Sixth International Symposium on Energy & Technology Innovation Forum,
Puerto Rico Energy Center - LACCEI, February 2014

Study of the Effect of Efficiency in Energy Resource Longevity under the Scope of Sustainability

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Introduction

- During the last decades, countries all over the world have being joining efforts to reduce their usage of fossil fuels with the objective of decreasing the planet's CO_2 contamination and limit their oil energy dependence, which are two important aspects that need to be taken care off if our society is committed in achieving sustainability

- Worldwide the path to sustainability has been approached two folded:
  - First, technologies that allow the usage of renewable energy resources have been developed and implemented
  - Also, governments have been introducing, promoting and in some cases enforcing policies and standards that improve energy efficiency of equipments, designs, structures or even procedures that normally require the consumption of high amounts of energy

Introduction

- Mainly, the strategy to improve efficiency has been applied by sectors
- For instance, in transportation (whose energy usage in 2008 was around 28% of the US total energy consumption) fuel-efficiency standards, labelling and fiscal incentives for new efficient vehicles have been applied in countries such as Canada, the European Member States and United States
- It is important to point out that the IEA estimates that energy efficiency improvements are anticipated in every end-use sector, with global liquids intensity (liquid fuels consumed per dollar of GDP) declining by 2.6 percent per year from 2010 to 2040
- Additionally, it is expected that continued efficiency improvements moderate the growth of energy demand over time, as relatively inefficient equipment is replaced with newer, more efficient stock (IEA, 2013).

Introduction

- The previous projections although positive need to be further studied because it is not clear if the rebound effect has been taken into consideration while doing this estimations

- This effect also known as Javon's paradox is extremely important as it suggests that an improvement in efficiency may result in more demand of a resource, in this case energy, which at the end may produce a negative impact in the worldwide energy consumption

- In this article we present the reasoning behind our motivation to include the rebound effect as key aspect in calculating the factual level of contribution that efficiency provides to sustainability.

Efficiency

- In general terms efficiency is a measure of how much resources it takes to complete a task. In engineering, it's more common to use a definition that is based on the comparison on the measurable inputs and outputs of the system.

- In energy systems, these measurable quantities are Energy (E) and Power (P), therefore, in technical terms Energy Efficiency can be defined as:

$$\eta = \frac{P_{OUT}}{P_{IN}} = 1 - \frac{P_{LOSS}}{P_{IN}}$$

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Efficiency

- Efficiency Improvement
  - The objective of energy efficiency improvement initiatives might be to reduce energy input for a desired task (which will fix the energy or power output of the control system), or to increase the useful output of a system for a fixed energy or power supply level.
  - In either case, it is evident that as efficiency is increased, the improvements in input reduction or output maximization are continuously diminishing.

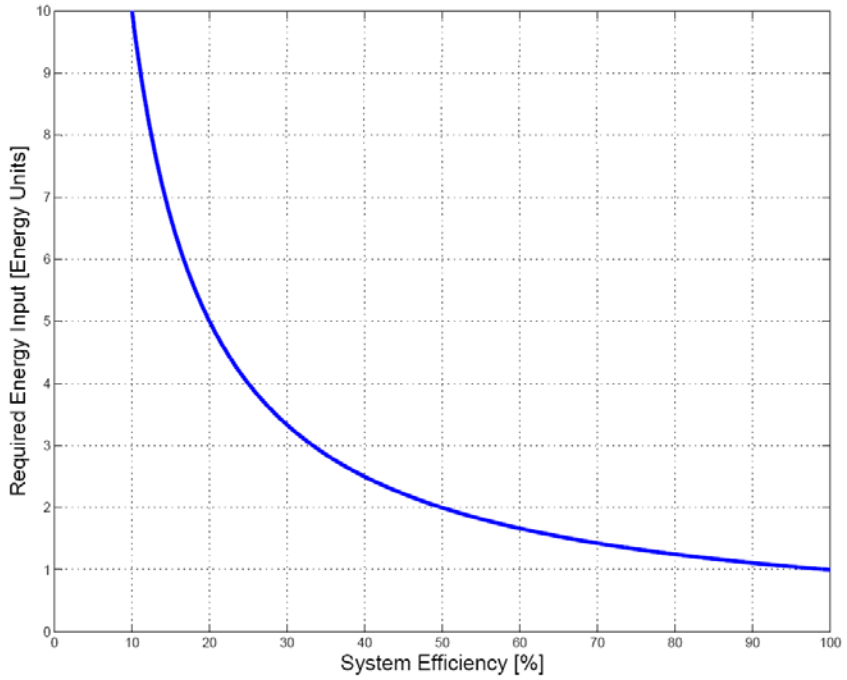


Figure 1: Increase in efficiency and its effect in input requirements for a fixed output

