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# Sustainable energy

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**Summary.** — A brief overview of why it is important to think of energy in a sustainable way is given. The starting point is that the future of mankind depends on a sufficient energy supply, both in terms of electric power and liquid fuels, at present based on fossile resources. A shift of paradigm towards Sustainable Development is needed, based on ethical considerations and on some legal rules. A possible technological solution to the liquid fuel problem is also presented.

## 1. – Introduction

The problem of energy supply to humankind must be examined on a time scale at the civilisation level. In shorter time scales (politics —10 years and generation— 50–100 years) vested interests would dominate, therefore a guide from the longer term vision should be developed. Figure 1 shows, in the time scale spanning 6000 years, the energy consumption and energy need of humanity. Most of the non-renewable resources have been exhausted in the last couple of centuries, and the prospective is doom in the sense that we have to imagine very different energy sources for the millennia ahead. A first list may include fusion, direct solar energy, wind power and hydropower (including tidal and wave power) which can essentially be used to produce electricity, geothermal and ambient energy for heat, biomasses for biofuels and materials.

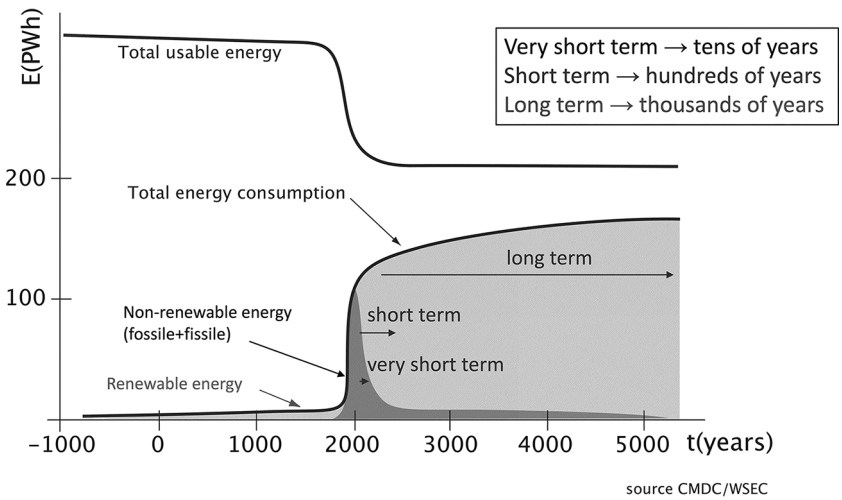


Fig. 1. – Total energy available and energy consumption in a civilisation time scale. The dark surface indicate the non-renewable energy consumed in the last couple of centuries.

In fig. 1 a "very short term" is defined, spanning the next two to three decades, where a development of present-day technologies can be envisaged, using both renewable and non-renewable sources. The "short term", up to 2500 a.d., must already consider the full panoply of renewable energies to keep the consumption level similar to present days. But to keep constant in the long term the availability of energy, the supply must be sustainable.

Three key questions must be answered in order to describe the concept of "Sustainable energy":

- How do we define sustainability?
- Why do we need sustainable energy?
- How much energy do we need?

Tentative answers will be given in sects. **2**, **3** and **4**. Section **5** will present a possible solution for the production of biofuels based on the transformation of residual biomasses.

## 2. – Principles of sustainability

Sustainability is a concept which has been declined in 1987 by the Brundtland Commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Since then, several interpretations have been developed by scientists and politicians. I found very much interesting a publication written by Michael Decleris, former Vice-president of the Hellenic Council of State, for the Environment Directorate-General of the European Commission [1], because

it describes how the rule of law can help to define sustainable development in practical and applicable terms.

The principles which are listed are: Public Environmental Order, Sustainability, Carrying Capacity, Obligatory Restoration of Disturbed Ecosystems, Biodiversity, Common Natural Heritage, Sustainable Urban Environment, Aestetic Value of Nature and Environmental Awareness. In the following these principles are shortly described.

