# The Interdependency of Energy, Information, and Growth

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**Abstract** This contribution is based on the talk I gave at the conference on ICT for Sustainability, February 14–16, ETH Zürich [1], in which I reopened the discussion on the impact of ICT on energy consumption [2]. The chapter has four sections. The introduction connects my topic to the conference theme. In part two, I discuss energy conservation; the mutual substitutability of energy, time and information; and some fundamental aspects of the nature of these three quantities. In the third part I present two empirical case studies of this mutual substitutability. Finally, in the fourth section, I conclude by speculating on what these results may mean in term of ICT's effects on sustainability, mindful of the role of time and of economic growth in this interaction.

**Keywords** Substitution · Rebound effect · Energy · Time use

## 1 Introduction

ICT holds great potential to contribute to sustainable development. Doing things in a more controlled and intelligent manner can be an essential ingredient for a long-term viable future.

Often energy consumption is used as a proxy for sustainability. Many people would consider the use of this proxy to be a terrible simplification. There is no room here to go into much detail here, but I would argue as long we do not assume a linear relation but some sort of convex relationship, the energy consumption per capita is good a proxy for sustainability as one can find.

For energy use per capita below 1 or 2 kW/capita sustainability increases (extreme poverty decreases) with increasing energy consumption, however for

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energy consumption per capita above a few kW/capita, and this is the case we are interested in here, sustainability decreases with increasing energy consumption (compare [3, 4]). Therefore, it is not inappropriate to narrow down the theme of the conference to the effect of ICT on energy consumption.

## 2 Mutual Substitutability of Energy, Time and Information

In the 1970s I thought about energy conservation and postulated that in order to conserve energy, either time or information or both were needed. To produce any given good or service, perform a task, some amounts of energy, time, and information are required. Reducing the energy input is achieved by increasing the time and/or information input for the task.

In order to save energy one can either perform a task smarter or slower:

- more time reduces friction, losses in heat-transfer, etc.
- more information reduces unnecessary safety margins, trial-and-error operation, and—this is most important—useless and unused energy services.

A trip from A to B can be made more energy efficient

- by choosing a slow mode of travel, by not speeding
- by taking the best route, and best (high-tech) vehicle.

Thus, the inputs to produce a good or service can be characterized by the three quantities energy, time and information. My hypothesis is that these inputs are partially substitutable. The graphical representation of the hypothesis is an equilateral triangle. The various ways of perform a task are then represented by points in the triangle, the distance to the sides measure the amounts of the three inputs applied to the job (Fig. 1).

The triangle, sometime called Spreng Triangle, applied to energy conservation then looks as follows (Fig. 2):

This mutual substitutability is often, but by no means always, observed in processes and equipment on the technical plane.

The mutual substitutability of energy, time and information can, however, also be seen on a micro-economic plane. It is possible to position economic sectors within this equilateral triangle by calculating for each sector the cumulated energy and cumulated time (labor) input to produce a good or service worth a dollar and then examining what the relative, cumulative information input is, assuming no other input is necessary [5]. Standard economic theory would suggest that besides labor, capital is the most important input, supplemented perhaps by additional resources other than energy. However, focusing on physical inputs at the level of the triangle, one can argue that energy is reasonably good proxy for *any* resource and that capital is money earned at some earlier time period and therefore not much different from cumulated labor. Marx called capital "geronnene Arbeit," labor hardened like blood.

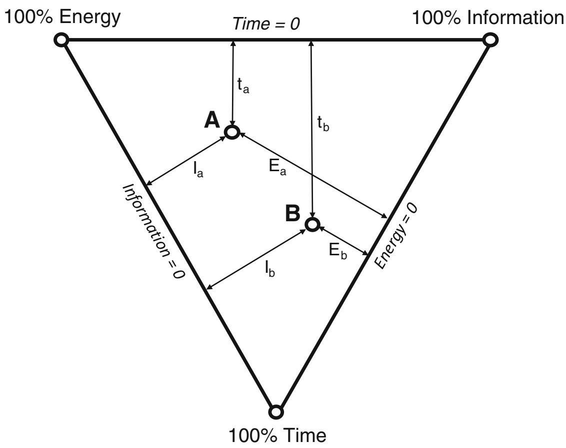



**Fig. 1** A good or service can either be produced by the inputs $E_A$, $t_A$ and $I_A$ or the inputs $E_B$, $t_B$ and $I_B$,—i.e., by the input relationships *A* or *B*