Efficiency

- Motivations
  - The motivations behind developing and implementing energy efficiency solutions are different for industrialized and developing countries. Industrialized (developed) countries need to improve efficiencies to reduce greenhouse gases and local pollution; furthermore, they do this to achieve energy independence
  - On the other hand, although developing countries also seek to improve their efficiency, they do so for very different reasons. The most important, is to alleviate the financial burden that oil imports puts on their economies.
- Implementation
  - Efficiency improvement can result from both technological or organization and management changes. Either way, implementing efficiency improvement changes consist of a trade-off between immediate cost associated with the solution (investment cost) and long term decrease in energy expenses (and how it will reflect in cost reductions of the process)

Efficiency

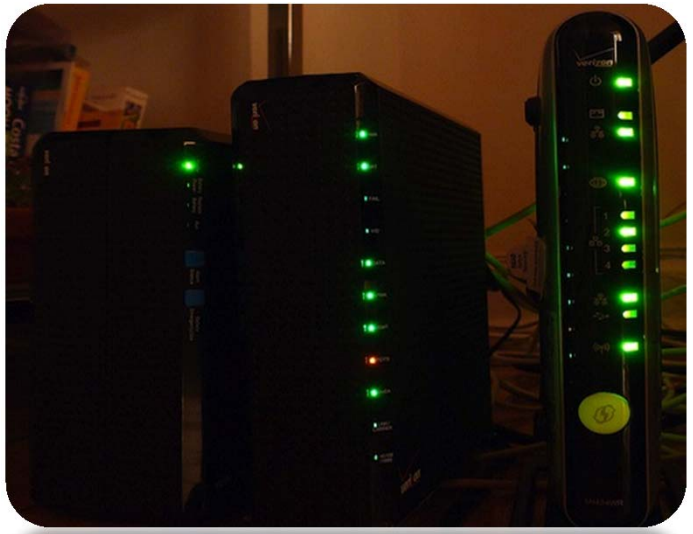
- In order to study the trends of world efficiency and efficiency improvement, several regional groups have been defined whose economic activity similarities and regional placement make sense to use, mainly because this shows the differences in economic structure and energy efficiency accomplishments among them

- These groups are classified as: Europe, Commonwealth of Independent States (CIS), North America, Latin America, Asia, Pacific, Africa and Middle East (Enerdata, 2013). In 2012, North America experienced the largest decrease in energy intensity (4.1%) since the previous year; meanwhile, the European Union remained the region with the lowest energy intensity in the world

- Even though the average global annual energy intensity decreased by 1.6%, regions like CIS, the Middle East, China and other Asian developing countries remained with high values of energy intensity mainly due to the predominance of energy-intensive industries and low energy prices (Enerdata, 2013).

Major Loads

- Every load has an impact on the overall efficiency. There are a number of loads whose presence in modern society has been increasing in the last years and consequently have contributed to a dramatic rise in electrical power usage
  - Heating, ventilating and air conditioning (HVAC)
  - Lightning
  - Data centers
  - Power generation
  - Transportation



The Soft Energy Path

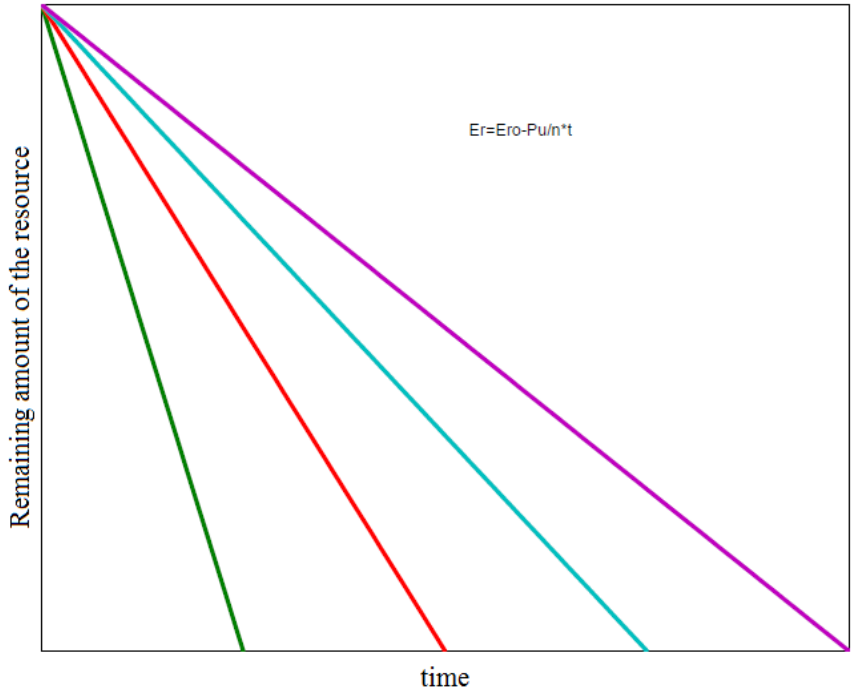
- The ability to extend the remaining time of finite resource availability is angular to the function of energy efficiency improvement as part of the soft energy path philosophy (Lovins, 1976)

- It consists of an energy development plan based on three main ideas:
  - Decentralization of energy supply, so that the sources are closer to the users and they have full management abilities over them
  - Maximization of renewable energy content of the mix in order to reduce the environmental impact of our development which inherently needs energy
  - Emphasis on technology as a way to provide energy needs (Negawatts). That is, technological solutions that reduce the amount of energy we need to perform tasks.

