LOCALITY

AND THE

GLOBAL CHALLENG-ES OF ENERGY TRANSITION

Edited by
László Bokor – Dávid Karátson – Béla Munkácsy

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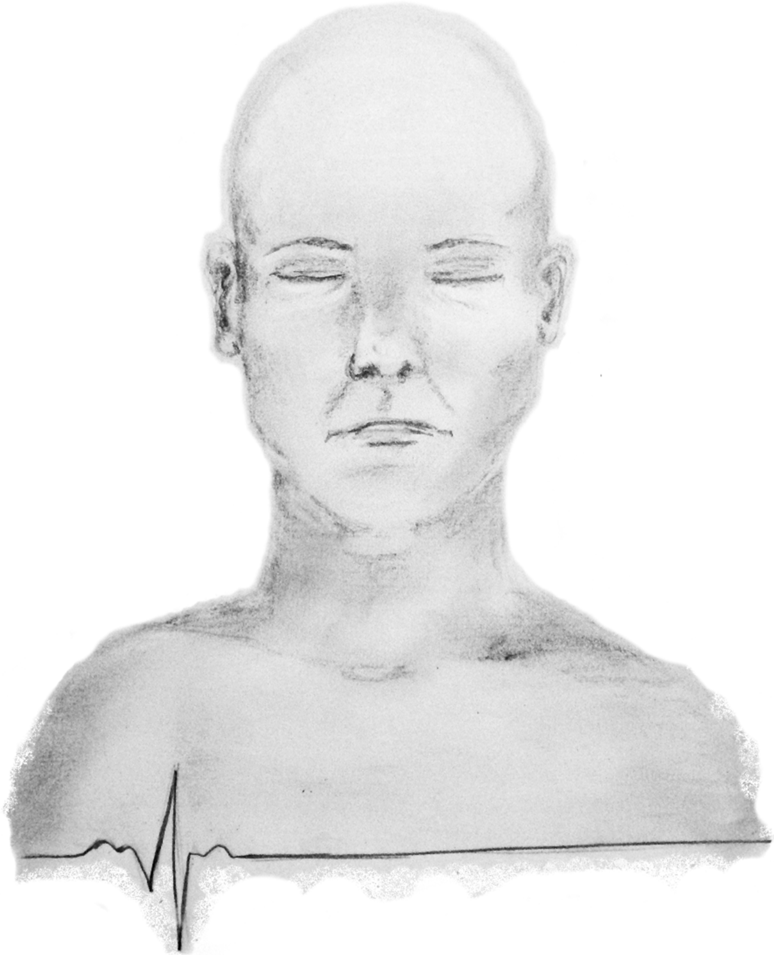

Nuclear devastation *~ a poem by László Bokor*

Protons and neutrons that's what we were,
Atomic energy that powered our cells.
Nature created us as a monstrous force,
Human hands made us something to be afraid of.
Bombs and power stations in their shadows we lived,
Our dawn was drawn by threats and risks.
The radiation that we couldn't see,
Ate us alive, poisoned everything.

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Publisher's Preface

Number four. In 2013, after the release of the first issue of *Geographical Locality Studies* entitled *Locality and the Energy Resources*, we believed that we could one day get as far as we are now; although, we did not think that by this time, we would have published one issue every year. I remember the day, 18th June 2013, when the official workshop took place at the *University of Pécs* in *Hungary*, and we celebrated the issuing of the first number. A colleague, however, challenged me by telling me that he did not think this journal would work out. In the spotlight of this, it is a great feeling to express that *GLS* has done something unbelievable. It is a bit of a cliché, but I always tend to push harder when I sniff a hint of scepticism or jealousy. The past few years, therefore, make a great overall summary of achievements for the journal, and 2017 looks promising for exceeding the limits of the annual publications. Number four, however, has been through a long journey, the most difficult in the existence of the series so far.

The fourth number originally started off as a co-operative project of *Frugeo* and the *European Association of Geographers*, *EUROGEO*, early 2016, and we wanted to encourage our student contributors to craft the year's best papers in sustainability-themed topics. We even founded an award with modest prizes along with an invitation to the annual *EUROGEO* conference which was held in *Malaga*, *Spain*. We expected a lot of contributions and outstanding papers; however, we were incredibly shocked when we had received only two articles by our May deadline! Eventually, we had to abandon the original project and to return to the preparation phase of a usual thematic issue. But by the time we started reorganising ourselves, we were already half a year delayed.

The idea and concept of this number goes back to April this year, when I met up with *Béla Munkácsy* and *Dávid Karátson* in regards to the previous number, *GLS 3*, when a future thematic issue on nuclear energy came also in view. On that day, we agreed that we would deal with that project some time and hence we laid down the foundations of this present publication. Since the abolishing of the *Award project* was unavoidable, the focus was set on this concept. During the later months, we extended this theme to *Global Challenges of Energy Transition* and the preparation began in early August which did not give us much time to organise the work's entirety within a short period that the year and other work obligations had left for us. We set up a new deadline for the end of September, which was eventually shifted and the submission of papers were closed by the end of November. Luckily by then, enough contributors had sent us their papers and *GLS 4* was on its way to becoming a reality.

The new project successfully exceeded our expectations, as number four has happened to be much larger than any previous issues in the series. Since we received mostly highly extensive articles, the editorial works have taken longer than we had originally anticipated. *GLS*, as being a peer-reviewed journal, also had to find extra time for the reviewing and proof-reading process. We are, therefore, very honoured to have so many helping hands in the team, as without them, there would be no journal. I would also like to highlight that everyone who contributes in *GLS* does it as a part-time hobby as the entire project is a not-for-profit activity. The online version is also an open-source which means that anybody can access the journal issues and the individual articles free of charge via the official website of *Frugeo Geography Research Initiative* (www.frugeo.science). It is, therefore, important for us to receive donations or other forms of support to keep our scientific activities going.

Whilst the overall funding for *GLS* projects is certainly challenging, there are plenty of reasons that motivate us to keep on track. Among others, the journal discusses important environmental and geographical topics that we try to build into articles which can be read by a wide range of audiences. The papers we publish, therefore, covers many different scientific areas and bear academic properties whilst also focuses on general understanding and, therefore, provides clear structures and explanations. The quality, topicality, and the credibility of the papers is secured by an acclaimed editorial board and reviewer team; and we aim to be a verified journal by *Scopus* which has been officially requested by *Frugeo*. We hope that the number in our contributor and reader audience carries on growing and every time a *GLS* number is issued, we can deliver the same high standards of publications as we have done so far.

There have also been some changes in the look of the journal and its papers too. This action had to be pursued, because 'Number four' is the first issue when there is a higher limitation on the number of authors involved in production of a single article which required us to redesign the articles' 'first pages' and give more room to the introduction of the authors and the abstracts of the papers. Among the new changes, this is also the first time when the publication is not dedicated to one certain person, but rather to a group of people: those who were affected by nuclear radiation, either because of a power station accident or irresponsible human activities (for example, bomb testing). The timeline, therefore, has also been themed with the 'devastation' that no other energy resource can bring upon the planet and its earthlings. After all, it is unavoidable to say that this number of *GLS* is definitely a subjective issue, but it clearly reflects on our beliefs that the more environmentally friendly and sustainable energy resources are, the less harm and fewer risks can be done to all environmental spheres.

In the name of the current issue's *Editorial Board*, including *Dávid Karátson* and *Béla Munkácsy* as special issue editors; the reviewers, *Zoltán Baranyák*, *János Csapó*, *Ivan Hollins*, and *Dénes Lóczy*; the language editor, *Katie Eccleston*; and *Viktória Nemes* who was responsible for the graphic and portrait art works; and all the other contributors and supporters who helped in production, I am honoured to personally thank you *Dearest Reader*, for taking the time for turning these pages and helping to keep our journal alive. Thank you once again.

Shrewsbury, 11 December 2016

László Bokor
Editor-in-Chief of Geographical Locality Studies
Managing director of Frugeo Geography Research Initiative

Introduction

1942: *Manhattan Project*. 1945: *Hiroshima* and *Nagasaki*. 1949: *Semipalatinsk*. 1954: *Bikini Atoll*. 1957: *Mayak* and *Sellafield*. 1979: *Three Mile Island*. 1986: *Chernobyl*. 1997: *Tokaimura*. 2011: *Fukushima*. It is highly likely that, at least, one of these dates and associating places may call the attention of the reader who will possibly understand the strong cohesion of events in the timelines that we have used in this publication. These notable and certainly symbolical events are all related to the same, powerful earthly force: nuclear energy, and due to the catastrophes and accidents listed above, their serious impacts on both physical and social environments, has undoubtedly gained a negative reputation worldwide within conscious environmental thinking. This type of energy resource involving weapon testing, exemplary 'landscape shaping', a high rate of death tolls, and a significant number of power station incidents and accidents have deeply shaped the last almost 75 years of human history.

During this three-quarter of a century, nuclear power stations of the planet have generated a high proportion of energy, mostly electricity. Despite the nuclear threat, in the era of global warming, it is a common belief that nuclear power is clean (with a low CO_2 emission compared to conventional power stations), and can be presented as a reliable and secure source of energy. Whilst its air pollution has indeed little impact on the environment compared to coal- and oil-fired power stations, if the whole life cycle and the progressively lower uranium ore grade is considered, the CO_2 emission of nuclear plant operation is not neglectable. With this in mind, and given the risk of power station malfunction, nuclear contamination that may affect the environmental spheres makes this type of energy resource the most feared, and in progressively more countries, the least wanted.

Since ground-breaking technological and efficiency improvement of renewable energy services, the use of nuclear energy could be significantly reduced or fully abolished. In Europe, many countries' electricity generations are dependent on domesticated atomic energy; but more and more of these state formations (for example *Sweden*, *Switzerland*, and *Belgium*) realise its dangers and the challenges that come with the deposition of its highly radioactive waste and exhausted parts. Therefore, the aim of developing, and investing in, renewables is becoming more and more important. But, as long as the encouragement of the utilisation of renewables is a common European ethos, especially in the era of global environment and climate challenges, politicians in some countries do not seem to bear rational thinking when the decision should be made between the locally available or the imported and, therefore, dependency-bounding resources.

This current thematic issue of *Geographical Locality Studies* presents seven papers that all deal with energy resources from certain aspects. The main theme is set on nuclear energy as this is the type of resource of which further development should be strongly analysed. It is just ironic that this publication coincides with the anniversary of a few of the above infamous events (for example *Chernobyl*); and due to these events' negative nature, we have decided to abandon one of *GLS*'s traditions, and have not dedicated this issue to a particular person, but to all of those who have been affected in any way by a nuclear incident or accident. The timeline has also been designed accordingly by *Tihamér Kovács* and *László Bokor*. The structure of this publication then deals firstly with nuclear energy, and secondly with regional and local examples mostly related to the national energy systems.

As an introduction to the prime topic, therefore, the first paper, written thoroughly by *Jan Willem Storm van Leeuwen*, gives a considerable insight into nuclear power and its utilisation set in a global context. One of the main messages of the paper is that, in the next 50 years, given the decreasing uranium ore grade, nuclear power may become not only economically but also environmentally unsustainable, by emitting increasing amounts of CO_2.

This paper is then followed by a local example inspired by the current anti-renewables and pro-nuclear campaigns in *Hungary*. The author, *Fanni Sáfián*, navigates us through the current challenges that affect the development of Hungarian energy systems. *Béla Munkácsy* and his team, including *Norbert Kohlheb*, *Ádám Harmat* and *Fanni Sáfián*, continue to look at *Hungary* and expand on the topic concerning the previous article where they address issues related to sustainable energy production and their environmental aspects whilst it also attempts to calculate the country's overall renewable energy potential.

László Bokor's article was originally inspired by the uncertainty and false-news spreading on social-media in regards to *Brexit*. It quickly evolved and became an analysation of the British energy economy focusing on the local availability, the countrywide utilisation, and the local–global integration of all types of energy resources in the *United Kingdom*.

The last three articles focus on specific research areas, thus *Katalin Juhász-Dóra* and fellow researchers including *Katalin Ásványi*, *Melinda Jászberényi* and *Gábor Michalkó* present us with a paper based on website research into how hotels in *Hungary* use energy resources as a marketing tool; the Slovenian colleagues *Mojca Golobič*, *Špela Kolarič*, *Tadej Bevk* and *Naja Marot* give us an insight into the Slovenian wind energy dilemma; and the journal then closes with *Béla Munkácsy* and his team "Erre van előre" (This is the Way Ahead) discussing the electricity storage possibilities from a geographic viewpoint.

The editors of the present volume are convinced that the shift from conventional to renewable, conscious energy use, at least in *Europe*, is progressively accelerating in the near future; this volume is expected to be a modest but definite contribution towards that acceleration.

Shrewsbury–Budapest, 13 December 2016

László Bokor – Dávid Karátson – Béla Munkácsy

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Nuclear Power in its Global Context

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Abstract

Nuclear power is often recommended to the general public by reason of two benefits: nuclear power would be a vital component of a secure energy supply for centuries to come, and it would be indispensable for climate change mitigation.

Energy security and climate change mitigation are physical issues important at a global scale and with a long-time horizon, so an assessment of these benefits should be independent on political, economic and military considerations. For that reason, this study is based on a two-track physical analysis of the current nuclear energy system and advanced nuclear technology concepts. Novel notions are introduced: the energy cliff of nuclear power, the thermodynamic quality of uranium ores and the CO_2 trap.

Based on this analysis the significance of the two benefits in the long run are assessed.

Key words

Thermodynamic assessment; greenhouse gas emissions; prospects; energy cliff; CO_2 trap

Findings

Nuclear power is generated from a mineral found in nature by means of the most complex system of industrial processes ever designed, with a cradle to grave period of 100–150 years. Energy security and climate change by anthropogenic greenhouse gas emissions are global issues. Assessment of the role nuclear power currently plays and might play in the future requires a thermodynamic analysis of the nuclear energy system over its full cradle to grave period with an indefinite time horizon.

Thermodynamic quality—The thermodynamic quality of a uranium resource is defined as the amount of electricity that can be generated from 1 kg uranium minus the direct plus indirect energy inputs consumed by the industrial processes required to produce nuclear fuel from that resource as present in nature. The thermodynamic quality of uranium resources depends on several geologic variables; it declines exponentially with declining ore grade.

Energy cliff—The inputs of materials and energy per kg recovered uranium rise exponentially with declining ore grade. Consequently, the net energy production of the nuclear system depends on the thermodynamic quality of the uranium resources feeding the system: it declines exponentially with declining ore grade. At a grade below 0.2 gram of U per kg ore the net energy production falls to zero and the nuclear energy system becomes an energy sink instead of an energy source. The relationship between the net energy production of the nuclear energy system and the uranium ore grade is called the energy cliff.

Uranium-for-energy resources—Uranium-for-energy resources present in nature, resources that are suitable as energy source, are limited by their thermodynamic properties, set by the Second Law of thermodynamics. Consequently, unconventional uranium resources, such as shales and phosphates cannot be classified as nuclear energy sources. Feeding the nuclear energy system by uranium from the oceans would also turn the system into an energy sink—if large-scale extraction of 10,000s of tonnes of uranium a year from the oceans would be technically possible at all.

Closed-cycle reactor systems—Concepts of closed-cycle reactor systems, designed to fission a large part of natural uranium (30–60% versus 0.6% in the present reactors), and systems designed to use thorium as nuclear fuel are implicitly based on assumptions that conflict with the *Second Law of thermodynamics*. Therefore, the breeder function of these closed-cycle systems is inherently impossible. These systems, as whole, would have a negative energy balance: they would consume more energy than they could produce.