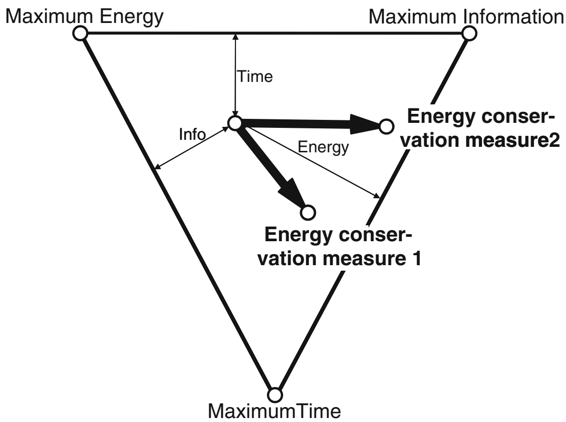



**Fig. 2** From the substitutability hypothesis follows that there are various ways to save energy. Both using more time and using more information can have the desired effect

A good worth a dollar can be produced and a service worth a dollar can be rendered in various sectors with different characteristic ratios of the energy, time and information. The result of plotting economic sectors in such an energy-information-time triangle (Fig. 3) is supportive of the idea of substitutability and also hints at the meaning of cumulated information (see footnote 1 in [5]). Cumulated information turns out to be high in modern, high-tech industrial sectors. For energy and time (measured in working hours) the cumulated inputs are calculated. The information input is the plausible result of the plotting procedure.

On the macroeconomic plane, the triangle allows to speculate about the direction of the future development of nations. ICT pushes nations powerfully in the direction of the top right corner of the triangle. Whether this leads to less time, a society of harried men and women, or less energy, a society of starving philosophers, depends also on other factors, such as price level of labor and resources (Fig. 4).

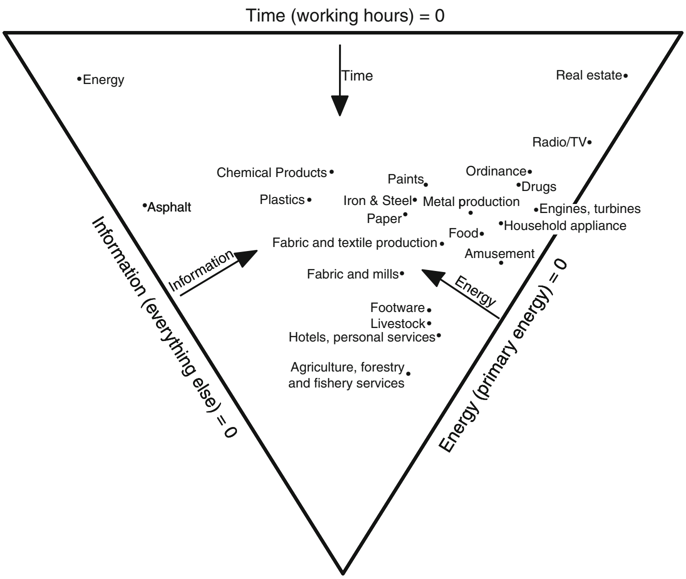
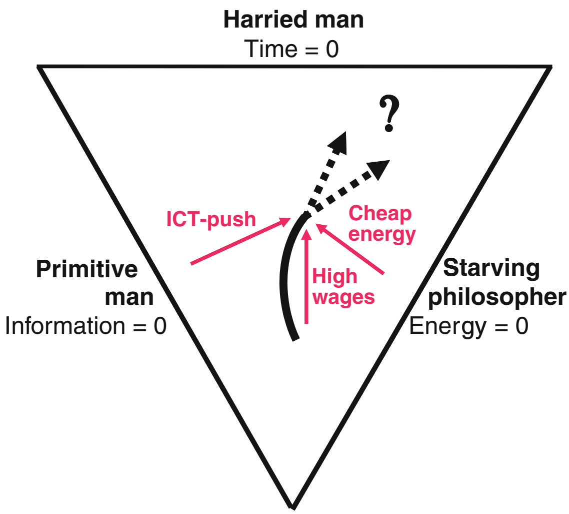