**2**˙1. *Public Environmental Order*. – All the members of society, the Administration, groups, organisations, businesses and citizens are called upon to collaborate in sustainable development, but under the strategic control and supervision of the state. Sustainable development must be a long-term choice at constitutional level.

**2**˙2. *Sustainability*. – If there is complete identity between the interests of man and nature, sustainability is the self-evident term for the dynamic equilibrium between the two and for the co-evolution of both within the Earth mega-system. The deeper meaning of sustainability is the harmonisation of all public policies and social practices and their convergence towards ensuring the co-evolution of man-made systems and ecosystems.

**2**˙3. *Carrying Capacity*. – All man-made systems are constructed and developed at the cost of ecosystems, but together with the latter they constitute greater composite systems within the Earth mega-system. Carrying capacity is the optimum size which will maintain the equilibrium of the whole (greater) system.

**2**˙4. *Obligatory Restoration of Disturbed Ecosystems*. – During the ruthless development so far, many ecosystems have been destroyed owing to ignorance of their value. Thus, today it is futile to strive for balance between man-made systems and ecosystems unless, in parallel, immediate action is taken to restore ecosystems destroyed illegally and also all those which may be deemed essential for the full re-establishment of the disturbed equilibrium, provided of course that such restoration is still physically possible.

**2**˙5. *Biodiversity*. – The inherent value of all wild flora and fauna species and protection for all the variety of these species and for their habitats must be recognised. The value of species is that they are biogenetic reserves and constituents of the ecosystems. The stability and vigour of ecosystems follow from the rationale that the greater an ecosystem's biodiversity, the greater is its stability.

**2**˙6. *Common Natural Heritage*. – Areas of nature in the wild, with exceptionally sensitive ecosystems, of great ecological or biological value, with a rich biodiversity, untouched by human activity, with special ecological or aesthetic value, *i.e.* the "common property of all" are to be preserved and protected.

**2**˙7. *Sustainable Urban Environment*. – In settlements, the way people live must be sustainable, the settlements themselves must be sustainable, and the ecosystems that support them must also be sustainable. Priority must be given to improving degraded areas in cities.

**2**˙8. *Aestetic Value of Nature*. – The "landscape" is an aesthetic system whose element are certain geomorphological characteristics of the area which are interdependent and have unity. The landscape does not belong to anyone, it is a common asset like the air and the sea, and anyone who spoils it is violating the rights of other people. Only the spatial planning, applying criteria of public interest, can determine where interventions are to take place.

**2**˙9. *Environmental Awareness*. – Citizens should take an active part in protecting the environment, in collaboration with the state. Citizens are entitled to receive information. Systematic education and training for citizens on environmental issues must be given. It is a legitimate interest of citizens the setting in motion of the mechanism of judicial protection of the environment.

**2**˙10. *Summary*. – The first three principles —Public Environmental Order, Sustainability, Carrying Capacity— promote coordinated efforts towards an equilibrium with nature within the capabilities of the system. The Biodiversity principle promotes natural rules avoiding, *e.g.*, mono-coltures of energy crops. The Sustainable Urban Environment promotes reduced pollution in cities (*e.g.*, transportation). Environmental Awareness wraps everything up promoting a participated effort by citizens.

## 3. – Why sustainable energy?

The principles listed above may help answer two general questions:

1) Should all members of mankind have equal opportunities?

2) Should next generations have the same opportunities as we have today?

A positive answer to the first question means that equality must be pursued between all members of mankind. A negative answer, which is not in agreement to most of the principles of sustainability, means that whoever controls the access to resources is allowed to prevent (even by force) others to access them. However, this second scenario may be much more costly in the long run as sooner or later we will anyway run out of resources.

A positive answer to the second question means that resources must be preserved for future generations. A negative answer means that we may well avoid investing in new technologies, as we have enough resources to keep our present standard of living - our life span is short.

