any of them to limit, reduce or mitigate the Impacts caused by Driving Forces, Pressures and State, with the objective of modifying the interrelations of the energy process in order to achieve a more sustainable energy system.
Diverse types of measures can be adopted by the different participants:

- From the energy supply side: performances of the energy providers, for intermediate uses or for final uses of energy.
- From the energy demand side: performances of the final energy users and the services and products that use this energy.
- From the institutions: their performance in regulatory matters, such as policy measures to mitigate the Impacts, to reduce the Pressures or to contain the Drivers.

For the particular case of Spain, the Responses indicators that have been considered, are:

- Regulatory issues.
- Energy saving and energy efficiency.
- Reduction of pollutant emissions.
- Renewable energy.
- Research, development and innovation on energy.
- Education and environmental awareness of the population.
- Universal access to advanced energy forms.

To sum up, the five steps of the energy process have many links among them. Thus, Pressures are direct consequences of Driving Forces, where it is necessary to consider two basic types of influences:

- The larger the Driving force, the larger the Pressure.
- The larger the energy consumption of the Driving force per unit of it, the larger the Pressure that is produced.

The connection between Pressures and Impacts usually depends on the social, environmental and economical State. Finally, Responses can be very varied and they can affect to each one of the previous stages of this interrelated process.
This suggests a set of options that are meant to reducing the Pressures associated with the use of energy (energy production and consumption):

- Reduce the Driver by adopting alternative social or economical practices (e.g. a modal switch from private to public transport).
- Reduce the linkage between the Driver and the use of energy (i.e. the energy intensity) through more efficient energy use and less energy-intensive processes.
- Reduce the Pressure generated by the use of energy (i.e. the pressure intensity), for example by:
    - Less dependence on the more polluting fuels through the development of alternative energy sources.
    - Deployment of advanced conversion and end-use technologies that are less polluting.

Responses of the participants in this process should be analysed under a global reference frame, according to sustainable development definition. Social, environmental and economical issues should be considered when thinking about Responses and a necessary long-term perspective should be adopted to face up to sustainability problems.

3. Application to the Spanish energy context

The methodology proposed in this paper has been applied to the Spanish case. The evolution of the energy system up to 2004 has been studied, see [6]. The main characteristics of the Spanish energy context are summarized next.

3.1. Energy supply and energy dependency

- The Spanish economy has grown in the last years well beyond the average rate of the European Union (EU-15). In 2003 the rate of growth of the Gross Domestic Product was about 2.4%, in contrast to the average value of 0.7% of the European Union. In accordance with economic growth, primary energy demand (136 Mtep in 2003) increased by 2.5% in the same year, a similar value to the average of the last five years.
- Oil (50.3%), followed at a large distance by natural gas (15.8%), coal (15.2%) and nuclear energy (11.9%) are the most significant primary energies, followed by hydro (2.5%, including mini power plants) and other renewable sources (altogether 4.3%; biomass 2.9%, wind energy 0.8%, urban solid waste 0.2%, biogas 0.2%, biofuels, 0.1%, solar thermal 0.03%, geothermal 0.01% and solar photovoltaic 0.002%). Gas consumption is growing quickly, replacing oil, while renewable energies are growing too.
- Energy dependency in Spain has grown from 66% in 1990 to 77% in 2000 and 78% in 2003, whereas this percentage is about 50% in the European Union (EU-15).
- It is foreseeable that, in the future, national coal will lose participation in the primary energy supply.
- Practically 100% of oil consumed in Spain is imported. The origin is diversified.
- According to the present trend, natural gas is identified as the major source of change in the medium term. Spain depends strongly on North Africa (two third parts of the consumption comes from Algeria and Libya). Infrastructure to allow supply of liquefied natural gas is presently being built.
- Nuclear energy provides more than 10% of primary energy demand and about 25% of electricity generation. In the third decade of this century the totality of the nuclear power plants will have exceeded 40 years of life. The electoral commitment of the party at the government, about closing these power plants, requires an ample debate on the power model for the medium and long-term.
- Spain is still far from reaching 12% of renewable energy contribution to the primary energy demand in 2010 (less than 7% today). This objective, assumed by the Member States of the European Union, seems difficult to attain in most of them. Making of renewable energies a pillar of the future power model needs a significant technological and economical effort, and an ample dialogue is also required.

3.2. Energy consumption and energy intensity

- Primary energy consumption per capita in Spain, at about 3.2 tep/person, is higher than the world average, 1.65 tep/person, but near half of the European Union (EU-15) average, 6.5 tep/person. A gradual approach from the Spanish consumption per capita to the European one has been observed during the last years, although some existing causes justify the difference, as the climatology. Electricity consumption per capita in Spain is about 5,480 kWh/person (2001 data).

