

The Role of Nuclear Energy in Sustainable Development

Julio Vergara¹ and Rodrigo Escobar¹

¹Escuela de Ingeniería, Pontificia Universidad Católica de Chile, Santiago, Chile
jvergara@ing.puc.cl

ABSTRACT: An exploration of the status and potential of nuclear energy amongst other energy sources and technologies is presented, within the context of sustainable development as defined by the United Nations 1987 Brundtland's Commission. Sustainable energy forms, which are based on enduring resources that may be converted with minimum environmental offence as well as delivered at reasonable costs, needs to be enhanced. Most current energy technologies and resources fail in this concept. One of the most challenging issues in today's World is the development of new policies, culture and technologies to arrest or mitigate the consequences of climate change, accelerated by anthropogenic interference in the atmosphere. Nuclear power can contribute to sustainable development, provided that more competitive concepts become available, and that these are utilized with responsibility. Technologies under current development may allow this energy source to deliver energy for use in the transportation, power, and other sectors.

Keywords: Energy policy, sustainable energy, nuclear energy, nuclear hydrogen.

1. INTRODUCTION

Sustainable development (SD) was defined in 1987 by the World Commission on Environment and Development (WCED) -the Brundtland Commission- created by the United Nations General Assembly to address concerns about environment and natural resources degradation, and their effects in socioeconomic development.

WCED defined SD as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Extensive literature on SD has developed since then, generally dividing it into social, economic and environmental areas that ought to evolve balanced as shown in Fig. 1. There is no mystery that these are misaligned at different levels, globally, regionally and locally. The definition has set a general guide of the requirements to achieve SD, and created a framework to deal with strains

between social and economic development with the need of environmental protection.

SD has emphasized the relevance of economic development to satisfy the needs of society, as well as the primary role of nature as both a source of water, food, materials and energy resources and a repository of such resources once wasted. Other authors extend this concept to all living species and their interdependency with human society, while others criticize the human interference in a living planet.

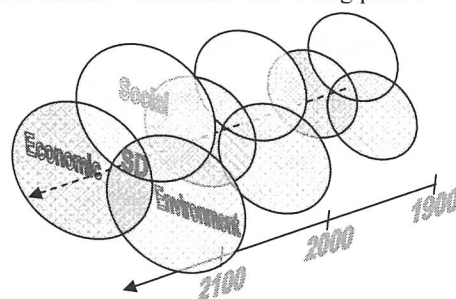


Figure 1: Sustainable development areas

Many environmental assessment reports have been published since then, confirming the early concerns of the WCED. Perhaps the most severe threat to modern society is the risk of abrupt climate change due to the unbalance of greenhouse gases (GHG) in the atmosphere. Gases such as water vapour, carbon dioxide, methane and nitrous oxide absorb long-wave radiation emitted from the Earth's surface and re-emit this energy, modifying the planet's thermal balance. GHG emissions are mostly linked to fossil energy production and use, which supports the economic development. It is hard to argue with the claim that it is a challenging situation for international security.

Climate change refers to a long-term alteration of climate, whether due to natural variability (orbit induced, rotation precession, volcanism, solar activity, etc.), or as a result of human activity (energy use, land-use, livestock industry, wastes, etc.). Today's consensus is that anthropogenic warming has had a mayor influence on many physical and biological natural systems synthesized in three major first cycle effects: temperature increase, precipitation changes and sea level rise, for which the Intergovernmental Panel on Climate Change (IPCC), in its Fourth Assessment Report (FAR), has projected ranges and distributions based on scenarios, climate models and uncertainties. These effects are in turn promoting changes in several aspects of nature and life, such as those in Fig. 2. Depending on the complex natural response and further human behaviour, the climate change may either continue to augment, or to arrest and even shift into an inverse cycle.

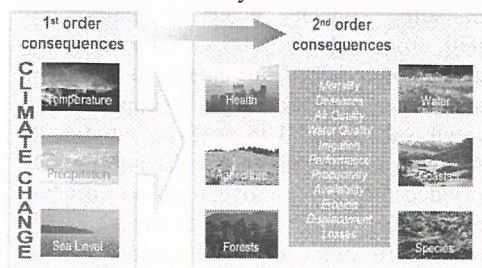


Figure 2: Climate change interrelations

The latter effect may result of thermohaline current (THC) momentum changes due to continued glacier retreat and ice melt in critical zones of the system.

The consequences for human society are broad in direction and intensity, a mix of mitigation and adaptation actions, the latter depending on the degree of vulnerability, that vary from continent to continent and country to country. What is mostly agreed today is that there would be a few winners and many losers with effects in several social and economic aspects of humanity.

