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Ecological impact of renewable resource based energy technologies

Michael Eder, Nora Sandor, Karl-Heinz Kettl, Michael Narodoslawsky*
Institute for Process Engineering, Graz University of Technology, Austria
Inffelgasse 21B, 8010 Graz
Narodoslawsky@tugraz.at

Renewable resources based energy technologies are currently gaining strong interest, particularly in the light of global climate change and volatile energy markets. A major argument for their use is their ecological advantage.
The paper will compare the ecological impact of various biofuel technologies, technologies providing electricity and heat on the base of different resources, both biogenic and direct as well as indirect solar energy. It will compare these technologies with the Sustainable Process Index (SPI), a comprehensive and sensitive ecological measure addressing resource as well as emission and global warming problems with a consistent methodology.
The paper will analyse different aspects of the ecological impacts of energy technologies and bio-fuels. On the base of this analysis conclusions will be drawn regarding the most important factors influencing ecological performance as well as unresolved questions for a solid evaluation for these technologies.

1. Introduction

The quest for an energy provision that will mitigate human caused climate change and the necessity to brace for the decline in the availability of fossil energy resources like crude oil and natural gas have increased interest in alternative energy technologies considerable since the turn of the century. There is a general consensus that energy technologies on the base of renewable sources such as solar radiation, wind power and biomass will not only achieve a sea change in terms of global warming but will be inherently friendly to the environment, too.
There is a methodological challenge in comparing different energy technologies that is caused by the fact that they are based on widely different sources and techniques to exploit these sources. Conventional technologies are mostly based on fossil resources like coal, crude oil and natural gas. These technologies usually exhibit their largest pressure on the environment during operation (as most other energy technologies) by blowing vast amounts of CO_2 into the atmosphere and thus changing the global carbon flow systems with grave consequences for the global climate.
Technologies based on biofuels and biomass in general exert quite different pressures on the environment. For these technologies the pressures caused by agriculture as well

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as transport become important, as do pressures caused by pollutants like NO_x produced during burning biogenic energy carriers.
Finally there is a group of energy technologies that do not cause appreciable environmental pressure during operation such as wind power, solar heat, photovoltaic and to a lesser extent hydro power. For these technologies the main environmental pressure is linked to the construction and installation of the equipment like PV panels, wind turbines and solar collectors.
The task of comparing these different energy technologies in terms of their environmental pressures requires a tool that may take into account different qualities of environmental impacts yet still leads to a meaningful evaluation of the overall environmental performance of the technique. This calls for a measure that is highly aggregated (to allow comparison) but evaluates different impacts in a transparent scientifically based way. The Sustainable Process Index (SPI) (Narodoslawsky & Krotscheck, 1995) is such a measure.
The SPI has already proved its usefulness in a number of studies involving renewable resource based technologies (Niederl & Narodoslawsky, 2004, Narodoslawsky & Niederl, 2005, Narodoslawsky et al. 2008) and is freely available on the internet (Sandholzer et al. 2005) via the web site www.spionexcel.tugraz.at . The SPI is a member of the ecological footprint family and measures the area that is necessary to embed a human activity sustainably into the ecosphere, taking resource provision, energy use, waste and emissions into account. By referring the environmental pressures incurred by manufacturing and construction of equipment to the economic life time of the installation, the environmental impact of infra structure can also be considered.

2. Differing environmental pressure for different technologies

Energy provision technologies offer an opportunity to investigate the environmental profiles of technologies based on widely different resources and technological structures. There are many ways to provide heat, electricity and fuel but there is a product that is very comparable, namely the energy output in MJ. Evaluating the impact of different technologies with the SPI is therefore not only interesting from the point of view which technology provides the needed energy while causing the lowest impact on nature. It is also interesting from the point of view of what particular impact a certain technology causes as this may be the starting point for optimisation as well as supporting strategic planning against the background of changing structures in the resource base of society in the 21st century.
The following figures show that “renewable resource based energy technologies” represent a very diverse range of technologies with large differences in both their overall pressure as well as the distribution of this pressure into different impact categories. For better overview the information rendered by the SPIonExcel program has been condensed in six categories, the use of fossil as well as non-renewable resources, area utilisation and emissions to air, soil and water. All comparative values of footprints refer to the impact incurred by providing 1 MJ of the energy form in question at the point of distribution.

2.1 Electricity provision technologies

Figure 1 shows the comparison between four different technologies to supply electricity, a wind turbine (based on data from a Vesta 3 MW turbine), a monocristaline photovoltaic panel (based on data from ecoinvent), a biogas unit (producing heat and power, based on ethanol mash) and a high performance natural gas combined heat and power system (with a 90 % overall efficiency and a 45 % electricity efficiency with respect to the gas input). It goes without saying that the value for the biogas unit can only be seen as one value within a range of ecological footprints for this technology as the impact on the environment is critically dependent on the raw material. The value represented here (as well as in all other biogas applications reported in this paper) may be seen as a lower boundary for biogas technologies as it utilises a typical by-product from industrial production. Footprints may become considerably higher (by a factor of three at least) if biogas production is based on fresh crops.