**Fig. 3** Industrial activities require energy, time and information inputs in various proportions [5]

**Fig. 4** ICT pushes nations powerfully in the direction of the *top right corner*; information input becoming more and more important




The concept of the triangle may seem to be a bit simplistic. However, by being careful about the exact meaning of the three inputs, the concept gets rather complex and subtle.

Characterization of the energy input: Even though there are

- four thermodynamic potentials (as well as energy),
- many commercial and non-commercial forms,
- although time and location matters a lot in terms of usefulness,

the definition is rather straight forward.

It is important to note, that energy is an extensive quantity (i.e. it depends on quantity). The quantitative relationship between energy on the three levels (technical, micro and macro) is the topic of many models (bottom-up, top-down etc.).

Time, on the other hand, is a mysterious quantity. Time is

- both extensive (time period) and quasi intensive (time availability: 24 h a day, life time),
- an irreversible flow,
- both linear (in the technosphere) and cyclical (in nature),
- chronos and kairos.

However, time is easily measureable on the technical level and labor (one aspect of time) or free-time, can be measured on the micro and macro level.

Information (as applied to a task) includes many aspects, depending on how close it is to being applied and also whether it is static or dynamic. Figure 5 is drawn to illustrate this complexity.

To some degree information has an elusive meaning, differently specified (and measured) on various levels. On the technical level it can have the specification as given in Fig. 5. On the microeconomic level it would refer more to the choice of technologies (in particular ICT), the skill of personnel, the choice of products and services by consumers.

On the macroeconomic level the penetration of ICT in national economies is important, as well as the education of the labor force, the concentration and clustering of high-tech firms and demand for quality rather than quantity of products and services.

In summary, the meaning of energy is rather straight forward, although one has to be careful of not mixing-up the technological, microeconomic and macroeconomic planes; time is a mysterious quantity, but neglecting it leads to serious errors; and information is what changes our societies and lives these days, it has different meanings in various and varying settings. Substitutability of energy, time and information is not a law of physics, but is

- often a fact on the technical level (old saying: haste makes waste), but there are many exceptions,
- on the microeconomic level, substitutability is often plausible (see triangle with economic sectors), but the elusiveness of energy, time and information makes quantification difficult and
- on the macroeconomic level it is an intuitive truth that nations with much stability (giving change the time it requires) and high innovative capacity (putting a high value on information) seem to be more sustainable (using energy and other natural resources sparingly).

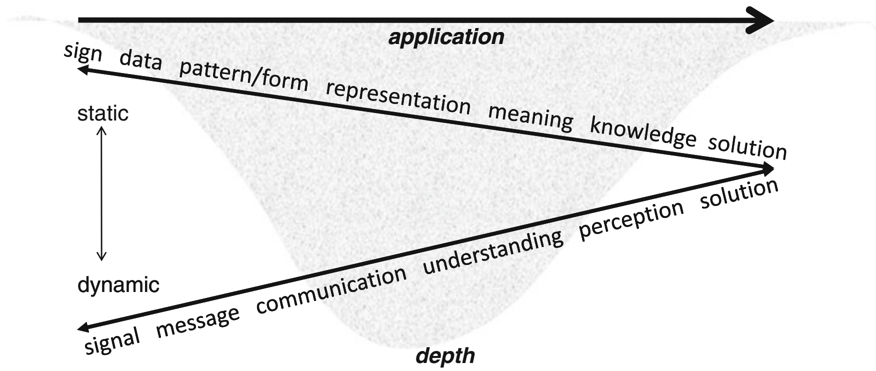



**Fig. 5** Various aspects of information on the technical level (as applied to a task)

## 3 Two Empirical Case Studies of the Mutual Substitutability

Research, my group did in the 1980s, particularly the two following case studies, was based on the triangle.