Nuclear power has been controversial in SD meetings. Some consider that it is incompatible with SD principles, while others judge it legitimate, leaving decisions to countries depending on their needs and constraints. The authors consider that, for the time being, it is an option of low environmental impact, while at the same time key questions remain: why renewables, whose primary source is nuclear energy, are considered valid options?, and why biofuels, whose source is solar heat, are considered to be fundamentally better than fossil fuels in general?. All energy forms find a link to nuclear processes: most renewable energy flows are either forms of solar energy, or are derived from geothermal heat, itself a product of nuclear decay in the Earth's core.

2. ENERGY ISSUES

Society faces issues related to energy harvesting, conversion, use, and waste. We summarize the most important of them:

2.1 Energy Demand

Rising levels of GHG emissions resulting from energy harvesting and use are a major variable in the sustainability problem; however, the main drivers of energy demand are population and economic growth, particularly in developing countries.

2.2 Global Population

Several research groups project global population trends: United Nations, World

Bank and the International Institute for Applied Systems Analysis (IIASA). The world population is about 6.5 billion, with declining growth rate due to socio-economic changes and fertility drop in most countries. Current studies, after downward revisions, project a global population of 9 billion by 2050, with a slight decline after that.

Nevertheless, the projected population increase between now and 2050 is about 2.5 billion people, which will occur almost entirely in developing countries that aspire to reach the economic standards of developed nations, therefore pressing for substantial increases in energy demand.

2.3 Economic Development

Energy availability is a requirement for continued economic development. Primary energy is converted into heat, light and traction, all basic to support production in modern society. Although energy it is not a good by itself, it is a mean for prosperity, and essential to achieving the goals of SD.

Energy systems are critical for urban life and industrialization, allowing growth in an integrated wealth system of nearly 40 trillion dollars, 80% of which is produced by the Organization for Economic Cooperation and Development (OECD) with less than 20% of global population. Of the world's primary supply of 460 EJ, one half is used by the OECD, reflecting service oriented economies and energy efficient devices.

2.4 Energy Use

Economic activities foresee increased global energy and power demand. Vehicles allow flexibility to meet transportation needs and leisure. Manufacturing firms have for long shifted to cleaner fuels and electricity along with modern machines and tools. Service firms and residences today rely on increasing electricity inputs for space comfort, computers, and other office gadgets and appliances. Most demographic projections anticipate industrialization and urbanization, which will cause electricity demand to grow at faster rates than primary

energy trends. Similar projections anticipate more transportation fuel consumption.

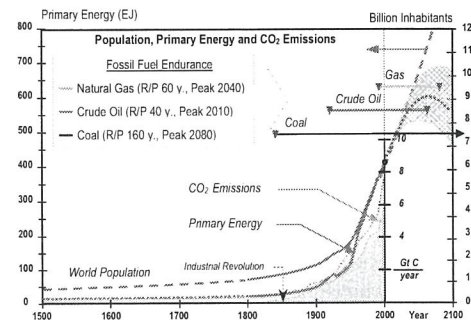


Figure 3: Population, primary energy and CO₂ emissions

Current energy use relies heavily on fossil fuels, the main source of GHG emissions. Such fuels are flexible, and the industry built an intertwined logistic system around them; however, with little care to the environment. For the International Energy Agency (IEA), such reliance will remain in the near and mid-term. About 80% of the current primary energy demand is based on fossil fuels. Longer term projections may be found in the Special Report on Emissions Scenarios (SRES) of the IPCC, which consider 40 scenarios within 4 families, up to the year 2100. For the SRES as a whole, median primary energy use triples by 2100. SRES predicts faster growth in developing regions and enhanced power use.

2.5 Electricity Use

In the IEA reference scenario, world electricity demand will grow at 2.4%/year. To meet such expansion, the global power generating capacity needs to double by 2030, from today's 3600 GWe. Electricity carries about 1/5 of the energy to the final user; however, this figure is expected to grow to about 1/4 in such period due to the suitability of this energy carrier for SD, provided that prime movers run on suitable technologies and clean resources. Such growth will strain industrial output to cope with not only the demand gap but also the

replacement of ageing units. About 5 TW of new power capacity will be needed within the first quarter of the century, or the equivalent of about 200 GW per year.

The Human Development Index (HDI), a measure of overall wealth, correlates well with the per capita electricity consumption. Figure 4 plots HDI against electricity use in regions and countries.