Reprocessing of spent fuel—Reprocessing of spent fuel is an exceedingly polluting process consuming massive quantities of energy and chemicals. Decommissioning and dismantling of closed-down reprocessing plants will be extremely expensive and time consuming, and will require exceedingly high investments of energy, materials and human effort. No advanced technology will be needed. Decommissioning and dismantling should be included in the energy balance of any nuclear power option that includes reprocessing.

Uranium–plutonium recycling in conventional reactors—The high-energy investments of reprocessing cause a negative energy balance of uranium-plutonium recycling in conventional reactors. Apart from this prohibitive condition, the contribution of U–Pu recycling in LWRs to more efficient use of uranium would be marginal: at best some 18% of the annual consumption of natural uranium might be saved, provided that all spent fuel of the world were to be reprocessed and all the separated plutonium could be used to produce U–Pu fuel.

From the finding that the uranium-plutonium and thorium-uranium breeder systems are infeasible may be concluded that nuclear power in the foreseeable future must be based exclusively on the technology of the existing conventional thermal neutron reactors and consequently on the conventional uranium resources.

The world average grade of exploited uranium ores is steadily declining with time, because the richest and most easily mineable deposits are always mined first, for these offer the highest return on investments. Thus, the remaining deposits are less easily mineable, have a lower ore grade and consequently a lower thermodynamic quality. Recovery of uranium from these less favourable deposits consumes more energy and auxiliary materials and emits more CO_2 and likely also other GHGs.

CO_2 trap—Below a grade of about 0.2 gU/kg ore the nuclear CO_2 emission surpasses that of fossil-fuelled power stations. This phenomenon is called the CO_2 trap.

Specific material consumption—At present, the specific material consumption of nuclear power comes to about 206 grams of materials per delivered kWh, of which only 5 grams are recyclable, versus 5.2 grams/kWh, all fully recyclable materials, for an equivalent wind power farm producing an equal amount of electricity. These figures do not include materials consumed during operation of the systems (cooling water, maintenance and refurbishments), nor the materials for the required electricity grid and backup power systems.

Specific CO_2 emission of nuclear power—The specific CO_2 emission of nuclear power is estimated at 90–150 gCO_2/kWh at the present conditions. The numerical spread is mainly caused by uncertainties regarding construction and dismantling of the nuclear power plant. These figures do not include the upstream losses of the fossil fuels consumed by the industrial processes of the nuclear chain.

The nuclear CO_2 emission figures published by the nuclear industry are much lower than found in this study, even lower than wind power, these figures sound unrealistic in view of the high specific material consumption of nuclear power compared to wind power.

GHG emissions other than CO_2—In the publications of the nuclear industry no statements are found that refer to the possibility of GHG emissions other than CO_2 by nuclear power. Also, absent in the open literature are reports proving that the nuclear process chain does not emit GHGs other than CO_2. This absence seems to suggest that nuclear power does not emit other greenhouse gases. However, absence of published GHG data does not mean absence of GHG emissions. Assessment of various chemical processes that are indispensable for the generation of nuclear power proves it is inconceivable that the nuclear process chain would not emit other greenhouse gases.

Krypton-85—Large amounts of the radioactive noble gas krypton-85 are emitted into the atmosphere by the nuclear energy system. Apart from its harmful health effects, the gas gives rise to unforeseeable effects for weather and climate; it causes the formation of tropospheric ozone, a greenhouse gas causing also smog and health problems.

Nuclear mitigation share—For the year 2014, this study found a nuclear mitigation share of 4.9% of the global CO_2 emissions, down from 5.8% in 2010, assumed nuclear power is CO_2 free; the real share is significantly lower because nuclear power does emit CO_2. The above figures include the mitigation of upstream losses of the fossil fuels, and ignore the emissions of GHGs other than CO_2.

Potential nuclear mitigation share—Three scenarios of the potential nuclear mitigation share in the future are:

1. Continuation of the current trend of declining global nuclear capacity. There are no signs that this declining trend would reverse in the foreseeable future. If it would continue the nuclear mitigation share would approach zero by the year 2060–2070.
2. In one scenario of *International Atomic Energy Agency* (IAEA) the world nuclear capacity would remain constant at the present level. In this scenario, the nuclear share of climate change mitigation would decline to 1.4–2.6% by the year 2050, depending on the growth rate of the world energy consumption (3.5%/year respectively 2%/year).
3. In its most optimistic scenario the IAEA projects a nearly threefold global nuclear capacity by the year 2050, from an effective 333 GWe in 2014 to 964 GWe by 2050. In this high scenario, the mitigation share would be 4.2–7.6% by the year 2050.

The IAEA high scenario would imply an average construction rate of 27 GWe of new reactors per year, compared with the current rate of 3–4 GWe/year. It is unclear how realistic this assumption is, in view of the current problems in the nuclear construction sector.

The CO_2 emission figures in *scenarios 2* and *3* are based on the assumption that nuclear power is free of GHG emissions, which it is not. As a result of the depletion of thermodynamically high-quality uranium resources, the CO_2 trap, the specific nuclear CO_2 emissions will rise with time. In *scenario 2*, constant nuclear capacity, the nuclear CO_2 emission would surpass that of fossil fuels by the year 2070–2080. In *scenario 3*, constant nuclear share, the nuclear energy system would reach the CO_2 trap by the year 2050.

Any growth scenario of the nuclear capacity and GHG mitigation share seems unlikely, unless millions of tonnes of thermodynamically high-quality uranium resources would be discovered during the coming decades. Such discoveries seem unlikely from a geologic point of view.

1. Introduction

For decades, nuclear power has been a component of the energy supply in many countries of the world. What role could civil nuclear power play in the future for society and the global environment? The old promises from the 1960s and 1970s of 'too cheap to meter' and 'toute électrique, toute nucléaire' faded away. Now newly stated benefits are put forward by the nuclear industry to recommend investments in nuclear power: nuclear power would be a vital component of a secure energy supply for centuries to come, and it would be indispensable for climate change mitigation.

Climate change mitigation and energy security are physical issues at a global scale and with a long-time horizon, so a scientific assessment of the twofold claim, independent on political, economic and variable assumptions, requires a physical analysis of the complete sequence of industrial activities making nuclear power possible. A physical analysis is based on unambiguously defined physical quantities, such as the conserved quantities energy and mass.

This study starts with outlining the global context of nuclear power: the present state of the global greenhouse gas (GHG) emissions and of the world energy supply. The most recent data on the global GHG emissions are from 2010. Published trends indicate that the mutual proportions of the various contributors are changing slowly; therefore, the results of this study may still be valid for the year 2014, the base year of this study; moreover, the uncertainty range of the numerical results is not negligible. The scope of the analysis is limited to the emission of carbon dioxide (CO_2) from burning fossil fuels for generating useful energy, for nuclear power is an energy supply system and could only substitute fossil fuels as energy source. Emissions of other GHGs are briefly addressed.

The thermodynamic assessment of the issues of the nuclear GHG mitigation share and energy security comprises two independent tracks, represented in *Figure 1*. Thermodynamics is the science of energy conversions and is at the basis of natural sciences, such as physics, chemistry, biology, and geology.

In the first analysis track this study assesses the specific CO_2 emissions of nuclear power and the long term global perspective of its relationship to climate change mitigation. The specific nuclear emissions of CO_2 and other GHGs are assessed by means of a thermodynamic analysis coupled to a life cycle assessment (LCA) of the complete system of industrial activities required to generate electricity from uranium and to safely manage the radioactive wastes.

Based on this analysis three novel notions are introduced: the energy cliff, the CO_2 trap and the thermodynamic quality of uranium resources, notions that set physical boundaries to the world uranium resources that can be called 'uranium-for-energy resources'.

In addition, the hypothetical contribution of nuclear power to mitigation of GHG emissions in the future is assessed in two scenarios: constant global nuclear capacity and a growth scenario proposed by the nuclear industry. How large could the nuclear contribution to mitigation of global greenhouse gas emissions hypothetically become, assumed nuclear power does not emit CO_2 nor other GHGs?

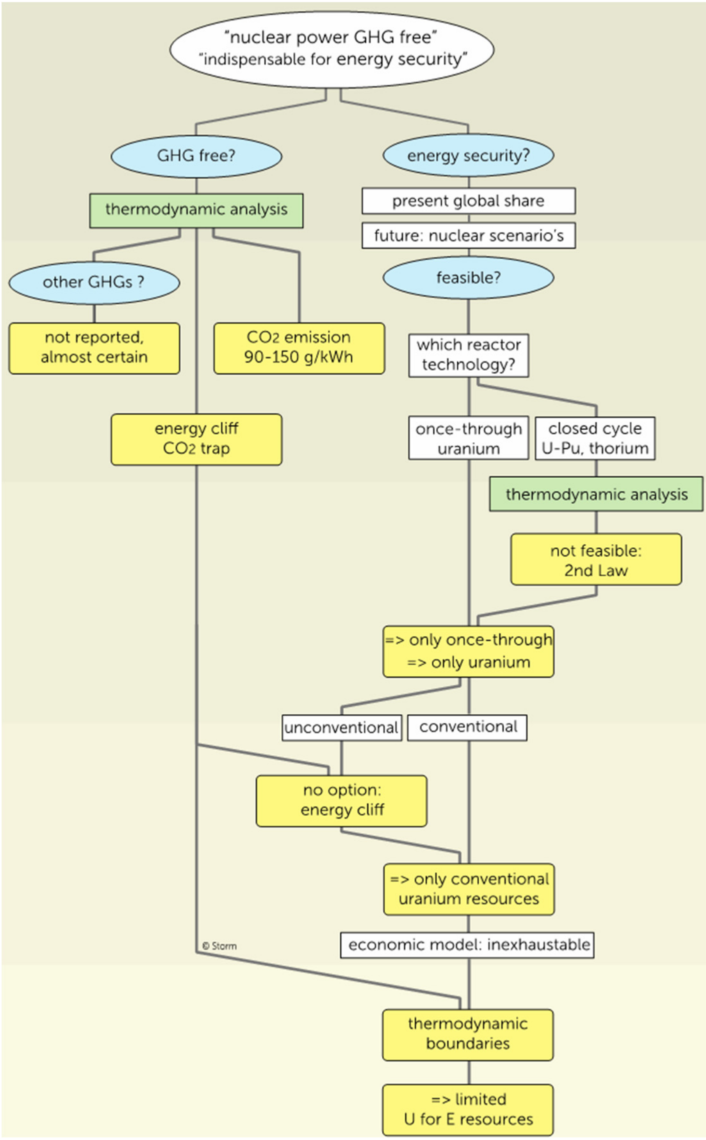

Figure 1 – Outline of the assessment of this study, with two independent analysis tracks

Designed by STORM VAN LEEUWEN, *J. W. (2016)*

In the second line of the thermodynamic analysis an important component in the prospects of nuclear power is the subject: the application of advanced nuclear technology, such as closed-cycle reactors and thorium reactors. Specific features of the proposed advanced nuclear concepts that limit their application are identified by means of a thermodynamic analysis.

Assessment of the energy security nuclear power might offer in the long run is possible using the results of both lines of analysis.

2. Contribution of nuclear power

2.1. Assessment method

Nuclear power is said to be carbon-free and would be indispensable for mitigation of the climate change, due to the emission of greenhouse gases (GHGs) by human activities. This claim of the nuclear industry suggests on one hand that nuclear power does not emit carbon dioxide CO_2, nor other GHGs, and on the other hand that the nuclear contribution to the world energy supply can grow significantly beyond the current level and will remain a safe, reliable energy source for many decades to come.

Assessment of the question whether nuclear power does not, or virtually not, emit carbon dioxide CO_2, nor other GHGs requires a thermodynamic analysis of the complete system of industrial activities required to generate electricity from uranium and to safely manage the radioactive wastes. A thermodynamic analysis charts the flows of materials and different kinds of energy involved in the nuclear energy system. By means of this analysis also the claim can be assessed that nuclear power would offer a safe and reliable energy source at a globally significant scale for many decades to come. After a brief description of the complete nuclear energy system in *Chapter 3*, *Chapter 4* discusses the thermodynamic analysis of the nuclear energy system, represented by the left track of the analysis outline in *Figure 1*.

Assumed nuclear power is GHG-free, as stated by the nuclear industry, the current nuclear contribution to the mitigation of GHG emissions can be estimated based on just two data sets:

1. sources of the global GHG emissions, and
2. nuclear share of the world energy supply.

Technical data on the nuclear system itself are not needed for this estimate. This chapter addresses the current nuclear mitigation share and the prospects by the year 2050, based on the assumption that nuclear power does not emit GHGs, in two scenarios as envisioned by the *International Atomic Energy Agency* (IAEA).

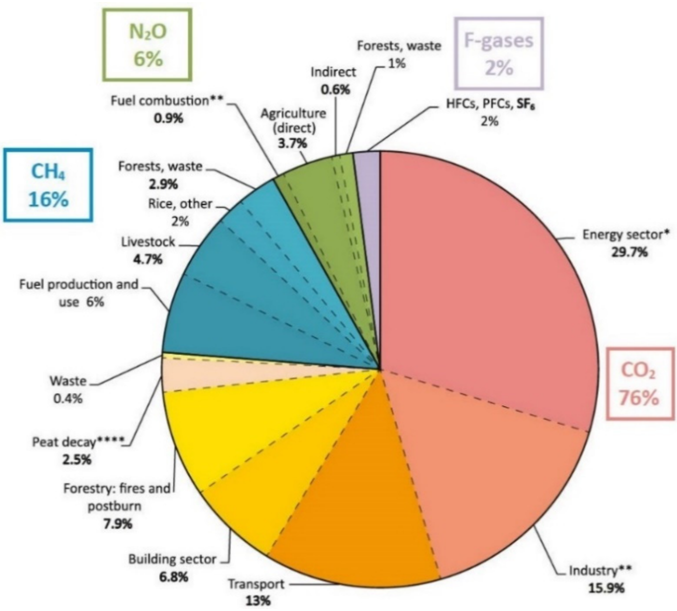

Figure 2 – Sources of global GHG emissions in 2010, weighted by their global warming potential (GWP). F-gases are fluorinated gases

** Power generation, refineries, coke ovens; ** Including non-combustion CO_2 from limestone use and from non-energy use of fuels and N_2O from chemicals production; *** Including wastewater; **** Including peat fires.*

Source: (UNEP, 2012)

2.2. Global greenhouse gas emissions

Anthropogenic global warming is understood to be caused by the emission of greenhouse gases (GHGs). The global warming potential (GWP) of the gases released into the air vary widely and are measured as a multitude of the GWP of carbon dioxide and expressed in the unit gram CO_2-equivalent. *Figure 2* shows for the year 2010 (UNEP, 2012) the shares of the main categories of GHGs: carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O and fluorinated compounds.

In 2010, the CO_2 emission of the energy sector, presumably the generation of electricity from fossil fuels, was 29.7% (rounded 30%) of the global GHG emissions. The other sectors emitting CO_2 by burning fossil fuels are industry (15.9%), transport (13%) and a part of the building sector. The sum of CO_2 emissions from burning fossil fuels in 2010 was 61%, according to IEA/a (2012), see *Figure 3*.