- A generalized analysis of the effects of efficiency improvement will be presented next for a constant and growing demand case in order to establish the base for future research regarding the last idea of Lovins' soft energy path philosophy.

Efficiency and Resource Longevity

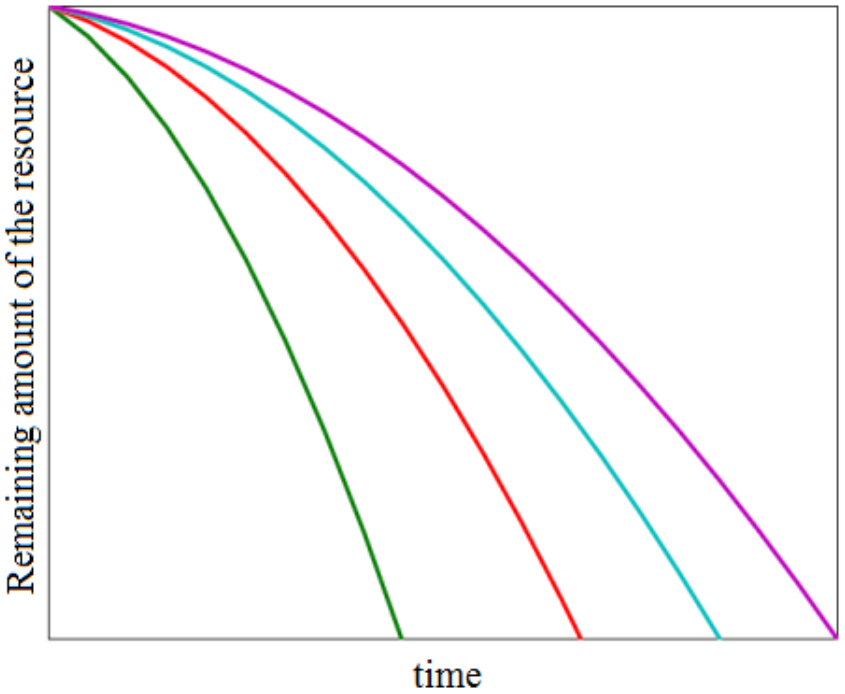
FINITE RESOURCE & CONSTANT DEMAND



$$E_R(t_r) = 0 = E_R(0) - \frac{P}{\eta} t_r$$

$$\therefore t_r = \frac{\eta E_R(0)}{P}$$

FINITE RESOURCE & INCREASING DEMAND



$$E_R(t_r) = E_R(0) - \frac{(P + \Delta P t_r)}{\eta} t_r$$

$$t_r = \tfrac{1}{2}\left[\sqrt{\left(\frac{P}{\Delta P}\right)^2 + 4\left(\frac{\eta E_R(0)}{\Delta P}\right)} - \left(\frac{P}{\Delta P}\right)\right]$$

Jevon's Paradox and the Limit of Efficiency Improvement

- Jevon's paradox proposes that technological changes proposed to increase efficiency tend to increase the primary energy resource consumption instead of reducing it

- This effect can be predicted when cost influence on demand is taken into account:
  - Efficiency increase lowers the cost of the resource because of increased availability
  - Lower cost allows more consumption, or consumption by those with more limited resources, increasing the demand and lowering the resource longevity

Jevon's Paradox and the Limit of Efficiency Improvement

- Mathematically, the effect can be studied using a number of equations representing the behavior of the elements of the problem including sensitivity of the price, availability of the resource, efficiency, resource remaining time, among others.
- However, the set of equations is implicit and have a circular solution, so the analysis is not trivial and further research should be done around this topic
- Nevertheless, based on the relative values of sensitivity of the price and demand to availability, the efficiency can be optimized for at least two functions:
  - Minimization of the cost for reasonable resource duration
  - Maximization of the resource duration for reasonable demand

Conclusions

- Efficiency is highly regarded as one of the two pillars of sustainable energy; however the limit of its efficacy hasn't been studied before beyond observation of some commercial systems

- The problem of optimal target efficiency will become crucial in the sustainable development of the new generation of the world's energy supply system.

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Questions

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