**Case Study I.** In the first project we looked carefully at the energy effects of the introduction of computers in various parts of textile industry. The heart of the research, the PhD thesis of Rolf Bergrath, was an examination of the energy conservation potential of electronics used for air conditioning spinning mills. As it turned out, the energy conservation potential was huge.

The automated control in all corners of the mill allowed the safety margins to be reduced and thus the temperature at which the climate had to be set could be increased. As the electricity requirement for air conditioning is a large part of the cost of spinning, this reduction in the cooling requirement proved to be economically important.

However, as it turned out, electronics also improved the spinning machines. The much more tightly controlled spinning process allowed higher speeds without increasing the frequency of yarn ruptures, a decisive factor for the productivity of the mill. The higher speed caused much more heat, and thus the energy requirement for air conditioning did not decrease. The energy requirement per yarn may have decreased, but the energy requirement in the now more productive mill increased rather than decreased.

Similar effects could be observed in all parts of the textile industry. However, with the introduction of computers everywhere in the industry, including the commercial side, the industry as a whole could react more quickly to the wishes and whims of the market, thus greatly speeding-up fashion cycles and increasing demand. The overall effect of the early introduction of modern IT in the textile

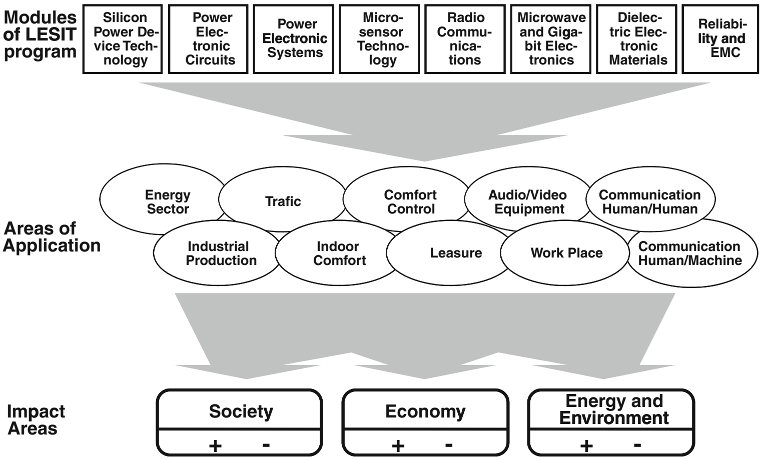



**Fig. 6** Advances in power electronics were pursued, within the LESIT program in various modules (*top row*), all of these could potentially lead to improvement of power electronics implementations in a myriad of applications (*middle row*). All of these would then have impacts on societal, economic and energy/environmental developments (*bottom row*)

industry was so profound that it could not be rigorously quantified. It was difficult to isolate the effect from changes that occurred in the global economy as a whole [6]. The only definite conclusion was that IT greatly amplified the potential for both increases and decreases in energy consumption; IT enabled both significant energy conservation measures, on the one hand, and new business opportunities and new ways of speeding-up production and demand on the other.

**Case Study II.** This case study was a technology assessment project. We were asked to find out how much energy was saved with the creation and introduction of improved power electronic components and devices. In particular we looked at a large research program, called LESIT, supported by the Swiss government, which had as its goal to advance the technology of power electronics. The program comprised the 8 modules listed in the top row of Fig. 6.

Like in case study I, our research came to the conclusion that although the use of newly developed power electronics did reduce the energy requirement of a given application, on the macroeconomic level the effect was more likely a speeding-up of industrial production, travel and consumption and thus an overall increase in economic activity and energy demand, even if energy efficiency had been improved at many points. Although the technology assessment we conducted was a sizable undertaking, involving several research groups and disciplines,[1] we could not study all possible effects (see Fig. 6), but we concentrated

[1] The assessment was done by a multi-disciplinary team including F. Varone, B. Aebischer, W. Eichhammer, E. Gruber, St. Kuhlmann, D. von Wichert-Nick and is described in [7].

on three topics, typical for the three stages of the innovation process involved (see Fig. 7).

In my opinion, discussions of the rebound effect often do not pass a reality check. Pure energy conservation measures are rare. Most technological innovations called energy efficiency innovations are innovations that *among other things* improve energy efficiency (Fig. 8).