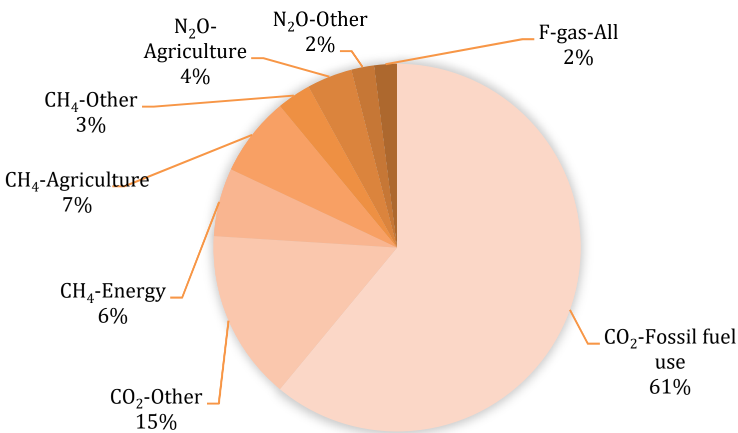

Figure 3 – Global greenhouse gas (GHG) emissions by gas/source in 2010, weighted by their global warming potential (GWP)

Source: (IEA/a, 2012), the most recent available data on the global emissions of greenhouse gases concerned the year 2010. Chart designed by BOKOR, L. (2016)

In 2010, 76% of the global warming potential was caused by CO_2: 61% CO_2 originating from burning fossil fuels and 15% from other sources (forestry, other land use, industrial processes: for example, cement production emitted 3% of the global greenhouse gases (IEA/a, 2012). At the time of writing of this paper the most recent data on the global GHG emissions were from the year 2010. Likely the mutual ratios of the various sources of GHGs did not change significantly in the years following 2010.

No data are available on the emissions of non-CO_2 GHGs by nuclear power, although emissions of fluorinated gases, most of which are powerful GHGs, are almost certain. For that reason, the assessment of the potential role of nuclear power as primary energy source in mitigation of the global GHG emissions has to be limited here to the CO_2 emissions from power generation by use of fossil fuels: 30% of the total global GHG emissions, or 30/61 = 49% of the CO_2 from burning fossil fuels.

2.3. Current nuclear share of the world energy supply

As it turns out the published figures concerning the world energy supply and its nuclear component are not always consistent; this will be explained in the following sections.

In 2010 the world gross energy production was about 517 EJ (1 exajoule = 10^{18} J), that is the sum of the combustion heats of fossil fuels and biomass plus the electricity generated by hydropower, nuclear power and modern renewables *(Figure 4)*. The total world energy production is not exactly known, for the energy consumption of traditional biomass (wood, dung, straw, peat, organic waste) in a number of developing countries can only be roughly estimated. In the energy statistics of BP (2011) only traded energy flows are listed: fossil fuels, hydro power, nuclear power and modern renewables. Data on non-traded combustibles, especially biomass and waste, are taken from IEA/b (2012).

Usually the energy flows in world energy statistics are given in million tonnes oil equivalent, 1 MTOE = 42 PJ (1 petajoule = 10^{15} J). In most statistical energy reviews, for example BP (2011) and IEA/b (2012), and in publications of the nuclear industry the electricity generated by nuclear and hydro is converted into thermal equivalences, measured in 'primary energy' units, by multiplying with a

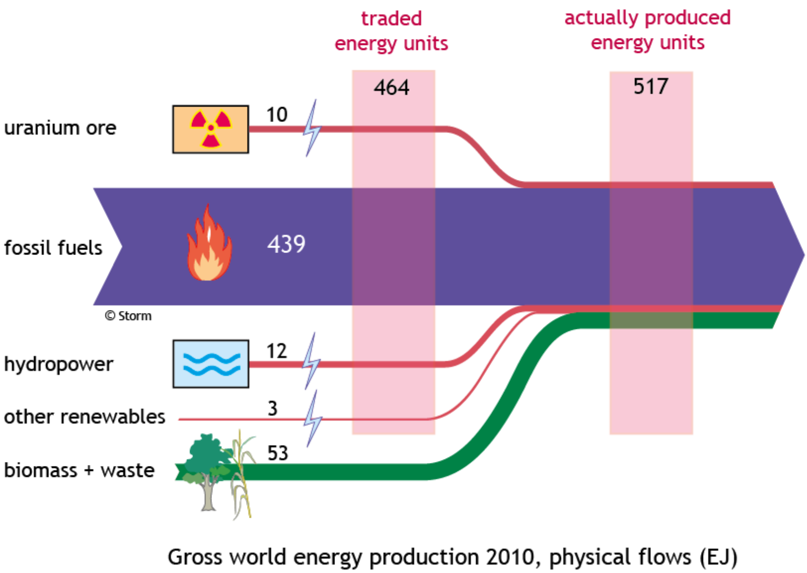

Figure 4 – Actually delivered, usable energy (in exajoules EJ) to the world economy in 2010. *This diagram is based on Table 1. The numbers are rounded. Designed by STORM VAN LEEUWEN, J. W. (2016); Source of traded energy figures: (BP, 2011). The figure of traditional biomass (53 EJ) is not accurately known; source: (IEA/b, 2012). Other renewables comprise: solar (PV and CSP), wind, small hydro, geothermal and 'modern' biomass.*

factor $f = 2.64$, as if the electricity has been generated from fossil fuels at a conversion efficiency of 37.8% (the currently operating nuclear power plants have 30–34% thermal efficiency). In its statistics before 2001, BP applied the factor $f = 3$ for nuclear and $f = 1$ for hydro; in other publications these conversion factors may still be used. Electricity from photovoltaics (PV), wind or *Concentrating Solar Power* (CSP) is usually not converted into 'primary energy' units MTOE.

The heat from a nuclear reactor cannot be used directly. The only form of usable energy from a nuclear power plant is the electricity it delivers to the grid. A hydropower plant does not produce heat at all. Applying the conversion into 'primary units', the contribution of nuclear power to the world energy supply seems to be nearly 3 times larger than the actually delivered quantity of useful energy units.

Conversion to thermal equivalence units would imply that 1 joule electricity from a nuclear power plant would generate nearly 3 J of heat in an electric heater and that 1 Joule electricity from a wind turbine would deliver 1 J of heat. Electricity is not labelled: 1 Joule nuclear electricity has exactly the same work potential as 1 Joule wind-generated electricity. One joule of electricity, from whatever source, can be converted into not more than exactly one joule of heat, as follows from the First Law of thermodynamics.

Above conversion introduces also variable and arbitrary assumptions, making the energy statistics unreliable for physical computations, because virtual energy units are added to the actually delivered energy units. In thermodynamics, one cannot add quality to quantity. Quality is not a conserved quantity in physics, like mass and energy, and it cannot be defined unambiguously, nor quantified.

This study presents all physical energy quantities of the world energy flows in exajoules (1 EJ = 10^{18} joule), as shown in *Table 1*, without using the notions 'primary energy units' and 'thermal equivalence'. The electricity production figures of nuclear, hydro and other renewables are also listed in the actual measurement unit terawatthour (1 TWh = 3.6 PJ). Terawatthours and million tonnes oil equivalent cannot be added, so at least one of the two has to be converted. In *Table 1*, all figures are converted into joules, that can be added up. Thermodynamics draws no distinction between 1 joule of electric energy and 1 joule of whatever other form of energy (heat, potential energy, mechanical energy, radiation), a consequence of the First Law of thermodynamics. The quality of a given quantity of energy is determined by variable human preferences, so quality cannot be added to a conserved quantity.

In 2010, the nuclear share of the world gross energy production was 1.9%, as calculated in *Table 1* and shown in *Figure 5*. Most energy statistics give another figure; for example, BP (2011) cites a share of 5.2%. This divergence has two causes:

- *1)* BP lists only the traded energy (464 EJ in 2010) and ignores the non-traded energy supply by traditional biomass and waste.

- *2)* BP uses the thermal equivalence of the world nuclear electricity production by multiplying it by a factor *f* = 2.64. This method of calculation results in a number of virtual energy units, which is thermodynamically incorrect, as explained above.

Table 1 – Energy made available in 2010 to the global economic system

Sources: BP (2011) and IEA/b (2012).

	energy source	electricity TWh	combustibles MTOE	EJ	fraction (%)
1	nuclear	2,762.2		9.94	1.9
2	hydro	3,427.7		12.34	2.4
3	other renewables	701.0		2.52	0.5
4	oil		4,028.1	169.18	32.7
5	natural gas		2,858.1	120.04	23.2
6	coal		3,555.8	149.34	28.9
7	sum fossil fuels (4+5+6)		10,442.0	438.56	84.9
8	sum traded energy units (1+2+3+7)			463.37	
9	biomass + waste		1,271.7	53.41	10.3
10	world total (8+9)			516.78	100.0

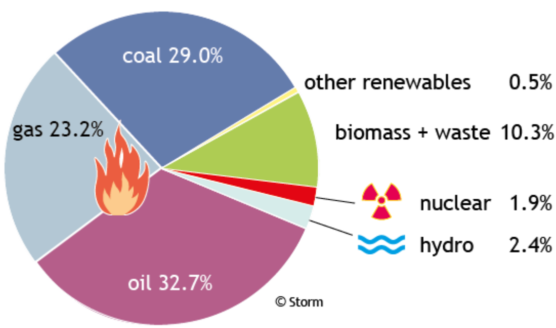

Figure 5 – World primary energy production in 2010 was about 517 EJ (exajoule), of which 464 EJ traded energy. The share of nuclear power was 1.9% in 2010 and is steadily declining

Sources: BP (2011) and IEA/b (2012). In 2014 the nuclear contribution had declined to 1.6% of the world energy supply, and the declining trend continues.

2.4. World final energy use

It may be helpful to look first at the final energy use of the world to determine which fraction of the fossil fuel production theoretically could be displaced by nuclear power.

A portion of the fossil fuels is used to produce asphalt, solvents, lubricants and chemical feedstock. In 2000, this non-energy use of fossil fuels amounted to 22 EJ, some 6% of the fossil fuel production, according to WEISS, M. *et al*. (2009). IEA/b (2012) determined a non-energy use fraction of 6.3% of the total primary energy supply (fossil fuels plus biomass) in 2010, but it is not clear how the IEA came at this figure.

There are three kinds of energy losses in the world energy system:

- *Upstream fossil fuel losses*. The recovery from the earth (production), refining and transport of the fossil fuels consumes some 23% of the energy content of the fuels. This figure is based on data from BP (2011) and the methodology of FRANKLIN, W. D. *et al*. (1971). Indirect energy use and losses due to flared and spilled fuels are not included so it may be a low estimate. This loss fraction will increase with time, as the most easily recoverable resources available are exploited first and will be depleted first; the remaining resources are less easy to exploit and consequently will consume more useful energy per unit of extracted fuel. In addition, the share of liquefied natural gas (LNG) is increasing, leading to higher upstream energy losses.
- *Conversion losses*. In 2010 the average conversion efficiency of fossil fuels into electricity was about 38% (BP, 2011), so 62% of the energy content of the fossil fuels are lost as waste heat into the environment.
- The *average transmission losses* of electricity are estimated at about 6%.

The final energy consumption of the world, that is the gross energy production minus above mentioned losses, amounted to about 326 EJ in 2010. *Figure 6* represents the various energy flows.

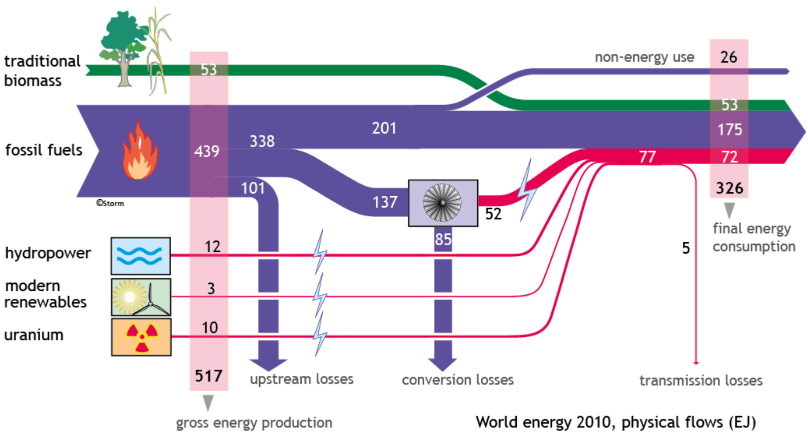

Figure 6 – Physical energy flows of the world in 2010, in exajoules (EJ). *Not accurately known are the amounts of energy embodied in traditional biomass and in the upstream losses of the fossil fuels. Therefore, the world final energy consumption, here presented as 326 EJ, has a significant uncertainty range.*

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A part of the extracted, transported and refined fossil fuels is used to generate electricity. BP (2011) presents an amount of 52 EJ of fossil-fuelled electricity generation, assumed that a negligible amount of electricity is generated from traditional biomass or agricultural residues. BP (2011) assumes a world averaged conversion efficiency (thermal energy to electricity) of 38%, so the amount of potential energy in fossil fuels consumed by the electricity generation in 2010 was 137 EJ.

2.5. Nuclear contribution to GHG emission mitigation in 2010

Non-fossil fuelled electricity generation techniques, such as nuclear, hydro, solar, wind, biomass and geothermal power, may considered to displace fossil fuels. Estimation of the amounts of displaced fossil fuel units seems a relevant method in the discussion on CO_2 emission and climate change mitigation.

Coupling *Figures 2*, *3* and *6* in a simplified model we assume that the input of 137 EJ of fossil fuels for generation of 52 EJ of electricity plus a proportional part of the upstream losses (137/338) x 101 = 41 EJ, amounting to a total of 178 EJ, would correspond with 30% of the world CO_2 emission *(Figure 2)*. Because it is uncertain how UNEP (2012) calculated the data presented in *Figure 2*, it is not clear to what extent the above assumption is reliable.

In 2010, nuclear power generated 10 EJ of electricity; this would displace a fraction of (10/52) x 178 = 34 EJ of fossil fuels, corresponding with a mitigation of the global CO_2 emission of (10/52) x 30 = 5.8%, assumed nuclear power is free of emissions of CO_2 and of other GHGs. This assumption is not valid, as will be proved in the following chapters. Evidently this way of calculating the mitigation of GHG emissions is also valid for renewables and for hydro power.

The nuclear contribution to the global usable energy supply in 2010 was 1.9% and the nuclear CO_2 mitigation share is estimated at 5.8%, assumed nuclear power is CO_2-free. In 2014, the nuclear contribution had declined to 1.6% of the world energy supply, and consequently the nuclear mitigation share declined to 4.9%. Because nuclear power does emit CO_2 and almost certainly also other GHGs, the mitigation shares in practice would be substantially lower than above estimated percentages. Moreover, the specific nuclear CO_2 emission most likely will rise (CO_2 trap), as will be explained in the following chapters.

In 2014, the global nuclear generating capacity comprised 388 operating reactors with a joint capacity of 333 GWe (SCHNEIDER, M. – FROGGATT, A. 2015) producing 2,410 TWh of electricity. IAEA (2015) mentions higher figures of the number of reactors (438) and total generating capacity (376 GWe). To get this higher number, the IAEA considers 40 reactors in long-term outage as 'in operation'; BP (2015) cites a higher figure of the nuclear electricity production in 2014 (2,537 TWh); this study uses the IAEA figure of the production (2,410 TWh) and the data of SCHNEIDER, M. – FROGGATT, A. (2015) of the operating reactors (333 GWe).

The global nuclear electricity generation of 2,410 TWh formed 1.6% of the world energy production in 2014.

2.6. Prospects

How large could the nuclear mitigation to climate change become in the future according to the nuclear industry?

On this issue, no figures were found in the open literature, for that reason this study estimates the mitigation consequences of the envisioned developments of global nuclear generating capacity.

During the past years, the *International Atomic Energy Agency* (IAEA) and the nuclear industry, represented by the *World Nuclear Association* (WNA), published numerous scenarios of global nuclear generating capacity in the future, measured in gigawatt-electric GWe.