My personal answers is positive to both questions, because I would like for myself and my children a peaceful World, in which everybody can develop his skills up to the maximum of his own capacity. From an ethical —but also practical— point of view, the advancement of humanity depends on each of us, therefore the loss of a single intelligence is a loss for anyone.

The consequences of a positive answer to the first question need some analysis which is developed in sect. **4**. The consequences of the positive answer to the second question is that in the field of energy there must be a shift from Common Goods to Public Goods.

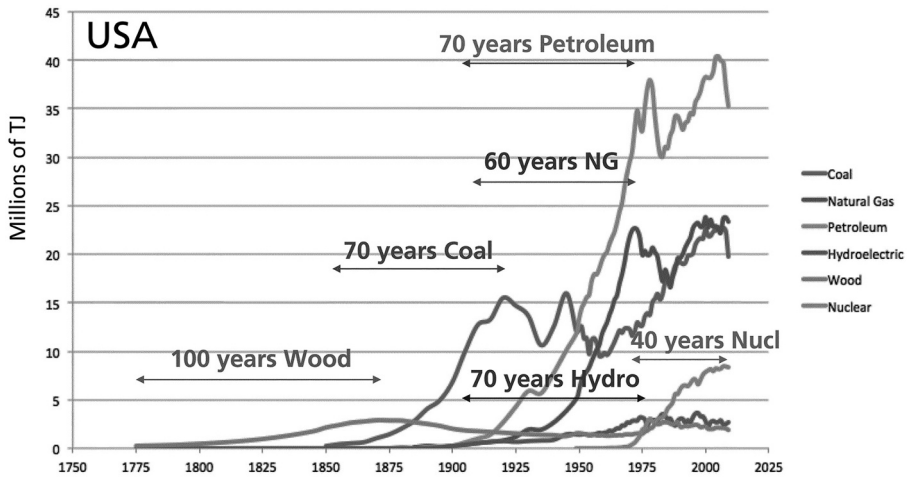


Fig. 2. – Energy consumed by source in the USA.

Common Goods (or common-pool resources) are non-excludable —shared, accessible to all— but rivalrous —consumption by one consumer prevents simultaneous consumption by other consumers. Common goods, *e.g.* non-renewable fossile resources, become subject to over-use or over-consumption, which destroys the very same resource in the process. Public Goods (non-excludable, non-rivalrous resources) are available to all, independently from the amount of consumption.

Renewable energies are based on the use of Public Goods, and this guarantees that most of the principles of sustainability listed in sect. **2** are respected.

The short-term problem in introducing renewable energies is the time it takes to substitute the present energy system based on fossile fuels with a new worldwide system based on solar light and energy, wind, hydropower, biomass-based fuels, etc. Figure 2 shows the energy consumed by source in the last 200 years in the USA. The time lap from the beginning of the use of a resource (wood, coal, petroleum, natural gas, etc.) to its full exploitation spans between 40 to more than 70 years. This time lap is valid also for most of the renewable energy sources, so that to solve the "very short term" problem in fig. 1 there is still a need for strong efforts and investments.

## 4. – How much energy do we need?

To analyse the consequences of a positive answer to question 1) in sect. **3**, a definition of the basic level of energy needed for a "good" life has to be found. In this paper a method based on publicly available data is proposed, which uses the Human Development Index from United Nations.

The Human Development Index (HDI) and its derived Inequality-adjusted HDI (IHDI) represents "a summary measure of average achievement in key dimensions of