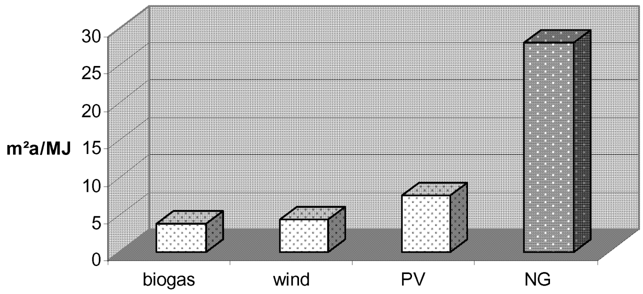

Fig. 1: Comparison of ecological footprints for different electricity provision technologies

From this figure it becomes clear that even a "clean" fossil based technology as natural gas turbines exert a higher pressure than all renewable resource based alternatives. The difference here is not just percent points but factors, with natural gas derived electricity (with 27,9 m^2a/MJ) exerting 7.5 times the impact of the biogas technology (with 3,69 m^2a/MJ) and still 3.7 times the impact of the "worst" renewable based technology photovoltaics (PV with 7,5 m^2a/MJ).

It is however interesting to look at the different impact profiles of the technologies. Fig. 2 shows a comparison of these pressures for wind turbine, PV and natural gas.

Analysing these figures one can easily find that the pressure on climate (represented by the fossil C sector) is strong in all technologies. Where it is obvious that this pressure category dominates the natural gas technology, it is interesting that it is also a strong influence in renewable resources based technologies like wind turbines and photovoltaic panels. The reason is that our current energy system is still mostly fossil based and any energy input to production and manufacturing of equipment is also causing pressures in this category.

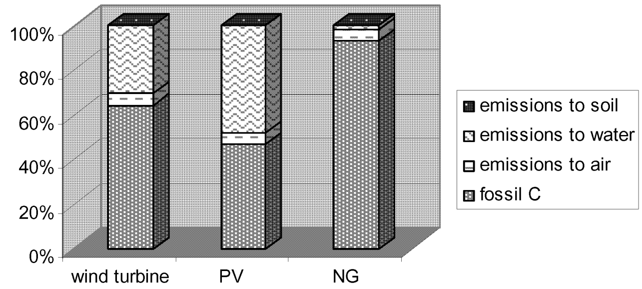

Fig. 2:Environmental pressure distribution for electricity generating technologies

Another interesting result is the difference in the profile between photovoltaic panels and wind turbines. A comparison reveals that the fossil carbon pressure dominates the wind turbine, reflecting the fossil contribution to steel processing. This cannot be reduced unless fossil coal is replaced by a renewable based alternative (like charcoal) in iron smelting, a change that has a low probability of realisation in this century. In photovoltaic panel production the emissions (especially to water) are prominent, as a result of the complex chemical process needed to produce the semiconductor wafers. This points to the necessity to have a sharp eye on the emissions from this process. Moreover it is interesting that the carbon emission pressure predominantly comes from the frames of the panels (which are made from metals), caused by the energy intensive production processes of the materials of construction. By and large the contribution from the raw material itself as well as the direct area use is negligible.

2.2 Heat generation processes

Figure 3 presents the comparison between three different heat providing processes, biogas (as combined heat and power), biomass (only heat) and natural gas (again with combined heat and power). The comparison shows a similar picture than in electricity generation, with renewable based technologies coming out on top with regard to environmental pressures.

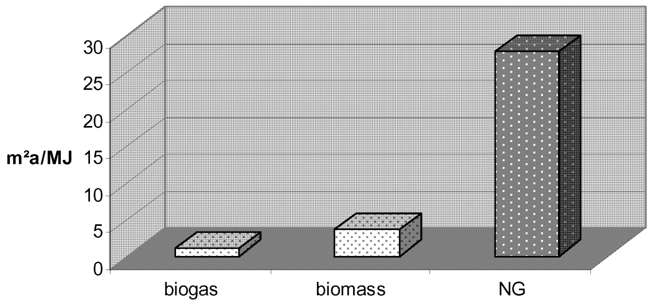

Fig. 3:Comparison of ecological footprints for different heat provision technologies

2.3 Biofuel systems

A particularly interesting picture arises with fuels. Fig. 4 compares different biofuels systems based on renewable as well as fossil resources.