IAEA (2015) expects a growth rate of the global energy consumption of 2–3.5%/yr until 2030. Here we assume that this growth rate will continue until 2050 and that the electric share will grow at the same rate. Conveniently we assume also that the global GHG emissions will grow at an equal rate of 2–3.5% per year. Consequently, each scenario has two variants: one at an assumed growth of 2%/yr and the other at a 3.5%/yr growth.

This study assesses two recent scenarios of the IAEA that can be considered typical of the views within the nuclear industry, and assumed nuclear power is free of emissions of CO_2 and of other GHGs (which it is not).

2.6.1. IAEA low, constant nuclear capacity

The low scenario of the IAEA as published in IAEA (2015) corresponds with a nearly constant nuclear generating capacity until 2050 *(Figure 7)*. In this *scenario 1* we conveniently assume that the global operating nuclear capacity would remain flat at the current level of 333 GWe and the annual electricity production would remain 10 EJ/year.

Scenario 1a. The world energy consumption would rise by 2%/yr and consequently would reach a level of 1137 EJ/yr by the year 2050, and the global fossil-fuelled electricity generation 114 EJ/yr. The nuclear contribution would have declined then to 10/1137 = 0.9% of the world energy supply.

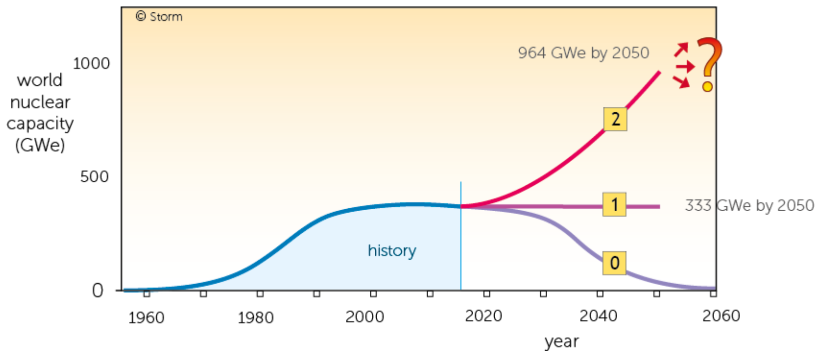

Figure 7 – Three scenarios of the nuclear capacity until 2050. *Scenario 0 represents phase-out of the existing nuclear capacity in the coming decades. Although the global capacity trend is declining, Scenario 0 is a hypothesis and is not discussed in the text. Scenario 1 represents the IAEA low scenario, and Scenario 2 the IAEA high scenario, discussed in the text. Both IAEA scenarios end by 2050, the IAEA did not indicate what they envision after that year.*
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The nuclear mitigating contribution would decline to about (10/114) x 30 = 2.6% by 2050, if both the global energy production and the CO_2 emissions rose at 2%/yr.

Scenario 1b. In the case of a global growth of 3.5%/yr, the global energy consumption would reach a level of 2068 EJ/yr by the year 2050, and the global fossil-fuelled electricity generation 208 EJ/yr.

The nuclear energy contribution would decline to 10/2068 = 0.5% of the world energy supply. The nuclear mitigating contribution would decline to about (10/208) x 30 = 1.4% by 2050, if both the global energy production and the CO_2 emissions rose at 3.5%/yr.

To keep the nuclear capacity at the present level, almost the complete current fleet of nuclear power stations would have to be replaced by 2060, because the currently operable reactors will reach the end of their operational lifetime within that period, meaning that during the next decades, each year 7–8 GWe of new NPPs have to come on-line, two times the current global construction rate of 3–4 GWe/year.

2.6.2. IAEA high, nuclear capacity grows to 964 GWe

In its high scenario, IAEA (2015) foresees a nuclear capacity of 964 GWe by 2050, nearly three times the current global capacity of 333 GWe. If the new nuclear power stations operated at the same load factor as the currently operating NPPs, the electricity generation would be 29 EJ/yr by 2050.

This scenario would imply an average construction rate of 27 GWe of new reactors a year, compared with the current rate of 3–4 GWe/year. It is unclear how realistic this assumption is, in view of the current problems in the nuclear construction sector.

Scenario 2a. The world energy consumption would rise by 2%/yr and consequently would reach a level of 1137 EJ/yr by the year 2050, and the global fossil-fuelled electricity generation 114 EJ/yr. The nuclear contribution would rise to 29/1137 = 2.6% of the world energy supply.

The nuclear mitigating contribution would rise to about (29/114) x 30 = 7.6% by 2050, if both the global energy production and the CO_2 emissions rose at 2%/yr.

Scenario 2b. In the case of a global growth of 3.5%/yr the global energy consumption would reach a level of 2068 EJ/yr by the year 2050, and the global fossil-fuelled electricity generation 208 EJ/yr.

The nuclear energy contribution would decline to 29/2068 = 1.4% of the world energy supply.

The nuclear mitigating contribution would decline to about (29/208) x 30 = 4.2% by 2050, if both the global energy production and the CO_2 emissions would rise at 3.5%/yr.

From the mitigation figures in 2050 follows that *scenario 2* may be roughly described as the 'constant share' scenario, and *scenario 1* as the 'constant capacity' scenario.

The nuclear mitigation share in the two scenarios depends not only on the nuclear generation capacity, but also on the growth rate of the global fossil-fuelled electricity generation and the growth rate of the GHG emissions. Because nuclear power does emit CO_2 and most likely also other GHGs, as will be explained in the following chapters, the real mitigation share would be considerably less than the figures of the IAEA scenarios by 2050, summarised in *Table 2*.

***Table 2 – Summary of the two nuclear scenarios through 2050**, both at a global growth rate of energy consumption and GHG emissions of 2% respectively 3.5%, assumed nuclear power does not emit CO_2, nor other GHGs.*
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scenario		Global growth rate (%/year)	Nuclear capacity In 2050 (GWe)	nuclear E production in 2050 (EJ/yr)	world energy in 2050 (EJ/yr)	fossil-fuelled electricity in 2050 (EJ/yr)	CO_2 emission mitigation in 2050 (%)
1a	IAEA low	2	333	10	1,137	114	2.6
1b	IAEA low	3.5	333	10	2,068	208	1.4
2a	IAEA high	2	964	29	1,137	114	7.6
2b	IAEA high	3.5	964	29	2,068	208	4.2

2.7. After 2050

The future does not end in 2050. No investor will start the construction of new nuclear power plants in the year 2049 without assured uranium supply. This is one of the consequences of the extremely long-term commitments inherent to nuclear power. The plants coming on line in 2050 should have an assured uranium supply during their lifetime of, say, 40–50 years.

In the most pessimistic view, all nuclear construction activities would cease in 2050, which is likely not the intention of the nuclear industry. All nuclear power plants then operating should be able to complete their normal operational lifetime. For that reason, the scenarios are to be extended up until 2100 in order to assess the minimal requirements for the availability of fissile material. The last plants coming on line in 2050 would reach their end of life by about the year 2100. The extended scenarios, based on the assumption of no new nuclear build after 2050, are illustrated by *Figure 8*.

Chapter 6 returns to these scenarios and assess their viability based on the results of the thermodynamic analyses discussed in the following chapters.

Obviously, the nuclear share of GHG mitigation after 2050 would decline in all scenarios depicted in *Figure 8*.

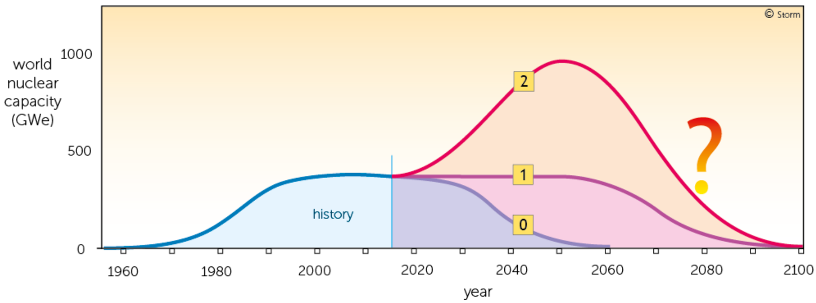

Figure 8 – Development of the global nuclear capacity in scenarios 1 and 2 assumed that after 2050 the nuclear capacity would be phased out

Scenario 0 represents the phase-out of the current nuclear capacity.

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3. The nuclear energy system

3.1. The nuclear process chain

Nearly all current nuclear power plants (NPPs) in the world are operating in the once-through mode, without recycling used nuclear fuel. Only a few NPPs use also MOX fuel (Mixed OXide) containing plutonium from reprocessed nuclear fuel. Expansion of the use of MOX fuel in the future is doubtful.

A nuclear power plant is not a stand-alone system, it is the central part of a sequence of industrial processes comprising three sections: the front-end processes, the production process itself and the back-end processes, a sequence called the nuclear process chain.

- The front-end of the nuclear chain includes the processes to produce nuclear fuel from uranium ore. Nuclear power is based on a mineral energy source, uranium. This radioactive metal has to be extracted from special rocks found at some places in the *Earth*'s crust, a process comparable to the recovery of most other metals. The raw metal has to be purified and processed and enriched in the fissile isotope uranium-235, in order to make it suitable as fuel in a nuclear reactor.
- The midsection encompasses the construction of the nuclear power plant (NPP) and the operation, maintenance and refurbishments (OMR) of the plant. At closedown, most components of an NPP have been replaced by new ones, except the nuclear reactor; the operational lifetime of an NPP is set by the nuclear reactor.
- The back-end comprises the processes needed to handle the materials containing the radioactivity generated by the nuclear reactor and the radioactive materials mobilised in the front-end processes. The purpose of the back-end processes, including dismantling of the radioactive parts of the power plant after final shutdown, is to keep the radioactivity out of the human environment as effectively as possible and as long as needed.

A flowsheet of the full nuclear process chain, as it ought to be, is presented in *Figure 9*. As this diagram shows, the back-end comprises a larger number of industrial processes than the front-end. In fact, the nuclear system has a much more extensive back-end than any other energy system.

Contrary to the front-end processes which involve mature technology and are fully operational, most back-end processes still exist only on paper, despite reassuring publications of the nuclear industry. This study starts from the idea that all radioactive wastes generated by nuclear power would be isolated from the human environment forever. Most activities of the-back-end of the nuclear process chain will be demanding tasks, requiring large investments of energy, materials and economic means.

Only a few processes of the back-end are operational. In the thermodynamic analysis of this study all processes indicated in *Figure 9* are included as if they were operational.

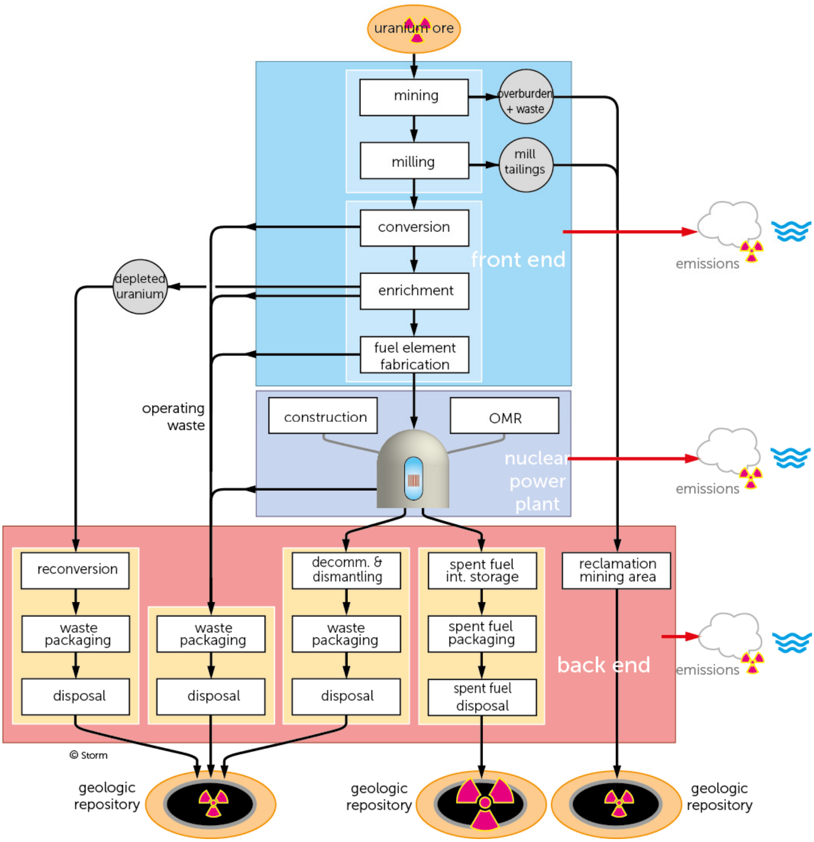

Figure 9 – Full process chain of a light-water reactor (LWR) nuclear power plant in the once-through mode from cradle to grave. *The black arrows represent flows of radioactive materials. Calculations in this study are based on this full chain. In the back-end of the nuclear chain only packaging of operating waste and interim storage of spent fuel are operational in the present practice.* *Designed by* STORM VAN LEEUWEN, *J. W. (2016)*

This study is an update and an extension of earlier studies, see for example STORM VAN LEEUWEN, J. W. (1985).

3.2. Cradle-to-grave period

The life cycle assessment (LCA) in this study comprises all processes related to a given nuclear power plant from cradle to grave, regardless of time and place of the individual processes. The period involved is here called the cradle-to-grave period, or shortened the c2g period. In *Figure 10* the c2g periods of a fossil-fuelled power station and a nuclear power station are compared. Each has three sections: construction, operational lifetime (both 40 years) and back-end. The front-end processes coincide with the operational lifetime.

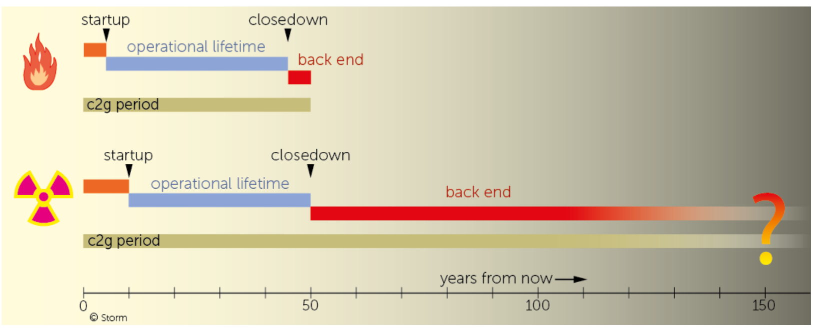

Figure 10 – Time frames (c2g periods) of a fossil-fuelled power plant and of a nuclear power plant, each with a nominal operational lifetime of 40 years
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The c2g period of a fossil-fuelled plant is 50 years or less: the construction takes a few years and the backend, decommissioning, dismantling and site clean-up takes another few years. The nuclear c2g period proves to become extremely long: some estimates mention 150 years or even longer. Nowhere in the world the process chain of a particular nuclear power plant has ever been finished.

3.3. Materials consumed by the nuclear energy system

All materials entering the nuclear energy system are extracted from the biosphere and all materials leaving the nuclear system will end up in that same biosphere sooner or later. During operation, the nuclear system generates tremendous amounts of radioactivity: a billionfold the radioactivity of the fresh nuclear fuel which is placed into the reactor. Each nuclear power plant generates a per year per GWe amount of radioactivity equivalent to about 1,000 exploded *Hiroshima* style bombs.

The human-made radioactivity is mainly contained in the spent fuel elements, but a part of it leaves the nuclear system dispersed over large volumes of construction materials as a consequence of neutron irradiation and contamination with radionuclides. In addition to the generation of human-made radioactivity the nuclear system mobilises vast amounts of natural radionuclides from the uranium ore. During operation and thereafter the nuclear system discharges radioactive and non-radioactive wastes into the environment.