Energy efficiency innovation almost always includes some co-benefits. In the case of the train engines, smoother traction, faster acceleration, smaller engines etc.

| Stages of the innovation process | Focus | Topic | Object of the analysis |
|---|---|---|---|
| Applied research and technology development | 1 | Perceptions of researchers on impacts on energy consumption | Selected products and research methods |
| Technology transfer and production | 2 | Research co-operation industry and academia / Technology transfer | Energy considera-tions when choosing industry partners |
| Sale and use of new products | 3 | Impactof "intelligent buildings" on users | Marketing situation for new energy optimal products |

**Fig. 7** The technology assessment was conducted by focusing on three topics

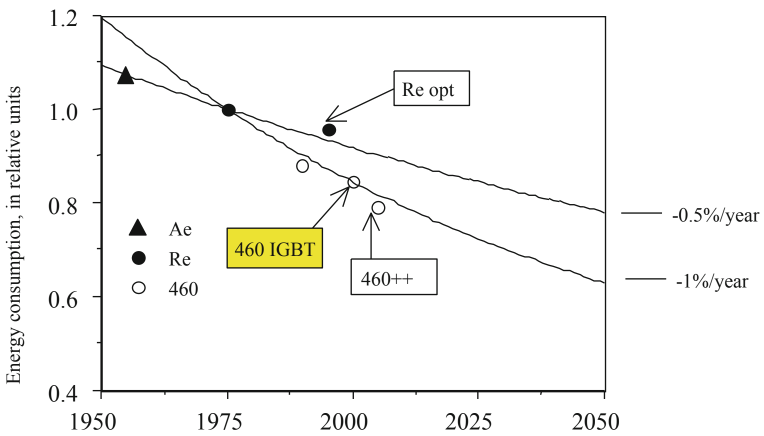



**Fig. 8** Energy consumption of several train engines (Ae 6/6, Re 6/6, 460) is plotted in function of their first year of service. 460 IGBT (incorporating much LESIT-technology) shows reduced energy consumption exactly in line with the business-as-usual trend

were economically more important to take advantage of than fully exploiting higher energy efficiency. Generally, co-benefits of energy efficiency innovation, like reduced cost and higher convenience (e.g., time savings for the user) are economically attractive and will often generate economic growth.

More often than not, as with ICT in the textile industry or power electronics, the energy efficiency effect, clearly evident at the level of one application, does not lead to energy conservation on the macroeconomic level. Energy conservation is a cultural achievement, but is not natural to us (Westerners), it requires valuing leisure, where as energy efficiency often increases without special effort and does not necessarily lead to energy conservation.

# 4 Conclusion

The disappointing results of the case studies show that ICT is mostly used to accelerate processes, markets and national economies: time is money. As long as time costs more than energy, ICT will likely be applied to save time rather than energy. The time saved may be labor on the production side or it may be time saved, i.e. greater convenience, on the consumer side. Economic growth is often regarded as the remedy for unemployment. However, promoting ICT applications indiscriminately is not a good way to combat unemployment. ICT, although very suitable to push economic growth, often contributes to economic growth by saving labor.

Only if ICT is applied discriminately to do things smarter, wary of automation and higher speeds, will its increased use lead to higher economic growth, without reducing the labor intensity of products and services. This type of growth has the potential to be less resource intensive as well. The debate on aiming at qualitative growth rather than quantitative growth, conducted in the 1980s, has almost been forgotten but needs to be revived.

If time (an important fraction of labor) and cumulated time (an important fraction of capital) cost more than energy (and other natural resources) and if consumer preferences remain unchanged then more ICT leads over all to

- no energy conservation, but instead to
- time savings, faster production and economic growth,
- i.e. higher labor and capital productivity (likely more unemployment and cheaper products).

ICT could easily lead to more sustainability, if

- leisure,
- quality of products and services and
- energy as well as other natural resources would be more highly valued.

Policy design should take into account both the

- massive transformative power of ICT and
- the necessity to correct present incentives on all levels (from international to personal) to steer ICTs application, and with that ICTs effects, in the desired direction.

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