- The ratio between the rate of growth of the primary energy demand and the final energy demand is about 0.85, showing an improvement in the efficiency of conversion. The average ratio is 0.5 in the European Union (EU-15).
- Primary energy intensity (Purchasing Power Parity, PPP) is 237 tep/M$ in Spain, a similar value to the average of the European Union (EU-15). However, primary energy intensity in Spain grows permanently (accumulated 4.7% from 1990), whereas in the European Union (EU-15) primary energy intensity is being reduced in average value (accumulated 9.6% from 1990). A similar phenomenon is observed with Spanish final energy intensity (152 tep/M$).
- By sectors, the greater contribution to the consumption corresponds to industry, about 38%, which is higher than in the European Union (EU-15). The industrial sector has experimented a reduction of the energy intensity, because of technological improvements and the reduction of most energy-intensive activities.
- The greater growth of the final energy consumption corresponds to the transport sector (with 36% of the total consumption, also larger than in the European Union – EU-15), because of the great increase of the mobility in Spain. The energy intensity of this sector has increased more than 30% in the last years. About 99% of energy consumption of the transport sector is covered with oil derivatives.
- The domestic and tertiary sector weight 26%, less than in the European Union (EU-15). Improvements in the equipment at the domestic and tertiary sectors has been developed during the last years.
- It does not seem to exist a clear consciousness in the Spanish society about energy saving and energy efficiency. Low energy prices (which have diminished in real terms on the last years) have strongly contributed to it.

4. Conclusions

A methodology to analyse the evolution and situation of the energy sector of a country, in terms of sustainability, has been presented in this paper. This methodology has been applied within the Spanish energy context, by studying the situation of the energy system at the present time and its evolution during the last years. The main conclusions of this analysis are as follows:

- Changing the current unsustainable trend, in order to move towards a sustainable energy model in Spain, will demand remarkable efforts, according to the information on partial experiences in other countries.
- The insufficiency of resources devoted to finding solutions to this problem, and the absence of a national in-depth debate on this subject, indicate that the seriousness of the problem is not even perceived by the Spanish society.
- Promotion mechanisms for electricity generation with renewable energy sources have had uneven results. There has been a fast development of wind energy for electricity generation, in contrast to the remaining technologies, which have stumbled against technological, economical or administrative barriers.
- There is an ample margin to obtain an additional reduction on energy consumed by unit of Gross Domestic Product. Nevertheless, a shift of paradigm is necessary to move from energy wastefulness to energy saving and efficiency. In addition, in Spain this shift of paradigm implies adopting a culture that is based on energy saving and efficiency. This culture does not exist today.
- Spain is among the world leaders in Research & Development for wind and solar photovoltaic technologies. But, in general, the Spanish effort in Research and Development is too weak to contribute to addressing the problems of the increasing energy intensity and dependency.
- A drastic shift of paradigm is needed for the transport sector. The Spanish society must evolve towards more sustainable forms of transportation.

- Spain is far from meeting the objective of 0.7% of Gross Domestic Product for Official Development Assistance (ODA). Universal access to electricity and other advanced energy forms, as well as other related forms of cooperation with the world's poor does not appear to be a high-priority subject at this moment, according to Spanish financial contribution to it.
- There is also much to improve regarding public education and awareness on these energy issues. The serious existing problems in the present energy model are mostly ignored by the population, so that Responses to these problems are not strong enough.

Data show clearly how the strong economic development of Spain during the last decades (and particularly, during the last years) has been accompanied by a growth of the energy demand in its diverse forms. That does not imply, nevertheless, that economic growth in Spain should necessarily imply a greater energy demand. Implications on the society, the environment and the economy must be questioned. In conclusion, the Spanish energy model suffers from many problems of sustainability: first, on its security of supply and dependency, but also on its environmental impact.

It is essential to face all these challenges to be able to make the transit of the present unsustainable energy model towards a sustainable one. In addition, this change of direction has to take place as soon as possible, according to [7]. The trends that have been observed during the last years indicate that the more the time passes, the larger is the deviation from the sustainability path. In a sustainable energy model, energy prices would be foreseeably more expensive (according to the complete costs of the energy provision). The great question is how to evolve in time to a sustainable energy model, maintaining the economical and social development of recent years.

A broad debate is now necessary in Spain on the ways to bringing economic development into line with an acceptable environmental impact and with universal access to advanced energy forms. This may not be an unachievable objective, but this has to be proved.

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