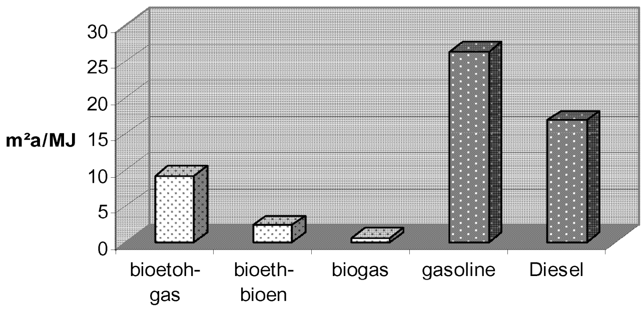

Fig. 4: Comparison of ecological footprints for different fuel systems

The two lefthand columns in this figure represent the ecological pressure of bioethanol, with the first column on the left side showing the value for a production of ethanol from corn, using natural gas as a energy source for the process. The column to the right shows the pressure exerted by ethanol from a process that uses biogas as a source of process energy. The comparison shows that the energy source for the process decides about the impact of two otherwise similar ways to produce fuel.

Biogas again shows a small ecological footprint. This is the value for a system based on ethanol mash and again represents a lower limit for this technology. Nevertheless biogas obviously is an interesting alternative for fuel purposes from the point of view of ecological pressures.

Fossil fuels again show relatively high impacts, with slight advantages for diesel versus gasoline.

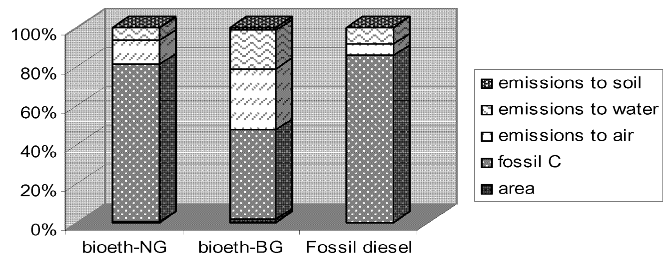

Fig. 5: Environmental pressure distribution for biofuel systems

The comparison of the impact profiles is shown in figure 5 for the two bioethanol alternatives and diesel. The main pressure for bioethanol from corn using natural gas as process energy source is clearly dominated by the fossil carbon impact. Even in the case of the bioethanol production using biogas as process energy source fossil carbon is an important environmental factor. The absolute size of the impact however is much lower and the origin is different. Whereas in the former case fossil carbon (and thus carbon dioxide going to the atmosphere) is linked to the energy provision of the process in the latter case the impact stems from agriculture, especially the fossil energy to generate fertiliser and the fuel for machines. The large fraction of fossil carbon impact for diesel is however not surprising.

3. Conclusion

Comparing different energy technologies with the SPI reveals some interesting insights:

- The environmental pressure of fossil based technologies and fuels are indeed much larger than that of comparable technologies and products on the base of renewable resources. The impact of fossil technologies is by factors (ranging from 3 to 40) larger than that of renewable resource based technologies.
- Fossil carbon plays a major role in the pressure even of renewable resources based technologies. This is linked to the fossil orientation of our current resource system as coal, fossil oil and gas dominate the energy provision of industry as well as transport and energy provision for society.
- Using fossil energy in processes based on renewable resources inevitably raises the ecological impact considerably as is evidenced by the bioethanol case.
- There are large differences in between different technologies/products based on renewable resources regarding their environmental pressure. Just using a renewable source does not qualify a technology or product to become overall sustainable.
- Technologies which exhibit high pressures stemming from energy provision (like photovoltaic panels) will become more attractive the more the overall energy system becomes more sustainable.

In general the evaluation confirms that a switch towards renewable resource based technology systems is indeed capable of reducing human pressure on the environment dramatically. This is mainly true because these technologies shift the environmental pressure away from fossil carbon impacts that currently dominate environmental considerations.

References

Narodoslawsky M und Krotscheck Ch., 1995. The sustainable process index (SPI): evaluating processes according to environmental compatibility. Journal of Hazardous Materials 41: 383-397,.

Narodoslawsky, M., A. Niederl, and L. Halasz, 2008. Utilising renewable resources economically - new challenges and chances for process development, Journal of Cleaner Production, 16 164-170.

Narodoslawsky, M.; Niederl, A., 2005. Sustainable Process Index, In Renewable-Based Technology: Sustainability Assessment Ed: Dewulf, J.; van Langhove, H., John Wiley & Sons

Niederl, A.; Narodoslawsky, M., 2004: Ecological Evaluation of Processes based on By-products or Waste from Agriculture – Life Cycle Assessment of Biodiesel from Tallow and Used Vegetable Oil in: Feedstocks for the Future, Ed: Bozell, J.; Patel, M.; ACS symposium series Vol. 921, American Chemical Society, Washington,

Sandholzer, D.; Niederl, A.; Narodoslawsky, M., 2005. SPIonExcel – fast and easy calculation of the Sustainable Process Index via computer Chemical Engineering Transactions 7 (2) 443-446