The material flows leaving the nuclear system and entering the human environment *(Figure 11)* can be divided into the following categories:

- recyclable construction materials;
- discharges of radioactive and non-radioactive materials into the human environment, intentionally and unintentionally;
- water used in mining and milling, most of it contaminated with toxic chemicals, radioactive and non-radioactive; cooling water of the reactor during operation not included;
- materials lost forever, due to radioactivity;
- waste rock.

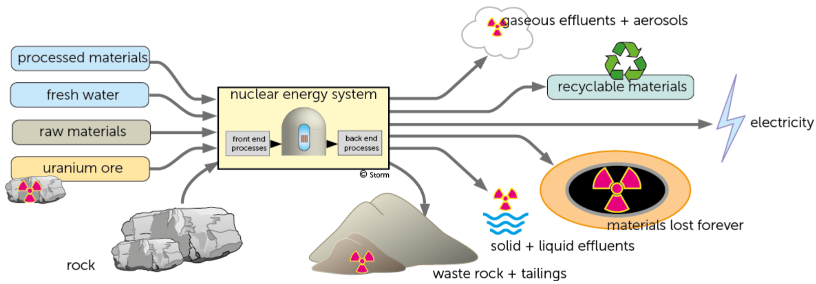

Figure 11 – Outline of the flows of materials of the complete nuclear energy system from cradle to grave.

Radioactive materials are assumed to be disposed of definitively in geologic repositories, except the intentional operating discharges (including the complete fresh water input) and unintentional discharges (leaks, accidents) into the environment. In the current practice, all radioactive wastes are still present in mobile condition within the human environment, including the 'materials lost forever', that are the materials that cannot be reused for any purpose because of their radioactivity.
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The recovery of raw materials and the production of processed materials (chemicals, construction materials) consume useful energy, fossil fuels and electricity, and consequently are accompanied by CO_2 emissions. *Figure 12* shows the material balances of nuclear power and wind power. Not included in both material balances are:

- materials required for mining and processing of the construction materials;
- materials for the distribution grid;
- materials for maintenance and refurbishments of the systems.

The cooling water for the nuclear power plant is also not accounted for.

Comparison of nuclear power with renewable and fossil power is only scientifically sound if all systems are assessed from cradle to grave.

Looking at the large amounts of materials passing through the nuclear system it is inconceivable that the nuclear system would emit less CO_2 than wind power and no other greenhouse gases, as asserted by the nuclear industry.

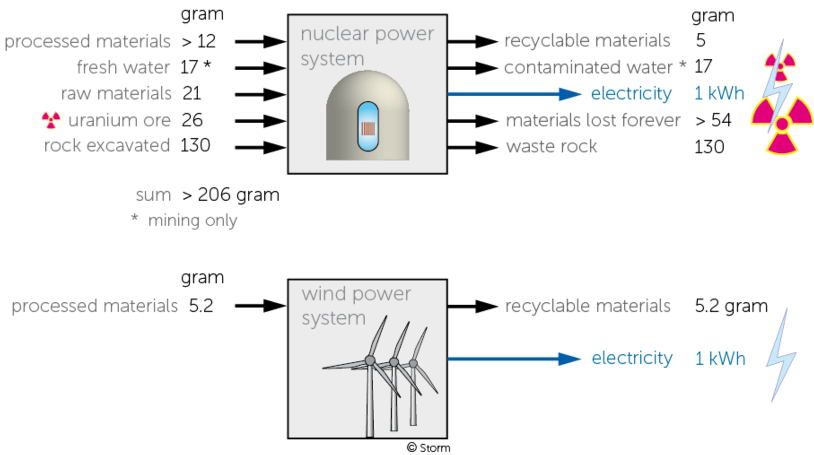

Figure 12 – Material balances of a generic nuclear energy system and an offshore wind farm of current operational technology

Both systems are assessed from cradle to grave. The uranium ore has an assumed grade of 1 gU/kg rock, slightly higher than the current world average. The input of processed materials (construction materials, chemicals) of the nuclear system is indicated by >12 gram/kWh, because the input is not exactly known, but certainly more than 12 g/kWh. Designed by STORM VAN LEEUWEN, J. W. (2016)

4. Nuclear greenhouse gas emissions

4.1. Energy costs energy

Each of the industrial processes of the nuclear process chain consumes useful energy (fossil fuels and electricity) and materials. The input of construction materials and chemicals represents an indirect energy input: the embodied energy is the energy needed to produce the materials from raw materials.

Figure 13 represents a simplified outline of the nuclear process chain as shown earlier in *Figure 9*. The input of the central part of the nuclear chain, the power plants itself, is enriched uranium assembled in fuel elements ready to be placed in the reactor. The materials and energy needed for construction, operating, maintenance and refurbishments of the NPP are included in the inputs of the front-end processes. The lifetime output of the NPP is electricity and a massive amount of radioactive materials, including a part of the NPP itself. This study takes the view that all radioactive wastes generated by the nuclear system are to be isolated from the biosphere for a geological timespan in a geologic repository, in *Figure 13* represented by a symbol. Those back-end processes will also consume materials and energy, for example packaging the radioactive wastes, construction of deep geologic repository, disposal of the wastes in the repository and closure of it. The back-end processes also include the decommissioning and dismantling of the NPP after its closedown and disposal of the radioactive debris and scrap in a geologic repository.

None of the back-end processes do need advanced technology, so their consumption of energy and materials can reliably be estimated by comparison with similar industrial processes that are operational, such as the construction of an underground mine.

The sum of the direct and indirect energy inputs needed to operate the full nuclear chain is the energy investment of the system. An informative parameter of energy systems is the Energy Return on Energy Investments (EROEI), that is the ratio of energy output over energy input. In the next chapter, we return to this quantity.

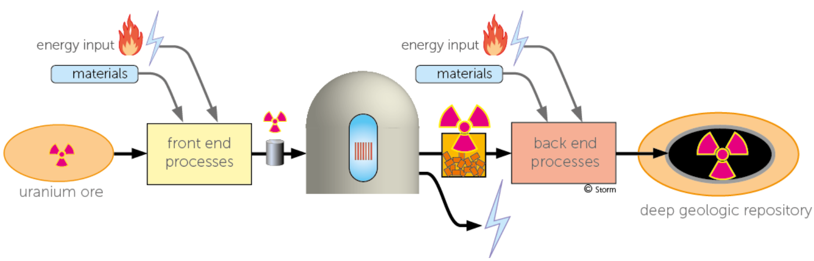

Figure 13 – Simplified outline of the nuclear energy system with the complete process chain from cradle to grave, as it ought to be, including the safe isolation of the radioactive wastes from the biosphere

The analysis of this study is based on this outline. In practice, no nuclear process chain has ever been finished.

Designed by STORM VAN LEEUWEN, J. W. (2016)

4.2. Origin of the nuclear CO_2 emission

Each process of the nuclear chain consumes thermal energy, provided by fossil fuels, and electricity: the direct energy input. In addition, all processes consume materials, the production of which also consumed thermal energy and electricity: the embodied energy of these materials form the indirect input. By means of a thermodynamic analysis the direct and indirect energy inputs of the full nuclear system from cradle to grave can be quantified.

The CO_2 emission of the nuclear system originates from burning fossil fuels to provide the direct and indirect thermal energy inputs of the system, and from chemical reactions (for example the production of cement and steel). In this study the electrical energy inputs of the nuclear system are assumed to be provided by the nuclear system itself. By this convention, the results of the energy analysis become independent of place, time, local conditions such as fuel mix of fossil-fuel-generated electricity. In practice, this convention would imply a steady state, in which the number of NPPs coming online would equal the number of NPPs being decommissioned. The operating plants would provide the electrical energy inputs needed for construction of new plants and for decommissioning of the closed-down plants. It should be emphasised that this steady-state model is hypothetical, because no commercial NPP has ever been dismantled completely.

By this convention the energy analysis of this study deviates from analyses of other energy systems, such as wind power and solar photovoltaics, in which the CO_2 emission associated with the generation from fossil fuels of the electricity consumed for construction is included in the total specific GHG emissions.

4.3. Full-power years FPY

To avoid discussions on load factor, capacity factor and availability factor—these factors are not always consistently defined or used by the nuclear industry – the operational lifetime of a nuclear power plant in this study is not given in calendar years, but in full-power years FPY. A full-power year is here defined as the period in which the reactor produces a fixed quantity of electricity equalling the production during 1 year continuously at full power. The electricity produced by a nuclear power plant with a nominal power of 1 GW_e during one FPY is:

1 FPY = 1 GW_e.year = 8760 x 10^6 kWh

The time-period measured in calendar years of an FPY varies among different nuclear power plants, and usually also with time at a particular one.

4.4. CO_2 emission of the nuclear energy system

The thermodynamic analysis of the reference nuclear power station, representative of the newest currently operating NPPs, from cradle to grave with a lifetime productivity of 25 full-power years makes it possible to estimate the specific CO_2 emission of the nuclear energy system. The current world average productive lifetime of NPPs is about 23 FPY.

Table 3 – Specific CO_2 emission of the reference nuclear energy system in the baseline scenario. Uranium from soft ores at a grade of 0.05% U, about the current global average

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	main components of the nuclear process chain	specific emission g CO_2/kWh baseline operational lifetime
1	uranium recovery (mining + milling), (ore grade dependent)	8.41
2	other front end processes	6.23
3	construction	23.2 ± 11.6
4	operation, maintenance & refurbishments OMR	24.4
5	constant back-end processes	12.08
6	decommissioning & dismantling	34.8 ± 17.4
7	mine rehabilitation (ore grade dependent)	7.57
	sum (mean with uncertainty range)	117 ± 29

The results are summarised in *Table 3*, assumed that the nuclear system is fed by uranium from ore at a grade of 0.05% U (0.5 gram uranium per kg ore, about the current world average).

The figures for construction and dismantling have an uncertainty spread of ±50%, causing the uncertainty range of the total figure to be: 88–146 gCO_2/kWh, rounded 90–150 g/kWh.

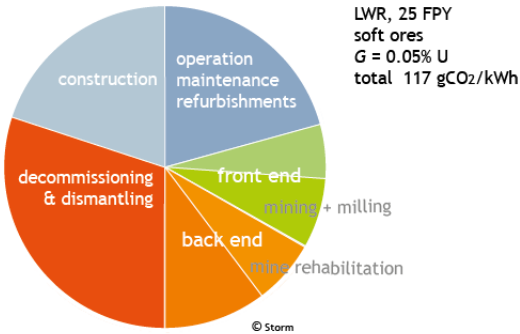

Figure 14 – Contributions to the cradle-to-grave (c2g) CO_2 emission of the nuclear energy system based on the reference LWR in baseline case, operational lifetime 25 full-power years (FPY), using soft uranium ores at an ore grade of 0.05% U (about the present world average)

The seven main components are represented as in Table 3. The contribution of mining + milling and mine rehabilitation are ore grade dependent.

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Figure 14 illustrates the contributions of the seven main components of the nuclear system from cradle to grave CO_2 emission, at an assumed uranium ore grade of 0.05% U and soft ores, about the present global average. Notable features of this diagram, based on *Table 3*, are for example:

- The back-end of the chain including decommissioning and dismantling of the reactor generate nearly as much CO_2 as all the previous components added together. As the back-end processes and decommissioning of all reactors have been passed on to the future, up until now, the emissions of these activities have yet to happen and are a kind of CO_2-debt.
- The front-end processes, excluding uranium recovery, generate only about 10% of the CO_2 emitted by the nuclear system during

its operation. Enrichment, usually presented by the nuclear industry as the main energy consumer and CO_2 emitter of the nuclear process chain, turns out to be of minor importance.

- The emission contributions of construction and decommissioning are half of the total specific CO_2 emission. The nuclear industry usually omits these activities from its estimates of costs, energy consumption and specific CO_2 emission, or uses unrealistically low figures.

4.5. Other greenhouse gases

Carbon dioxide is not the only greenhouse gas, although it is the most important one due to the vast amounts being emitted. This is not to say that for any industrial process CO_2 is the most important greenhouse gas produced. Many other greenhouse gases have a global warming potential (GWP) thousands of times larger than CO_2, so even tiny emissions of such gases may have a large effect. A zero-carbon process may have a significant contribution to anthropogenic global warming if it emits high-GWP greenhouse gases, such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and SF_6.

In 2001, the USA's enrichment plants alone had a specific GHG emission of 5 grams CO_2-equivalents per kilowatt-hour of Freon 114, as follows from data from EIA-DOE (2005). Apart from these we found no data in the open literature on the emissions of fluorine- and chlorine-related chemical compounds by the nuclear industry. The report EPD (2007) noticed the absence of data on emission of greenhouse gases by processes needed to convert uranium ore into nuclear fuel.

A chemical assessment of the industrial processes needed to make nuclear power generation possible proves it inconceivable that the nuclear process chain does not emit a gamut of fluoro and chloro compounds and it seems also inconceivable that no greenhouse gases are among them. Also in view of the large input of processed materials, see *Figure 11*, it seems unlikely that the nuclear energy system does not emit GHGs other than CO_2.

'Not reported' does not mean: *'no emissions'.*

4.6. Krypton-85, another nuclear climate changer

Krypton-85 (symbols ^{85}Kr or Kr-85) is a radioactive isotope of the noble gas krypton. Although krypton is not a greenhouse gas in itself the presence of krypton-85 in the atmosphere gives rise to unforeseeable effects for weather and climate. Kr-85 is a beta emitter and is capable of ionising the atmosphere, leading to the formation of ozone in the troposphere. Tropospheric ozone is a greenhouse gas, it damages plants, it causes smog and health problems (WMO, 2001).

Naturally, krypton-85 is present in minute quantities in the atmosphere due to natural processes. In nuclear reactors, massive amounts of krypton-85 are produced, as one of the major fission products. A small portion of it escapes into the atmosphere at the reactor site during operation, more will escape during storage of spent fuel in cooling pools and dry casks, for the number of leaking fuel elements increases with time due to unavoidable ageing processes. When spent fuel is reprocessed all Kr-85 is discharged from the spent fuel into the atmosphere. As a result of human nuclear activities, the inventory of Kr-85 in the atmosphere has risen by a factor of 10 million and this quantity shows a rising trend (AHLSWEDE, J. *et al*. 2012; THE SENECA EFFECT, 2015).

Being chemically inert, krypton and the other noble gases are usually not involved in biological processes. They are, however, absorbed into the tissues of the body via inhalation and dissolution in body fluids and tissues. Xenon has been shown to combine with specific sites in the body with certain protein molecules. Krypton is characterised by low blood solubility, high lipid solubility and rapid diffusion in tissue.

Exceptions to the biologically inert characterisation of inert gases have been noted by numerous studies. A comparatively high uptake of krypton by the adrenal gland has been reported. These phenomena are not understood (NCRP, 1975). During the 40 years following this publication, no investigations of the health and climate effects of krypton 85 are reported, as far as known.

On a global scale the genetic and overall carcinogenic effects from

Kr-85 are calculated to be small as compared with other possible sources of deleterious effects.

The possible interaction of radiation from krypton-85 and solar ultraviolet (UV) should be mentioned. In order to understand better the implications of long-term Kr-85 releases to the atmosphere, epidemiological and laboratory studies should be undertaken to define the nature and degree of interaction, if any, of UV radiation with ionising radiation in the induction of skin cancer (NCRP, 1975).

