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Biofuels from micro-organisms: Thermodynamic analysis of sustainability

By

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Nowadays, the societies' awareness is continuously growing in relation to the need to change the actual trends in exploiting natural resources, and in a more general framework, in the way in which the present societies interact with their environment, the Earth system. Just in this context, almost fifty years ago, the concept of Sustainable Development was introduced. During the last thirty years, the spotlight has been put into this concept, which has its roots in three different domains: economy, society and environment. However, how to measure sustainability still remains a tricky open problem. Furthermore, this century is characterised by several challenges, which must be addressed by considering the consequences of the present choices for future generations. Among these challenges, environmental pollution and greenhouse gasses (GHGs) emissions have gained attention, due to their harmful impact on climate change and human life. Energy represents the key-enabler for life. However, the societies' reliance upon fossil fuels is one of the major contributors to GHGs emissions and pollutants. Thus, a global energy transition is required, switching from fossil fuels to renewables.

The aim of this PhD Thesis is to develop a method to evaluate the sustainability of a country, by introducing an approach based on the link among the social, economic, and environmental domains to the engineering thermodynamics optimisation one. To do so, an indicator has been developed, by introducing the Gouy-Stodola theorem related to GHGs emissions into the Human Development Index, HDI, the United Nations (UNs) indicator based on three main aspects: long and healthy life, knowledge, and a decent standard of living. The resulting index, named Thermodynamic Human Development Index ($THDI$), considers the domains of the sustainable development, including a link with the technological pillar. Moreover, an improvement of the UNs' Education Index (EI) is proposed, to consider both the schooling years, as already set by the UNs, and the students' skills and knowledge, which are required to build the knowledge bases for the future citizens and workers in advanced technologies for sustainability. Thus, the Education Index-more-professional-oriented (EI_p), and the related Thermodynamic Human Development Index - professional-oriented ($THDI_p$) are obtained.

An approach to mitigation strategies is carried out by considering the biofuels production from micro-organisms. Thus, the irreversible thermodynamic analysis of the micro-organisms membrane heat and mass flows with their environment is carried out in order to obtain an optimisation approach to biomass generation for biofuel production. To optimize this process, it is possible to exploit a natural positive interaction, a behaviour that exists between different species, called mutualism, in which one of the species supplies useful metabolites to the other one and *vice versa*, or acts by changing the neighbouring external environment, supporting the behaviour of the other one. This behaviour can be exploited during the anaerobic digestion process of biomasses, too.

Hence, in this Thesis, the valorisation of a field residue - the rice straw - has been considered to obtain biomethane from the anaerobic digestion process. Actually, rice straw is acknowledged as an agricultural waste, because of its physico-chemical properties, which do not allow its use in the industrial sector. However, rice is the third global staple food, and the actual disposal methods of the related rice straw induce negative impacts on the environment, because it is mainly burned or slowly incorporated in the field, causing GHGs and pollutant emissions. The potential amount of biomethane from rice straw for different countries has been evaluated, and the *THDI* has been applied in this context, to analyse the biomethane production from anaerobic digestion with respect to the actual disposal methods.