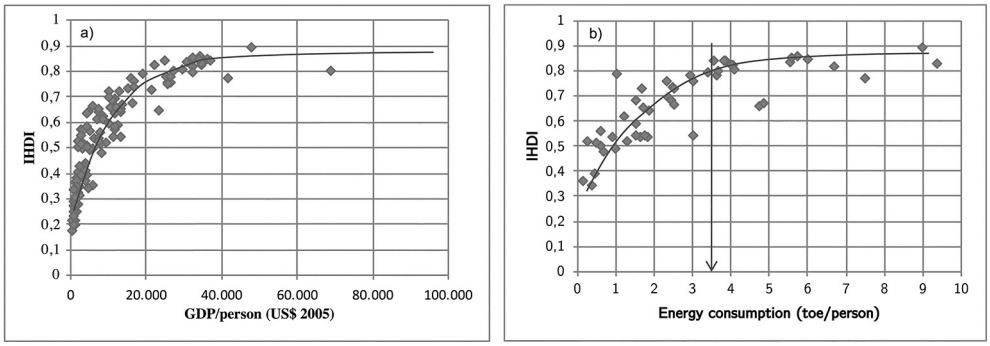


Fig. 3. – (a) IHDI *vs.* GDP; (b) IHDI *vs.* Energy.

human development: a long and healthy life, being knowledgeable and have a decent standard of living. The HDI is the geometric mean of normalised indices for each of the three dimensions" [2]. Figure 3(a) shows the IHDI plotted *vs.* the GDP, for all Countries in which IHDI is calculated. The IHDI saturates with growing GDP. A level of IHDI=0.8 is reached with an average GDP of about 28000 US$ (2011 PPP).

A further increase of GDP does not change in a significant way the value of the index. Figure 3(a) shows the correlation of the IHDI index with the energy consumption per person, for the Countries where data is available. The same level of IHDI=0.8 is correlated to a energy consumption per person of about 3.5 toe (tons of oil equivalent) per person. As shown in fig. 4, the present average energy consumption per person is about 1.8 toe/person. The World total energy consumption is about 14 Gtoe. Bringing the average to 3.5 toe/person means increasing the total consumption to about 32 Gtoe, *i.e.* more than double the present amount. The development of renewable energies to cover the short term needs must take this value into account.

The energy consumption can be attributed to three main sectors: Electric Energy, Civil sector (heat) and Transportation. Electric Energy is the easiest to produce through photovoltaic or wind power, provided the problem of intermittence can be solved at a low

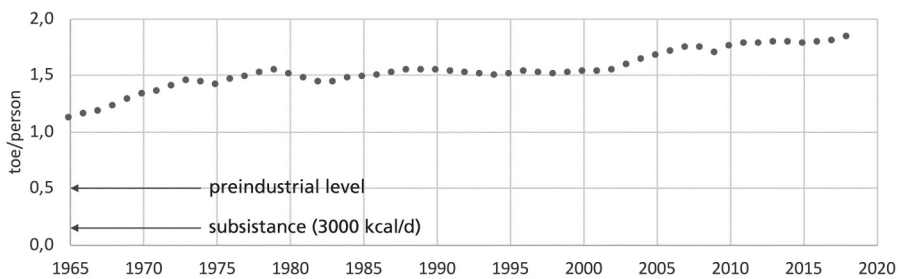


Fig. 4. – IHDI *vs.* Energy consumption per person (data from BP Statistical Review, 2019).

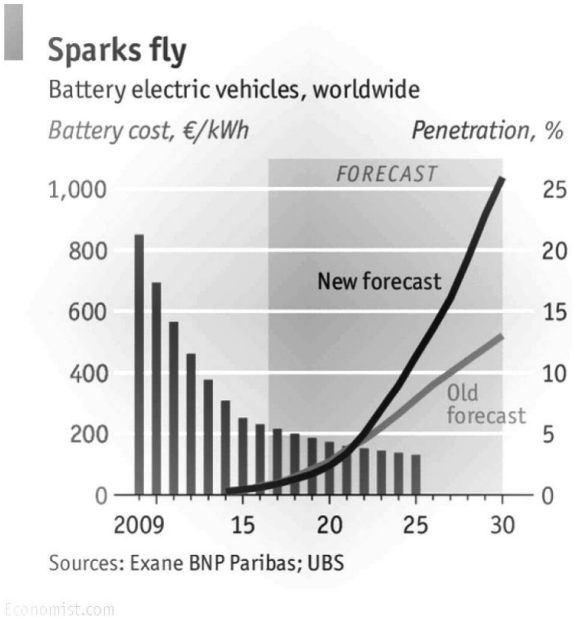


Fig. 5. – Expected battery cost and market penetration of electric vehicles to 2030.

cost. The heat need of the Civil sector can be satisfied using heat pumps running on electricity. The most difficult sector is transportation, which covers by itself about 30% of the total energy needs.