4.7. Specific CO_2 emission and uranium ore grade

Table 1 shows that the specific CO_2 emission of the nuclear energy system that is attributable to the recovery of uranium from the *Earth*'s crust amounts to 8.41 + 7.57 = 15.98 = 16 g/kWh if the nuclear system

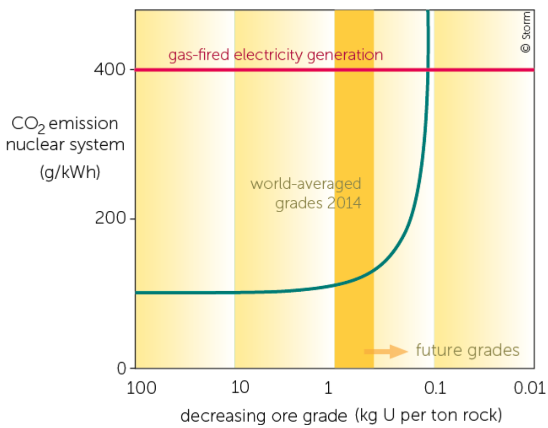

Figure 15 – Specific CO_2 emission of the nuclear system (baseline case) as function of the uranium ore grade

At present the world-averaged ore grade is 0.1–0.05% U. This diagram is called the 'CO_2 trap'. At grades approaching 0.01% U (100 g U per ton rock) the nuclear CO_2 emission surpasses that of fossil fuelled electricity generation. The curve is similar to the curve of the thermal energy inputs of uranium mining and milling + mine rehabilitation as function of the ore grade. From the thermodynamic analysis follows that the critical ore grade hardly depends on the energy consumption and CO_2 emissions of the other parts of process chain, such as construction and dismantling of the NPP.

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is fed by uranium from ore at currently average grade. This figure is ore grade dependent: the CO_2 emission rises exponentially with decreasing ore grade, as shown by *Figure 15*.

4.8. Energy cliff

Future nuclear generating capacity during the coming decades will rely on the present reactor technology. Based on this reactor technology the amount of useful energy extractable from 1 kg natural uranium has a fixed value: roughly 500 GJ/kg natural uranium thermal energy, from which about 170 GJ/kg U electricity can be generated; slight variations are possible due to different reactor types. The reference reactor of this study, a pressurised water reactor (PWR) corresponding with the newest types of light water reactors (LWRs) in operation, cannot fission more than 0.6% of the nuclei in natural uranium; a higher figure in the future is unlikely.

The energy input of the nuclear system increases exponentially with decreasing thermodynamic quality of the uranium ore. For that reason, the net energy delivered by the nuclear system to the economy as a whole decreases with falling ore grades. At a certain grade the energy input of the system equals the energy content of natural uranium. The use of ores at that critical grade results in a zero-net energy production by the nuclear system: the *energy cliff*.

Below a grade of 0.2–0.1 gU/kg rock no net energy can be generated by the nuclear system as a whole from a uranium resource. The diagram of *Figure 16* suggests that exploration for new uranium deposits may look worthwhile only at grades higher than 0.3 gU/kg rock, from an energy point of view.

The ore grades of the known uranium resources—ores are by definition economically recoverable—vary widely: from nearly 200 down to 0.1 gU/kg rock. A part of the resources that are classified by the IAEA as 'recoverable' are very close to or even beyond the energy cliff, such as *Valencia* and *Trekkopje mines* in *Namibia*. The energy cliff sets the thermodynamic boundary of uranium-for-energy resources, see the bar diagram in *Figure 16*. The ore grade distribution and total amounts of recoverable resources at known grades have little changed, because few new significant resources have been discovered during the past decades, if any.

Thermodynamic analysis proves that the energy cliff hardly depends on the energy requirements for construction and dismantling, nor on the operational lifetime of a nuclear power plant. Distinction between soft and hard ores is also hardly relevant, because leaner ores tend to be harder, so the energy cliff is effectively determined by hard ores.

In *Figure 16*, the energy cliff has been superimposed onto the ore grade distribution of the world known uranium resources graph, as function of the ore grade.

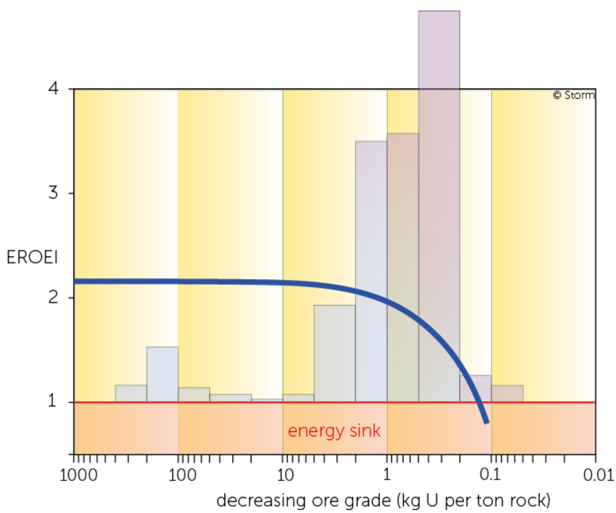

Figure 16 – The energy cliff

EROEI of the nuclear energy system as function of the uranium ore grade. Note the descending logarithmic scale on the horizontal axis. At uranium ore grades below 10 g U/kg rock the EROEI of nuclear power starts declining at an increasing rate and becomes zero at grades between 0.2–0.1 g U/kg rock. The bar diagram in the background represents the grade distribution of the world known uranium resources. The world average grade of available ores (currently 1–0.4 g U/kg rock) is declining because the richest and easiest recoverable resources are always mined first.

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4.9. Energy returned on energy invested, EROEI

An important quantity qualifying any energy system is the Energy Returned on Energy Invested (EROEI), also called Energy Return on Investment (EROI), which is defined as the ratio of the lifetime useful energy output over the lifetime useful energy input. This definition covers the full cradle-to-grave (c2g) period of the energy system, implying that the system boundaries include all energy investments related to a given NPP, regardless of place and time, even if occurring many decades from now.

4.10. Thermodynamic quality of uranium resources

Based on the thermodynamic analysis the thermodynamic quality of a uranium resource is defined as the amount of useful energy (direct + indirect energy inputs) to be invested for the recovery of a mass unit pure uranium from that resource. The thermodynamic quality of uranium resources depends on a number of variables, such as:

- ore grade;
- size of deposit;
- depth of the ore body below the surface;
- mineralogy of the uranium occurrence, refractoriness of uranium minerals and of the host rock;
- location of the uranium occurrence: availability of fresh water, climate, transport distances for chemicals, auxiliary materials, equipment and for the products of the mine.

Due to these variables, the ore grade is usually the most important one and moreover the most easily quantifiable. For this reason, this study quantifies the thermodynamic quality of uranium resources as function of the ore grade. A distinction is made between soft ores, from which uranium is relatively easily extractable, and hard ores, with more refractory mineralogy requiring more energy investments per mass unit recovered uranium. The grade dependency is determined by two variables: the dilution factor and the extraction yield.

4.10.1. Dilution factor

The ore grade is defined as the uranium content of the uranium-bearing rock, usually given as mass-% U, or in grams of uranium per kg rock. The minimum amount of rock to be mined and milled to obtain 1 kg uranium is inversely proportional to the ore grade. The *dilution factor* is a simple mathematical relationship between ore grade and mass of rock to be processed per recovered mass unit of uranium, and does not depend on recovery technology nor on ore type.

4.10.2. Coal equivalence

At an ore grade of 0.2 gU/kg rock, the annual mass of uranium ore to be mined and processed to fuel one nuclear power plant equals the mass of coal burned in a coal-fired power station to generate the same amount of electricity: the *coal equivalence*.

4.10.3. Extraction yield

The *extraction yield*, also called the *recovery factor* or *recovery yield,* is the ratio of the mass of uranium extracted and the mass of the uranium present in the processed amount of rock. The recovery yield decreases exponentially with decreasing uranium content; this follows from the Second Law of thermodynamics. The mixing entropy of uranium in a given mixture of other chemical types strongly increases with:

- decreasing concentration of the uranium in the mother matrix, and
- increasing number of other species in the matrix, and
- increasing concentrations of the other species in the matrix.

The higher the mixing entropy of a species the more energy and specialised effort is needed to extract that species from the mixture. Extraction processes are governed by basic physical and chemical laws, which cannot be circumvented by technology. Perfect extraction is impossible: separation processes never go to completion, as follows from the Second Law of thermodynamics.

At ore grades below 0.2 gU/kg rock the extraction yield rapidly declines to very low values, making uranium extraction by means of the current technology practically infeasible. The yield at low grades can be improved by application of more selective separation processes, however at the expense of higher specific energy requirements and higher CO_2 emission per mass unit recovered uranium.

4.10.4. Mine rehabilitation

Uranium mining is a polluting activity: radioactive dust is blown over vast distances from the immense heaps of mining waste (mill tailings) and large volumes of water contaminated with chemicals and dissolved radioactive materials are discharged into the environment. This study assumes that the mining area will be rehabilitated as well as possible. The energy input and consequently also the specific CO_2 emission depend on the ore grade in accordance with the dilution factor.

4.10.5. Conclusion

The combination of the exponentially rising dilution factor and the exponentially decreasing extraction yield explain why the energy input per kg recovered uranium exponentially rises with decreasing grade of the ore it is extracted from, and in consequence why the specific CO_2 emission of the uranium recovery rises. *Figure 15* represents the specific CO_2 emission of the nuclear system as function of the ore grade. The specific energy input of the system has similar curves.

4.11. CO_2 trap

At ore grades of 0.2–0.1 gU/kg rock the CO_2 intensity of nuclear power surpasses the CO_2 intensity of fossil-fuelled power, eliminating the low-carbon profile of nuclear power.

The world average grade of the mined ores is steadily declining with time. If no new large uranium ore deposits of high thermodynamic quality are discovered during the next decades, the nuclear CO_2

emission will surpass the specific CO_2 emission of gas-fired stations, and even coal-fired stations, within the lifetime of all new nuclear builds. *Figure 17* gives a rough impression of the CO_2 trap over time. Very likely the average ore quality of the available uranium resources will decline in the future and consequently the specific CO_2 emission by the nuclear energy system will rise over time.

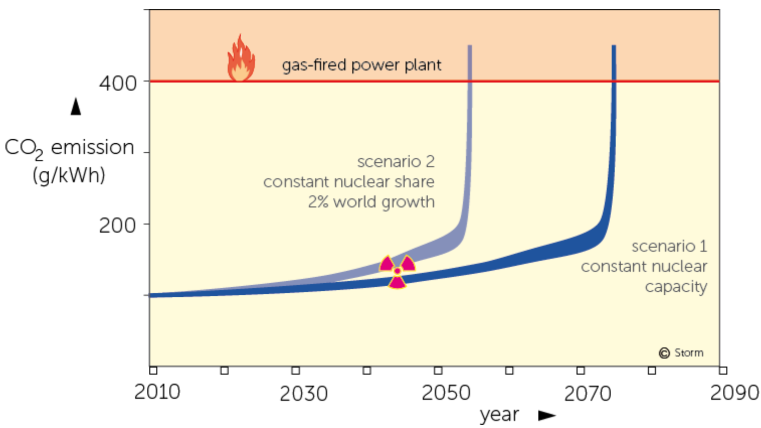

Figure 17 – The CO_2 trap: the nuclear CO_2 emission over time

The specific CO_2 emission of nuclear power rises with time due to decreasing thermodynamic quality of the uranium ores. If no new large high-quality uranium resources will be discovered during the next decades, the specific nuclear CO_2 emission may surpass that of fossil-fuelled electricity generation within the lifetime of new nuclear build. The coloured bands represent the uncertainty ranges regarding ore quality, mainly the difference between soft ores and hard ores.

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Thermodynamic analysis proves that the year of depletion, when the curve starts rising nearly vertically and the specific nuclear CO_2 emission surpasses that of fossil fuels, is not affected by variables such as operational lifetime and CO_2 emission of construction + dismantling, but is determined by the amount of new discoveries of high-quality uranium resources, and the development of the global nuclear generating capacity. Sooner or later the nuclear energy system will run aground in the CO_2 trap.

4.12. CO_2 emission figures from the nuclear industry

In its recent report concerning GHG emissions of nuclear power *Climate Change and Nuclear Power 2014* (AEA-*ccnap,* 2014) the *International Atomic Energy Agency* (IAEA) states:

- "Climate change is the foremost global environmental issue today."
- "Nuclear power plants produce virtually no greenhouse gas emissions or air pollutants during their operation and only very low emissions over their entire life cycle."
- "GHG emissions from nuclear power plants (NPPs) are negligible, and nuclear power, together with hydropower and wind based electricity, is among the lowest CO_2 emitters when emissions over the entire life cycle are considered (less than 15 grams CO2-equivalent (g CO_2-eq) per kW/h (kilowatt hour), median value of 60 reviewed sources)."

The IAEA cites specific emission figures far lower than this study: 5.6–19.7 gCO_2eq/kWh with a median value of 14.9 gCO_2eq/kWh. Notably, the specific CO_2 emission of just the construction of the *Sizewell* B NPP in the *UK* amounted to 11–15 gCO_2/kWh, according to EXTERNE-UK (1998), this study found a figure of 12–35 gCO_2/kWh for the construction. It is completely unclear how the figures of the IAEA are established and for what reason the results of the EXTERNE-UK (1998) study are not included. See also the publication of SOVACOOL, B. K. (2008) who compares a number of publications concerning nuclear GHG emissions, some of which find a higher figure than this study *(Figure 18)*.

The *World Nuclear Association* (WNA) comes in its assessment of the nuclear CO_2 emissions to about the same figures as the IAEA: 9–21 CO_2-eq/kWh in WNA (2014) and 10–26 g CO_2-eq/kWh in WNA/a (2015). Although WNA gives more details on the LCAs, on which the figures are based, than the IAEA in its report, it remains completely unclear how the CO_2 emission figures are derived by WNA or in the publications cited by WNA.

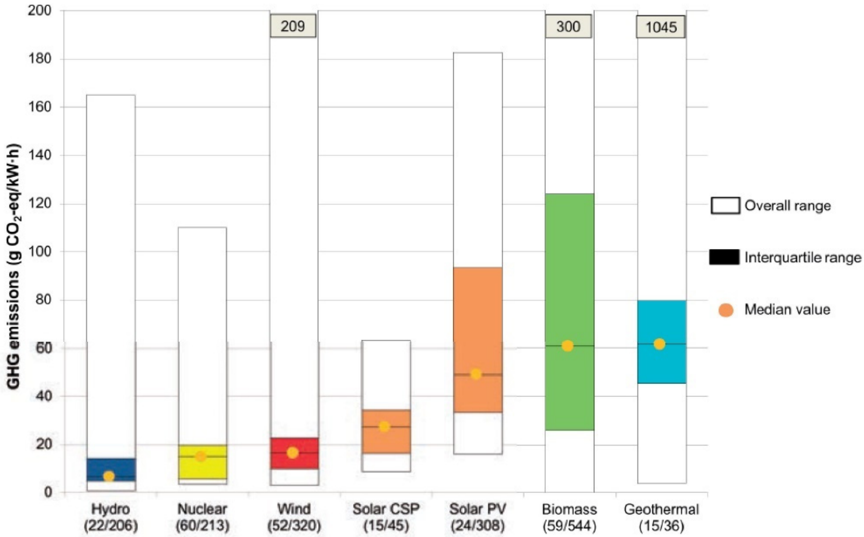

Figure 18 – Greenhouse gas emissions from nuclear power and renewable energy systems

The data source of this diagram from IAEA (2014) is an unpublished IAEA report

Noticeably absent from the publications of the IAEA and WNA are statements on the ore grade dependency of the nuclear CO_2 emissions, although this has been confirmed by PRASSER, H. M. *et al*. (2008).

A sound scientific comparison of the figures from the publication of the IAEA with the LCA of this study is not possible for several reasons:

- the original studies from which the used data were taken by the IAEA remain undisclosed;
- no life cycle assessment (LCA) is included;
- no system boundaries are defined;
- no time horizon of the study is defined;
- no CO_2 sources of the nuclear system mentioned.