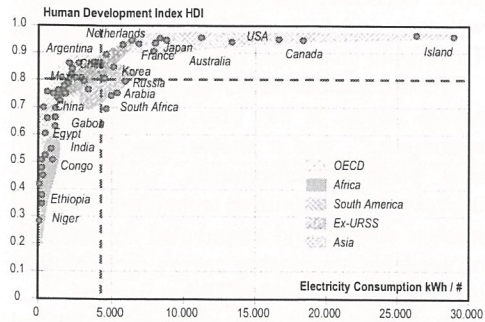


Figure 4: HDI and electricity consumption

2.6 Energy Emissions

While energy technologies emit different wastes, GHG are those that require the most attention. Today’s annual CO₂ emissions to the atmosphere from fossil fuel are 7.5 GtC. Energy related gases account for 65% of the total, as shown in Fig. 5, and non energy emissions (land-use change, agriculture, and waste) represent the rest or the equivalent of another 4 GtC/year [1].

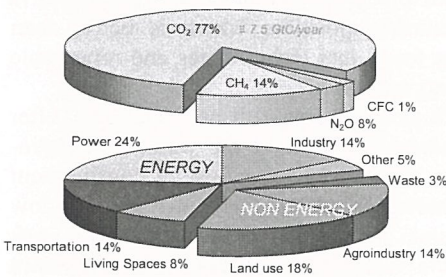


Figure 5: GHG emissions and sources

Figure 6 show the SRES CO₂ projections compared to the historical values. Such trend implies a temperature range increase from 2 to 6 °C, which demands the adoption of policies and technologies.

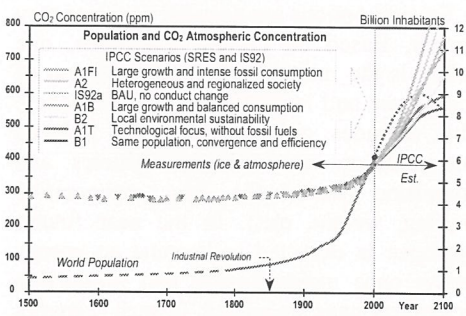


Figure 6: Atmospheric CO₂ concentration

3. SUSTAINABLE ENERGIES

In order to reduce the impact of energy utilization in the climate system, energy technologies need changes, and new ones are required. For the purpose of this paper, Sustainable Energy technologies are those aligned to the concept of SD. This means: a) systems based on very long-term availability of energy resources; b) those in which energy is converted with the least environmental impact during its lifecycle, and c) those which deliver at reasonable cost for the benefit of users, and maximum energy coverage. The latter is very often ignored. Energy is a means for SD and billions of people have limited or no access to it.

4. POLICY OPTIONS

The base chart of Figure 5 indicates an option to stabilize GHG emissions through sustainable energies. Pacala and Socolow [2] proposed the concept of “stabilization wedges”, derived to reduce GHG emissions from a projected business-as-usual (BAU) scenario. Each wedge represents a set of technologies and resources. No single set will solve the problem on its own. The solution is an array of slices of different size, based on global, regional and national factors, opportunities and technologies.

Starting at the non-energy branch of the GHG sources, several actions can be adopted including reforestation, soil improvement, livestock reduction and waste management.

Several options are possible at the energy branch. Based on current emissions, one policy is the rationalization or reduction of energy use and improved energy efficiency. This includes city planning for reduced transportation and efficient vehicles and propulsion systems (i.e. drag, regenerative braking, weight, etc.). In the near future, hydrogen is expected to become an energy carrier once major storage and production technology gaps are solved. In such scenario, transportation may reduce overall emissions. Fuels may also come from coal synfuels.

Energy efficiency also includes efficient lighting and appliances in buildings, with active-passive systems (i.e. geo-exchange, double windows, insulation, HVAC, etc.).

Another policy implies some changes in current power production technologies and practices. The power production system relies mainly in base load coal plants (40%), which are the most intense CO₂ emitters. This is followed by natural gas (20%), a milder GHG emitter. Immediate policy options appear from this resource mix, considering that electricity is a clean carrier that will enhance its contribution. One requirement is improved power cycles (i.e. shift to super critical steam plants, use of combined and regenerative cycles, etc.). Another alternative is to substitute coal in baseload power with gas, nuclear power, hydro power and other renewables. New coal (and synfuel) plants are expected to incorporate CO₂ capture devices along with sequestration policies and technologies.

Nuclear power and hydro power each stand for about 16% of power generation. Since these options do not emit CO₂, their share should increase. However, hydro may emit methane at rates depending on dam location and hydrology. Renewable energy technologies are also suitable, since these do not directly emit GHG. These options account for a small fraction of the power generation mix due to their diluted energy source, intermittency and generation costs, and may fit best in off-grid power supply.

5. NUCLEAR ENERGY AND POWER

Nuclear power use began in 1955 with submarine propulsion and later with small power plants. Build up of increasing nuclear power plants occurred in the 70's motivated by the oil crisis. Anticipated to offer abundant and cheap power supply, it slowed down in the USA and Europe due to oil price decrease, the association to nuclear weapons and two major nuclear accidents, Three Mile Island and Chernobyl.