Most of transportation energy is at present satisfied by liquid fuels with a very high energy density (gasoline and diesel), with about 1 billion of road vehicles at present on the roads. This number is expected to double by 2050 and triple by 2100. Even if part of the cars could run on electricity (see fig. 5) it is difficult to imagine that all the car and truck pool can be converted to electricity, so liquid fuel may be still needed for a long time. Moreover, the airplane sector, which constitute 15% of the total energy consumption for transportation, cannot run on electricity.

In the following section a possible technology to produce high-energy-density liquid fuels from residual biomass is presented.

## 5. – How to substitute crude oil

The major goal of advanced research in residual biomass treatment is to produce something sufficiently similar to crude fossile oil to be fed into standard refineries. Here the keyword is residual (or waste), because the limitation in the territory and the competition with food do not allow to satisfy demand with energy crops. The European Commission proposal for the RED II, the Renewable Energy Directive for the post 2020 period, introduces a gradual phase-out of conventional biofuels and sets a minimum

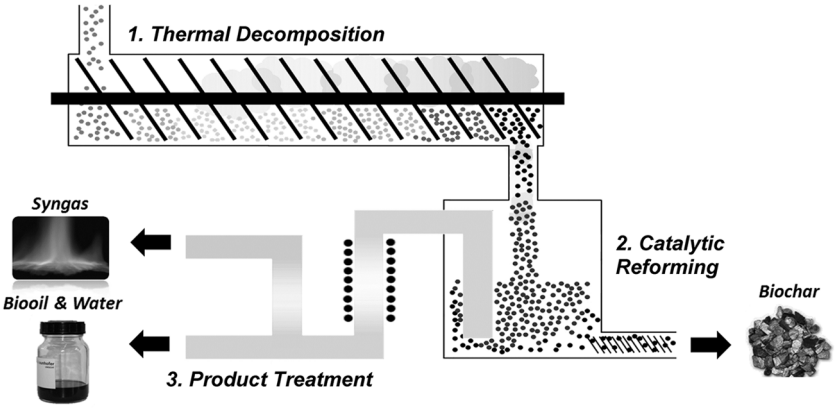


Fig. 6. – Thermo-Catalytic Reforming process overview (adapted from `http://www.susteen-tech.com/technology.html`). 1) Thermal Decomposition: biomass is carbonised to biochar at intermediate temperatures and volatile organic compounds are extracted. 2) Catalytic Reforming: the biochar is heated up to 600–750 °C and brought in contact with the volatile compounds. 3) Product Treatment: volatile compounds are condensed and the product syngas is cleaned for particles and aerosols in a relatively simple product treatment stage.

target for advanced (*i.e.*, derived from residual biomass) biofuels for transportation. Therefore, there is an urgent need to bring innovative biofuels from sustainable raw materials to the market.

I will illustrate one possible technology which can use essentially any kind of residual biological material in the following section.

**5**˙1. *The Thermo-Catalytic Reforming (TCR®) process*. – The Thermo-Catalytic Reforming (TCR®) process is a very recent development which uses intermediate temperature pyrolysis (500–600 °C), with residence time of about 5 minutes. The high temperature vapours are reformed in the presence of the hot carbonised residue (biochar) at 700 °C and then condensed into a liquid (bio-oil) and a gaseous phase (syngas) [3,4]. The catalytic process is provided by the biochar itself according to the principles described by [5]. Heating can be provided either by electricity or by heat exchangers with hot air from a burner. A functional scheme is shown in fig. 6.