Remarkably absent in the publications of the nuclear industry is any statement referring to the possibility or impossibility of GHG emissions other than CO_2 by nuclear power. This absence seems to suggest that nuclear power does not emit other greenhouse gases. However, ‘not reported’ does not mean ‘no emissions’.

This false suggestion is confirmed by the consistent use of the unit gCO_2eq/kWh (gram CO_2 *equivalent* per kilowatt-hour) in the nuclear publications. The unit $gCO_2\mathit{eq}/kWh$ is the unit of the global warming potential of all kinds of GHGs, for example 1 g/kWh methane (CH_4) corresponds with 23 gCO_2eq/kWh. In scientifically correct publications the IAEA and the nuclear industry should consequently use the unit gCO_2/kWh as long as the nuclear industry not has unambiguously *proved* that nuclear power does not emit GHGs other than CO_2.

Comparing the nuclear CO_2 emission with the total GHG emissions of other technologies is incorrect; the specific emission of solar PV for example includes the emissions of fluorinated compounds.

5. Thermodynamics of closed-cycle nuclear systems

5.1. Advanced nuclear concepts

The nuclear industry envisions the application of other fissile materials than uranium by means of advanced closed-cycle nuclear reactors that would make possible an almost limitless expansion of nuclear power. Theoretically the demand for uranium could be reduced by developing substitutes, recycling and more efficient use of the uranium. According to WNA/b (2015) this could be accomplished by:

- Reprocessing of spent fuel and recycling of uranium and plutonium in light-water reactors (LWRs).
- More efficient use of uranium by implementation of ‘fast reactors’ (breeder reactors) that would be able to fission 50–100 times more nuclei from natural uranium than the current generation of reactors (mainly LWRs).
- Development of reactors that use thorium as fertile material to breed fissile uranium-233. Via this conversion thorium could theoretically substitute uranium as input for nuclear power, according to the nuclear industry.

The only fissile nuclide found in nature is uranium-235, constituting 0.7% of the atoms in natural uranium, the remaining 99.3% being the non-fissile uranium-238 atoms with traces of uranium-234 (also non-fissile). By means of advanced nuclear technology, involving closed-cycle nuclear power generation, it would be theoretically possible to fission a much larger part of the nuclei in natural uranium: according to the nuclear industry, 50–100 times more than in an LWR at the current state of technology. In its prognoses and promises the nuclear industry is usually talking only about advanced reactor technology, but reactors are just a part of the technological challenge.

There are serious obstacles on the road to the materialisation of these technical dreams, such as:

- technical infeasibility of the breeder system;
- negative energy balance of the breeder cycle as a whole;
- uncontrollable and high risk of plutonium terrorism and the proliferation of nuclear technology.

A thermodynamical analysis, represented by the right track of the analysis outline in *Figure 1*, examines the technical feasibility of the advanced concepts in the following sections.

5.2. Reprocessing of spent fuel

Spent nuclear fuel from a light-water reactor (LWR) contains a large fraction of uranium-238, a part of the original uranium-235 remaining unfissioned, fission products, plutonium and trans-plutonium actinides. Both plutonium and the higher actinides originate from uranium-238 by neutron capture. Spent fuel is an exceedingly complex mixture of nuclides, representing a major part of the *Periodic Table* of the Elements, and is highly radioactive. The Zircalloy cladding of the fuel elements also becomes highly radioactive, as a result of neutron capture.

Separation of spent fuel into different fractions is possible by an intricate complex of physical and chemical separation processes, called reprocessing *(Figure 19)*.

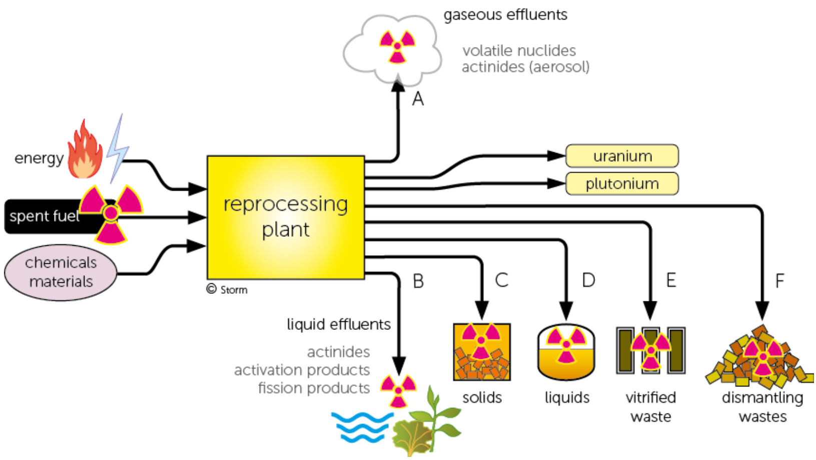

Figure 19 – Outline of the radioactive mass flows of reprocessing of fuel

The input of a reprocessing plant consists of spent fuel, chemicals and energy (electricity and fossil fuels). Spent fuel is separated into seven fractions: unfissioned uranium, newly formed plutonium and five waste fractions A–E: (A) gaseous effluents, discharged into the atmosphere, containing gaseous and volatile fission products, activation products, noble gases and aerosols of some other fission products and actinides; (B) liquid effluents, discharged into the environment (soil, sea, groundwater), containing some U and Pu and other actinides, in addition to a substantial part of the highly soluble fission products; (C) insoluble solid waste consisting of spent fuel cladding hulls and other solids, containing also small amounts of undissolved fuel: U, Pu, fission products, activation products and actinides; (D) liquid wastes containing fission products, activation products, uranium, plutonium and other actinides, resulting from imperfect separation and purification processes; (E) the fraction of fission products, activation products and actinides which can be vitrified; An eighth radioactive waste stream, fraction (F), consisting of dismantling wastes, will be released after final shutdown of the reprocessing plant, when the plant is decommissioned, cleaned up and dismantled.

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Reprocessing is the pivotal process in several nuclear concepts:

1. plutonium for weapons;
2. plutonium recycling in LWRs;
3. breeder reactors (U-238/Pu-239 cycle);
4. thorium reactors (in fact the Th-232/U-233 breeder cycle);
5. radioactive waste volume reduction by vitrification;
6. partitioning & transmutation, to convert long-lived radionuc-

lides into short-lived ones.

Only applications *2*, *3* and *4* are addressed in this paper.

Initially reprocessing was developed in the early days of the nuclear age to produce plutonium for atomic weapons. In later years, commercial applications of the reprocessing technology were developed from the military applications, when the breeder concept came into the picture. The main purpose of the civil reprocessing plants, in *Europe* at *La Hague* in *France* and *Sellafield* in *Great Britain*, was to get the plutonium to fuel fast breeder reactors (FBR's) and to recycle unused uranium.

5.3. Reprocessing and the Second Law

Reprocessing of spent fuel is a sequence of separation processes, involving numerous chemical equilibria and complicated by high radiation levels. Nuclear radiation causes radiolysis of the solvents and extraction liquids, which results in less effective separation and the generation of unwanted chemical species.

Separation processes are governed by the basic laws of nature. One of the consequences of these laws is that separation processes never go to completion. For that reason, it is impossible to separate a mixture of *n* different chemical species into *n* fractions without losses, and none of the separated fractions will be 100% pure. Separation of a mixture into fractions becomes more difficult and goes less completely as:

- more different kinds of species are present in the mixture;
- the concentration of the desired species in the mixture are lower;
- the constituting species are chemically more alike;
- the solution has a higher level of radioactivity.

Complete separation is a fiction. As a consequence, a part of each desired fraction will be lost in the waste streams and each fraction will be contaminated with species from other fractions. The selectivity of separating a certain fraction from a mixture can be enhanced, at the expense of more specialised chemicals and equipment and consequently more energy, and more losses of other fractions. Radioactive and non-radioactive isotopes of the same element cannot be separated, because their chemical properties are identical.

Economic considerations and the human factor are left aside here. The amount of radioactivity in spent fuel does not change with the mechanical and chemical treatments in the reprocessing plant, it simply means a redistribution of the radionuclides from one material to several other materials. Inevitably, mixing any amount of radionuclides, originally compacted in solid spent fuel, with non-radioactive fluids or other substances increases the volume of the radioactive waste, exacerbating the waste disposal problems.

Reprocessing of spent fuel is an exceedingly polluting process consuming massive quantities of energy and chemicals. Decommissioning and dismantling of the ageing reprocessing plants will be extremely costly, and very time and energy consuming. These activities should be included in the energy balance of any option that includes reprocessing.

5.4. U-Pu recycle in LWRs

A limited number the currently operational thermal reactors is partly fuelled (not more than 30%) by uranium-plutonium mixed-oxide fuel (MOX) replacing enriched uranium fuel elements. In addition to the high energy intensity of reprocessing the fabrication of MOX fuel is more energy intensive than the fabrication of fresh nuclear fuel from enriched uranium. Jointly these factors cause a negative energy balance of uranium-plutonium recycling in conventional reactors.

Apart from this prohibitive condition, the contribution of U-Pu recycling in LWRs to more efficient use of uranium would be marginal: at best some 18% of the annual consumption of natural uranium, provided that all spent fuel of the world were to be reprocessed and all the separated plutonium could be used to produce MOX fuel.

5.5. Uranium-plutonium breeders ('fast reactors')

The nuclear industry uses the term 'fast reactor' in reference to the breeder system, a system that would generate (breed) more fissile nuclei from uranium than consumed in the fission process, by conversion of the non-fissile uranium-238 nuclei into fissile plutonium nuclei. During the 1960s, 1970s and 1980s this type of reactor was usually called a 'breeder' or 'fast breeder reactor' (FBR) but this term has disappeared from the publications of the IAEA and the nuclear industry, presumably because of the failure to put the concept into practice. The prefix 'fast' refers to the fact that this type of reactor operates with fast neutrons, contrary to the currently operating commercial reactors, in which fission occurs by thermal (slow) neutrons. Now the breeder concept is part of the so-called *Generation IV program*. This program also includes other types of fast reactors without a breeding capacity that are not discussed here.

The nuclear industry promised (and is still promising) that a closed-cycle reactor system (breeder) could fission 50–100 times more nuclei present in natural uranium, and consequently generate 50–100 times more energy from 1 kg uranium, than the conventional once-through system based on light-water reactors (LWRs). *France ('tout électrique, tout nucléaire')* and the *UK ('too cheap to meter')* embarked at the time on the materialisation of the breeder concept, expecting that this could make their energy supply largely independent of fossil fuels. These promises ignored the thermodynamic aspects of the breeder.

The MIT (2003) study, *The Future of Nuclear Power*, does not expect breeders (in effect the breeder cycle) to come into operation before 2040–2050. The MIT study concluded that for the next three decades, and probably beyond, nuclear energy generation has to rely on thermal-neutron reactors, mainly LWRs, in the once-through mode. The IAEA (OMOTO, A. 2007) does not expect the first fast reactor or breeder of *Generation IV* to come on line before 2040.

What is called a 'breeder' is not just a reactor type or a stand-alone system. To exploit fully the promised potential of natural uranium, a complex breeder cycle system is a prerequisite. The breeder cycle comprises three components: a breeder reactor, a reprocessing facility and a fuel fabrication plant *(Figure 20)*.

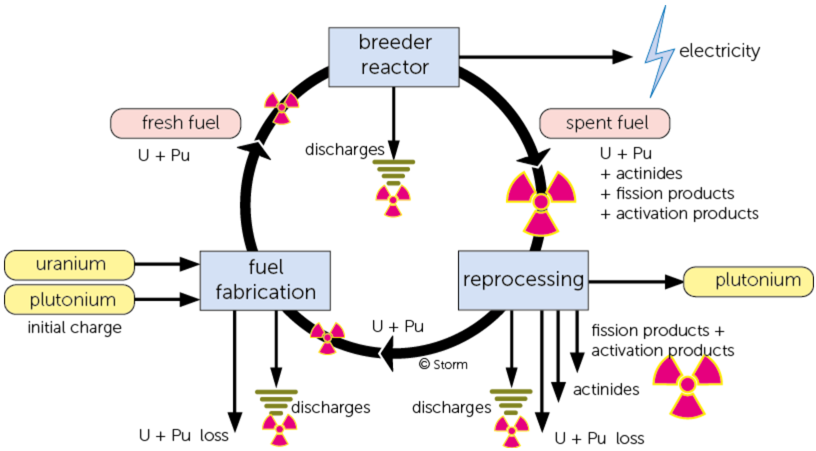

Figure 20 – Outline of the breeder system concept in steady state

By repeatedly recycling spent fuel, it would be theoretically possible to fission the main part of natural uranium. If all would work as advertised, the cycle produces during its operational life a plutonium gain, large enough to start up two or more new breeders: one to replace the closed down unit, and one or more additional breeders. The cycle represents the mass flows of uranium and the nuclides originating from the nuclear processes in the reactor (fission, activation and decay). The initial plutonium charge to start up the breeder reactor is about 3 Mg Pu for a 1 GW(e) FBR.

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Important parameters of the breeder system are, among other:

- initial inventory of plutonium in Mg/GW, should be as low as possible;
- breeding ratio, this factor should be as high as possible;
- full-power operating time of the reactor, should be as long as possible;
- out-of-pile time of the plutonium, should be as short as possible;
- plutonium losses in the cycle, should be as low as possible.

The first three are reactor parameters, the latter two are determined by two of the other components of the cycle: reprocessing and fuel fabrication.

All three components of the breeder cycle must operate flawlessly, continuously and exactly tuned to the other two components, in order to let the system actually breed more fissile material from non-fissile uranium-238 than it consumes. If one component fails, the whole system fails. In fact, none of the three components have ever demonstrated operation as required, let alone the three components together as one integrated continuously operating system.

Due to the rapidly increasing radioactivity of the spent fuel with each cycle, reprocessing and fuel fabrication become increasingly difficult. The isotopic compositions of the recovered uranium and plutonium become less favourable with each cycle. Due to the unavoidable and increasing separation losses, the cycle produces less fissile nuclides than it consumes. For these reasons, among other, the breeder cycle is technically infeasible.

Breeder systems exist only on paper. Nearly 60 years of intensive research in seven countries (*USA, UK, France, Germany*, former *USSR* now *Russia*, *Japan* and *India*) and investments of more than a 100 billion dollars have failed to deliver an operable breeder cycle, due to insurmountable technical hurdles. The failure of the breeder concept is not caused by protests of environmental activists nor by actions of leftist politicians, nor for economic reasons, as the nuclear industry asserts, but is caused by fundamental technical limitations.

Problems of the breeder system are discussed in more detail by, for example, LIDSKY, L. M. – MILLER, M. M. (1998). These authors concluded that the breeder system is not feasible, not only due to the technical hurdles, but also because the system cannot meet the requirements of safety, proliferation and economy.

5.6. Thorium

Thorium is a radioactive metal, more abundant in the *Earth*'s crust than uranium. The concept of the thorium reactor is based on the conversion by neutron capture of non-fissile thorium-232 into uranium-233, which is as fissile as plutonium-239. In common with the uranium-plutonium breeder, the thorium–uranium breeder is not just an advanced reactor, it is an intricate cyclic system of reactor, reprocessing plant and fuel element fabrication plant. Each of the three components of the cycle has to operate flawlessly for decades, finely tuned to the two other components.