Today, nuclear power faces a scenario of robust return. It has been called "nuclear renaissance", and it shows more than 130 new plant announcements, supported in improved and simplified technologies, better nuclear culture and augmented by the lack of available sustainable energy technologies to moderate increasing GHG emissions.

Is nuclear power a sustainable energy form? First, there are more uranium resources than fossil fuels. The industry is beginning to reconsider the use of thermal reactors for fast reactors, which amplifies the available resource by an order of magnitude. Nuclear power generation does not emit GHG, although some fuel cycle activities, mainly uranium enrichment, do it in low quantities. Nuclear power generation costs are low, which allows for providing electricity at reasonably low prices. These issues place nuclear power generation in a sustainable position, which is better than what fossil fuel technologies and renewable energy can offer.

Nuclear externalities are different. After reprocessing, most of the waste is a radioactive solid that require lasting confinement technologies, although for a relatively low volume. Nuclear accidents are low risk events with current technologies, far from the scale of Chernobyl. Nuclear weapons proliferation risks face resistance with intrinsic measures that limit access to nuclear materials. Such utilization needs a very strong political will, rather than reactor and fuel technologies.

Table I compares the sustainability of nuclear power with two nuclear fuel cycles (NFC) and two coal plants, with and without carbon capture and sequestration (CCS).

Table I: Nuclear power and coal power as Sustainable energy options.

	Coal (Open)	Coal (CCS)	Nuclear (Open NFC)	Nuclear (Closed NFC)
Endurance				
Reserves (years)	230	190	160	1000*
Environment				
GHG (tCO ₂ /GWh)	800	100	20	30
Ext. cost (¢/kWh)	2	1	0.2	0.3
Economics				
Investment (\$/kW)	1400	2100	1800	2200
Generation (¢/kWh)	5.0	7.5	4.5	5.0

New designs include evolutionary fixes to further improve economics, proliferation resistance and safety. Some systems include architectural arrays and modules to shorten construction times and reduce capital costs. Most innovative reactors are small (less than 300 MWe) and some are medium size units (300–700 MWe). These are suitable for the SD of developing countries while large units (700–1600 MWe) are appropriate for large grids in developed countries. Figure 6 shows one PWR loop (Pressurized Water Reactor). About 270 units of the total 443 reactors and all propulsion plants are of this class. The left-hand side is a new array: four 300 MWe integral PWRs instead of a 1200 MWe unit.

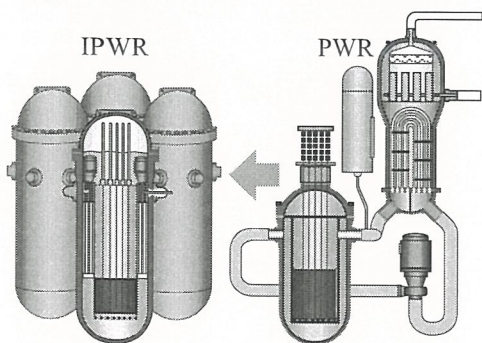


Figure 7: Integral PWR arrangement

Advanced features include: passive safety, standardization of components to allow for economies of scale, better safety codes, new

construction procedures, more enduring nuclear fuel, reliable components, higher plant efficiency, systems simplification, etc. Another example of advanced system is the HTGR (High Temperature Gas Reactor) of Figure 8. Based on a different fuel, this concept has one crucial feature. If all the coolant leaks out, the core heats up to about 1600°C without melting down, allowing less active safety systems. This reactor has the ability to produce hydrogen for future vehicles in a coupled thermochemical cycle.

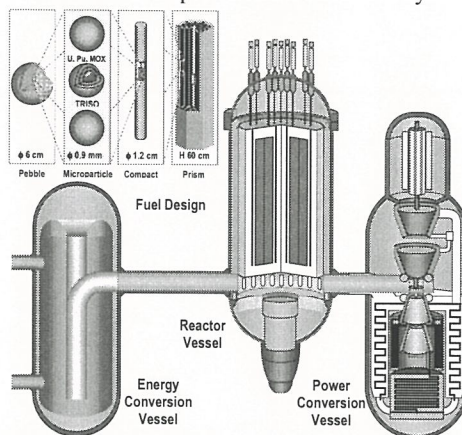


Figure 8: HTGR with nuclear fuel form

6. CONCLUSION

Nuclear power has a clear role in SD. Beyond electricity, it has a chance to drive cargo ships and provide hydrogen for zero emission vehicles. Nuclear technology can rapidly penetrate to provide energy for the economic growth of society to differ abrupt climate change. Externalities are known and confined through technology.

REFERENCES

- [1] K. Baumert et al., Navigating the Numbers, World Resources Institute, 2005.
- [2] S. Pacala and R. Socolow, Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies, Science **13**, 968-972, 2004.