Results on municipal wastes, anaerobic digestate, sewage sludge and wood, validated and verified at pilot scale [6], have shown that the technology can produce a bio-oil with superior physical and chemical properties when compared with traditional fast pyrolysis oil, and a hydrogen-rich syngas. The TCR® bio-oil is low in oxygen content, low in acidity and viscosity, phase separates from water, has a high calorific value and is completely miscible with conventional fossil fuels, as illustrated in [7]. The syngas contains up to 40% of hydrogen. The process is well suited to poor quality waste organic feedstocks (sewage sludge, paper industry residues, the organic fraction of municipal solid waste, anaerobic digestate and others) which are high in moisture and ash content [6]. TCR® oil

Table I. – *Properties of TCR-HDO oil compared to fossile diesel.*

| Parameter | Units | TCR-HDO oil | Fossile diesel |
|---|---|---|---|
| Higher Heating Value | MJ/Kg | 46 | 44.7 |
| Lower Heating Value | MJ/Kg | 43 | 41.9 |
| Acid Number | Mg KOH/g | 0.02 | 0.02 |
| Viscosity | cSt | 1.4 | 3.0 |
| Water | Wt% | $< 0.1$ | $< 0.1$ |
| Ash | Wt% | $< 0.01$ | $< 0.01$ |
| Ultimate Analysis | | | |
| C | Wt% | 86 | 84.7 |
| H | Wt% | 13.6 | 13.2 |
| N | Wt% | 0.5 | $< 0.1$ |
| S | Wt% | $< 0.1$ | $< 0.1$ |
| O* | Wt% | 0.7 | 1.4 |

has better characteristics compared to fast pyrolysis oil because of the high temperature reforming and the biochar catalytic effects. As shown in table 3 of [6], the characteristics of bio-oil, and in particular the TAN value, only slightly depend on the feedstock. A near commercial TCR® capable of treating 300 kg/h sludge has been constructed and is undergoing tests at Fraunhofer UMSICHT in Sulzbach-Rosenberg.

**5**˙2. *TO-SYN-FUEL Project*. – TO-SYN-FUEL (`http://www.tosynfuel.eu`) is a project funded by Horizon 2020 EU's new research and innovation programme, with the aim to build-up, operate and demonstrate the production of Synthetic Fuels and Green Hydrogen from organic waste biomass, mainly sewage sludge.

By integrating high pressure hydrodeoxygention (HDO) and conventional refining processes, the bio-oil can be upgraded to green fuels that are ready to be used directly in internal combustion engines. These fuels comply with European standards for gasoline and diesel EN228 and EN590, and have already been demonstrated at pilot scale. Table I shows the comparison of the properties of TCR-HDO oil compared to fossile diesel [8].

**5**˙3. *FlexJET project*. – The FlexJET project, financed through the Horizon 2020 EU programme, is building a pre-commercial plant for the production of advanced jet biofuel from waste vegetable oil and food waste, demonstrating the integration of several technologies, traditional transesterification (TRANS) and Thermo-Catalytic Reforming (TCR®) combined with hydrogen separation through pressure swing adsorption (PSA), hydro-deoxygenation (HDO) and hydro-cracking/isomerisation (HC), to produce a fully equivalent Sustainable Aviation Fuel (SAF) compliant with ASTM D7566 standard.

In the first phase, non-food competing waste vegetable oils (cooking oils) will be transformed into aviation biofuel in line with existing standards (HEFA route —ASTM

D7566, Appendix 2), using green hydrogen from residual biomass conversion by TCR®. In the second phase, organic waste fats will be co-refined with TCR® oil from food and market waste: the resulting novel aviation biofuel will be targeted for the ASTM approvals process.

**5**˙4. *Further development*. – To increase the economic value of the TCR® system, an R&D program is starting in the new Fraunhofer Innovation Center for Waste Valorisation and Future Energy Supply at the University of Bologna (FIC_WE@UNIBO) in Ravenna. Using a lab-scale TCR® with a processing capacity of 2 kg/h, the goal is to find better alternatives to Heat and Power production, like material for wastewater filtering from biochar, green hydrogen and methanol from syngas and chemical building blocks, *e.g.* phenols and other aromatics, from oil.

**5**˙5. *Biomass availability*. – In parallel to the development of new technologies, an assessment of the quantity of residual biomasses must be made.

The study presented in [9] provides a comprehensive and exportable categorisation of the residual biomasses from different supply sectors. Thanks to the individual descriptive and quantitative parameters introduced in the paper, an estimate of the theoretical and techno-economic potential is presented for a well-industrialised, agricultural-oriented and environmentally advanced European Region.

In a relatively small region like Emilia Romagna (Italy), 106 different types of residual biomasses belonging to 6 main groups have been characterised. Over half of the total residues come from the agro-industrial and food businesses (58) followed by the agricultural sector (33). The estimate reveals a theoretical potential of $3544 \pm 291$ Gg/year of total solids for thermochemical valorisation and $3460 \pm 639$ Gg/year of total solids suitable for biological treatment. Taking into account only the still unused potential, the quantities decrease respectively to $2120 \pm 298$ Gg/year and $915 \pm 167$ Gg/year. The theoretical energy that can be obtained from the Region's residues corresponds to about 1.8–2.3 Mtoe/year, corresponding to 13–17% of the total regional consumption.

## 6. – Conclusions

Providing energy for humanity is a critical task if our civilisation wants to survive. Both electric power and liquid fuels, at present based on crude oil or natural gas, must be substituted with renewable resources. The brief summary given in this paper shows that a real shift of paradigm towards Sustainable Development can only stand on three pillars: ethical considerations, legal rules and technological development.

REFERENCES

[1] Decleris M., *The Law of Sustainable Development - General Principles* (Directorate-General for Environment, European Commission) 2000, ISBN: 92-828-9287-5.
[2] UNDP, *Human Development Report 2019* (United Nations Development Programme, New York, USA) 2019, ISBN: 978-92-1-126439-5.

[3] Neumann J., Binder S., Apfelbacher A., Gasson J. R., Ramírez García P. and Hornung A., "Production and characterization of a new quality pyrolysis oil, char and syngas from digestate —Introducing the thermo-catalytic reforming process", *J. Anal. Appl. Pyrolysis*, **113** (2015) 137.

[4] Neumann J., Binder S., Apfelbacher A., Gasson J. R., Ramírez García P. and Hornung A., "The conversion of anaerobic digestion waste into biofuels via a novel Thermo-Catalytic Reforming process", *Waste Manag.*, **47** (2016) 141.

[5] Henriksen U., Ahrenfeldt J., Jensen T. K., Gbel B., Bentzen J. D., Hinds-gaul C. and Srensen L. H., "The design, construction and operation of a 75 kW two-stage gasifier", *Energy*, **31** (2006) 1542.

[6] Conti R., Jäger N., Neumann J., Apfelbacher A., Daschner R. and Hornung A., "Thermocatalytic Reforming of Biomass Waste Streams", *Energy Technol.*, **5** (2017) 104.

[7] Hornung A., *Transformation of Biomass. Theory to Practice* (John Wiley & Sons) 2014.

[8] Neumann J., Jäger N., Apfelbacher A., Daschner R., Binder S. and Hornung A., "Upgraded biofuel from residue biomass by Thermo-Catalytic Reforming and hydrodeoxygenation", *Biomass Bioenergy*, **89** (2016) 91.

[9] Greggio N., Balugani E., Carlini C., Contin A., Labartino N., Porcelli R., Quaranta M., Righi S., Vogli L. and Marazza D., "Theoretical and unused potential for residual biomasses in the Emilia Romagna Region (Italy) through a revised and portable framework for their categorisation", *Energy Rev.*, **112** (2019) 590.