The feasibility of the thorium breeder system is even more remote than that of the U-Pu breeder. After five decades of research there are still no solutions for the basic problems mentioned by ABBOTT, L. S. *et al.* (1978). The fundamental obstacles that render the U-Pu breeder technically infeasible apply also to the thorium breeder. Problems include:

- the high radioactivity of U-233, which is always contaminated with traces of U-232, a strong gamma emitter;
- similar problems in recycling thorium due to the highly radioactive Th-228, a decay product of both Th-232 and U-232;
- technical problems, not yet satisfactorily solved, in reprocessing;
- the use of U-233 as fuel requires specially developed reactors;
- by recycling of U-233 its isotopic composition deteriorates, and so its usefulness, by the increasing generation of the unfavourable isotopes U-232, U-234 and U-236 (ABBOTT, L. S. *et al.* 1978).

Research and development on the thorium cycle has been less intensive than on the U-Pu cycle and never reached the prototype phase, like the U-Pu cycle with the *French Superphénix*.

Among a number of other countries, the *USA* conducted Th-232/U-233 research in the 1960s and 1970s (for example, in the *Shippingport* reactor), the research has not been continued.

To generate sufficiently pure U-233, special reactors are required, likely not appropriate for use as power reactors. It would take decades to construct these reactors and to generate sufficient U-233 to start up the first operating Th-232/U-233 breeder system. Then it would take 9 doubling times to attain a thorium breeder capacity equalling the current nuclear capacity (370 GWe). Even assuming an unrealistically short doubling time of 20 years, 9 doubling times would mean a period of two centuries.

In this scenario, a perfectly operating breeding cycle is assumed, including the separation processes of the spent fuel and the fuel element fabrication. The high radioactivity of U-233 demand remote operations of the material throughout all steps of the fuel handling. The monetary costs, but also the energy requirements of the fuel cycle will be high.

Another drawback of the thorium cycle is that a thorium reactor cannot sustain a fission process in combination with breeding uranium-233 from thorium-232, but will always need an external accelerator-driven neutron source, or the addition of extra fissile material, such as plutonium or uranium-235 from conventional reactors.

5.7. Conclusion of Chapter 5

Implicitly the various breeder concepts are based on a few basic assumptions. *Conditio sine qua non* is the availability of:

- perfect materials;
- fail-safe and fool-proof technical systems with perfectly predictable properties across decades;
- perfect separation of strongly radioactive, complex mixtures of numerous different chemical species into 100% pure fractions.

Not one of these conditions is possible, as a consequence of the Second Law of thermodynamics, and for that reason whatever breeder concept is inherently infeasible.

Consequently, the nuclear generating capacity in the future will completely rely on the conventional technology of thermal-neutron reactors in the once-through mode.

6. Prospects of nuclear power

6.1. Uranium resources

In the *Earth*'s crust uranium is present in the form of numerous different chemical compounds, embedded in various types of host rocks. Uranium in the earth's crust is unevenly distributed among the rocks comprising the crust. The grade distribution of uranium in uranium-bearing rocks in the *Earth*'s crust shows a geologic pattern common to most other metals: the lower the grade of uranium the larger the amounts of uranium present in the crust.

The size distribution of uranium deposits shows a similar pattern as the grade distribution: the larger the size, the rarer the deposits. From a statistical point of view the chances of finding new uranium deposits increase with decreasing ore grade, decreasing ore body size and increasing depth below the surface. In *Figure 16*, the ore grade distribution of the known uranium resources is represented by a bar diagram.

From this aspect of observation, the chance of discovering new resources increases with lower grades and smaller sizes of the deposits. One may assume that the most easily discoverable resources have been found already and that the most easily mineable deposits are already being mined. The chances of discovering new, large, high-grade resources seem low; no such discoveries have been reported during the past decades. Undiscovered high-grade deposits may be present at greater depths than the existing mines and/or in poorly explored areas, such as *Antarctica*.

6.2. Unconventional uranium resources

Usually, the global uranium resources are classified into two categories: conventional and unconventional resources. Phosphates are the main constituent of unconventional uranium resources, other types of uranium-bearing resources (for example black shales) are insignificant on global scale.

Phosphates are irreplaceable for agricultural use, so mining of these minerals should be tailored exclusively to agricultural needs. Moreover, the thermodynamic quality of phosphates as a uranium-for-energy source lies beyond the energy cliff: no net energy generation is possible by exploitation of phosphate rock.

The nuclear industry places its hope for a future expansion of nuclear power not only on advanced reactor technologies, discussed in the previous chapter, but also on advanced extraction technologies that would make possible the extraction of uranium from seawater in an economically viable way. This would open access to an almost limitless source of uranium. However, extraction of uranium from seawater is also governed by the Second Law of thermodynamics, and lies far beyond the energy cliff—if large-scale extraction (at least some 10,000s tonnes a year in a nuclear expansion scenario) would be possible at all.

6.3. Depletion of uranium resources: a thermodynamic notion

In *Chapter 3*, the thermodynamic quality of uranium *in situ* (as present in nature) has been introduced: below grades of 0.2–0.1 gU/kg rock deposits cannot be classified as energy sources. Uranium-for-energy resources are governed by the basic laws of thermodynamics and not by economic notions and rules.

From a quantitative viewpoint, the uranium occurrences of the world are practically inexhaustible. The depletion of uranium resources as a source of useful energy is a thermodynamic notion. *Figure 21* represents the depletion of the known uranium resources, assumed no new significant deposits would be discovered.

Usually the richest and most easily discoverable and exploitable uranium resources become depleted first, because these offer the highest return on investments for the mining companies. Low-hanging fruit is harvested first. As the most easily available uranium resources are exploited first, the world-averaged ore quality of the remaining resources decreases with time. This phenomenon is not only typical for uranium ores, but applies to all mineral resources, see for example MUDD, G. M. (2009).

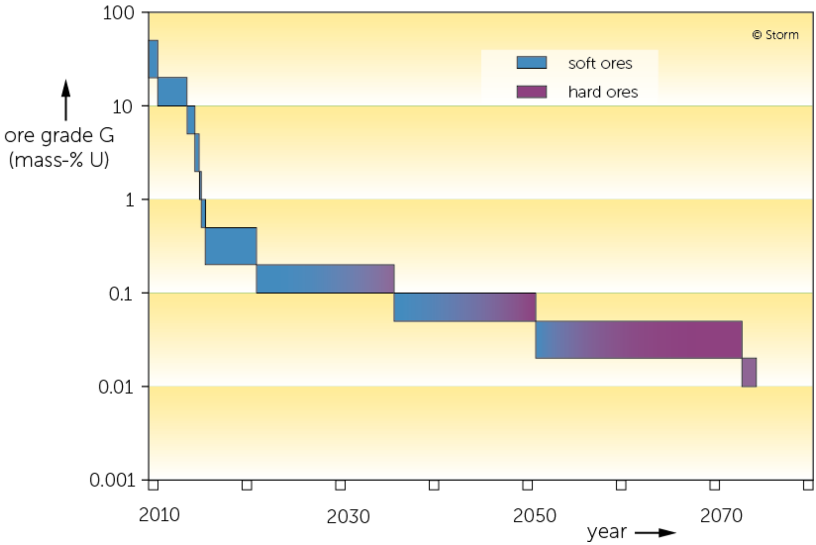

Figure 21 – Depletion of the currently known recoverable uranium resources, at an assumed constant annual uranium consumption of 66 Gg/a

This constant capacity scenario is based on the assumption that no major new resources will be discovered during the next decades, as has been the case during the past three decades, and that the richest available resources are exploited first. This figure is based on the ore grade distribution of the known uranium resources.

Designed by STORM VAN LEEUWEN, J. W. (2016)

6.4. Nuclear climate change mitigation share in the future

This section returns to the nuclear capacity scenarios, as presented in *Figure 8*.

The uranium requirements in the three scenarios are summarised in *Table 4* in teragram Tg (1 Tg = 10^{12} g = 1 million metric tons), assumed that all reactors would be light-water reactors (LWRs) in the once-through mode. In *scenario 2*, roughly corresponding with a constant mitigation share of nuclear power, the total uranium requirements would be some 13.7 Tg. This amount would be nearly ten times the all-time uranium consumption up until today.

Table 4 – Uranium consumption in three scenarios through the year 2100
The figures are rough estimates. The figure of scenario 2 depends on the growth rate of the world electricity consumption. 1 Tg = 1 teragram = 1 million metric tonnes.
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scenario	cumulative uranium consumption (Tg)
0 phase-out present capacity	1.6
1 constant capacity, IAEA low, phase out after 2050	4.7
2 constant share, IAEA high, phase out after 2050	13.7

The known recoverable uranium resources amount to, according to *Red Book* (OECD, 2014):

- 2.0 Tg in the cost category up to 80 USD/kgU;
- 5.9 Tg in the cost category up to 130 USD/kgU, including the first category;
- 7.6 Tg in the highest cost category, up to 260 USD/kgU, including the first two categories;
- The market price as of December 2016 was about 50 USD/kgU.

The figures presented by the IAEA in the *Red Book* are not compiled by an independent scientific institute but are submitted by the concerning countries. The *Red Book* does not contain information on the ore grades and other parameters of the listed uranium resources, so the data of the *Red Book* do not allow an assessment of the thermodynamic quality of those resources. Using data from other sources, it becomes clear that large resources in the highest cost segment (1.7 Tg, 130–260 USD/kgU) are near, or sometimes even beyond the energy cliff. This observation would imply that about 6 Tg of known uranium resources could really contribute to mitigation of GHG emissions, assumed nuclear power is GHG free, so *scenario 1* may be considered a realistic one.

In *scenario 2* the nuclear energy system would get stuck in the CO_2 trap halfway its fulfilment. For *scenario 2* more than twice the amount in the cost category up to 130 USD/kgU has yet to be discovered.

The *World Nuclear Association* (WNA) sees no problem: 'the market will do the job'.

"Rising uranium prices will stimulate more exploration, which will result in new uranium discoveries, as is with all other metals."

This viewpoint seems a serious misconception, for it does not account for the thermodynamic quality of the uranium resources.

6.5. Findings of Chapter 6

Two findings important for the future of nuclear power, that result from the thermodynamic analyses conducted in this study, are:

1. The amounts of uranium resources present in nature that are suitable as energy sources are limited by their thermodynamic properties. As a consequence, unconventional uranium resources, such as shales and phosphates and uranium from the oceans are not uranium-for-energy sources.
2. Closed-cycle reactor systems, designed to fission a large part of natural uranium (30–60% versus 0.6% in the present reactors) and systems designed to use thorium as nuclear fuel are implicitly based on assumptions that are in conflict with the *Second Law of thermodynamics*. The conclusion is unambiguous: the as-designed functioning of these closed-cycle systems is inherently impossible.

Moreover, the systems as a whole would have a negative energy balance: they would consume more energy than they could produce.

From these findings, it may be concluded that nuclear power in the foreseeable future has to be based exclusively on the technology of the existing conventional thermal neutron reactors and consequently on the conventional uranium resources. Any growth scenario of the nuclear capacity and GHG mitigation share seems unlikely, unless millions of tonnes of high-quality (in the thermodynamic sense) uranium resources would be discovered during the coming decades. This seems unlikely from a geologic point of view.

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Modelling and Analysing the Effects of a New Nuclear Power Plant. Is there Room for Renewables in Hungary by 2030?

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Abstract

As a solution for capacity deficiency expected in the following decades, building a new nuclear power plant has been decided in Hungary. According to a hypothesis, this unit will overbalance the energy system and hinder renewable technologies from spreading; therefore, it will not provide a sustainable solution. In this research, the effects of the new nuclear units and a possible alternative scenario are investigated and compared. Three energy models were created with EnergyPLAN software for the year of 2030: an Official one, based on the Transmission System Operator's projections; an Alternative one, based on Energiaklub's energy vision, outlined in this research; and a Hybrid one, which blends these two.

The results show that, even by a conservative development, more than 27% of the renewable electricity production is possible in Hungary by 2030, while it is only 10% in the Official scenario, where 75% of electricity production is nuclear, coming from one physical site. Critical Excess Electricity Production (CEEP) analysis showed, that significant excess electricity production will arise due oversized nuclear capacity for six years when altogether 4,400 MW nuclear capacity will co-work. This results not only in hindering renewables, but also in endangering normal working conditions of combined (CHP) and condensational power plants, which may cause hazards and shut downs of these units.

Key words

Energy system modelling; EnergyPLAN; Hungary; nuclear power; renewable energy; critical excess electricity production

1. Introduction

Hungary has a population of 9.9 million inhabitants (CIA, 2016). Its *Total Primary Energy Supply* (TPES) was 962 PJ in 2014 and its electricity demand was 42.7 TWh in 2014 (KSH, 2015). Due to decreasing international electricity prices, the electricity import has increased in the last years up to 31.4% in supply (KSH, 2015). The country had 8,558 MW_e total capacity in 2015 (MAVIR, 2015), from which only 4–5,000 MW will have been remained by 2030 (MAVIR, 2014a), due to the closing old power plant capacities. Therefore, according to the *Hungarian Transmission System Operator* (TSO), *MAVIR*'s calculations from 2014, 6–7,000 MW of new power plant capacities has to be built (or extended) in *Hungary* by 2030 (MAVIR, 2014a). The official *Hungarian Energy Strategy* of 2011 planned to have 11,300 MW capacity by 2030, from which 4,000 would be nuclear capacity: 2,000 MW of the existing *Paks nuclear power plant* and a new 2,000 MW nuclear power plant. However, this energy strategy should have been reconsidered every two years, which has not occurred.

In January 2014, the Hungarian *Minister for National Development* and the head of the Russian *Rosatom*, signed a contract about a new nuclear power plant construction in *Hungary*, in *Paks*, which was announced to the surprised Hungarian population by the media (FÜLÖP, O. 2015). The new power plant of 2,400 MW (two VVER-1200 reactors) will be built by *Rosatom* which was decided without a tender (FÜLÖP, O. 2015). The construction of the power plant (excluding supplementary investments, like grid improvements) will cost around 12.5 billion Euros, from which 10 billion Euros will be provided by Russian loan for *Hungary* for 21 years (FÜLÖP, O. 2015). However, independent financial feasibility studies show that a return of the investment is unlikely and a significant state aid will be needed (ROMHÁNYI, B. 2014; FELSMANN, B. 2015) Much of the background studies, data and contracts are classified for 30 years by the Parliament

(Szentkirályi, B. 2015), which results in difficulties or no possibility to gather information, even for future analysis, and increases risk of corruption (Fazekas, M. *et al*. 2014).

There will be a critical period in the Hungarian energy system for approximately six years, expected between 2026 and 2032. During this period, the existing four reactors *Paks Nuclear Power Plant* (2,000 MW) will run next to the *Paks II power plant* (2,400 MW). Not only building a new nuclear power plant, but also this large amount of nuclear electricity production—which will be more than half of the Hungarian electricity production—can have lasting effects on the electricity system in the following six years. Therefore, the year 2030 has been chosen to be investigated in this research and because most of the energy strategies and forecasts are calculated to that year.

1.1. Scope of the article

The aim of this research was to model and analyse the effects of a new nuclear power plant in *Hungary*, especially in the critical six years, focusing on the future possibility of spreading of energy generation from renewable resources and to create an alternative scenario to see the possibility of substituting the needed capacities with energy efficiency and renewable development. Therefore, three different, hourly based models of the Hungarian energy system were created with the *EnergyPLAN software*.

1) *Official:* is based on the *Hungarian Energy Strategy* from 2011 (Ministry of National Development, 2012) and the *Hungarian Transmission System Operator*, *MAVIR*'s projection of future power plant capacities from 2014, including the new nuclear power plant (MAVIR, 2014a).
2) *Alternative:* an energy vision of *Hungary* by 2030 was created through a six-month process to build this scenario, hosted and professionally supported by *Energiaklub Policy Institute and Applied Communications*. Only an informative summary was available until now about this vision (Sáfián, F. 2015); therefore, the detailed methodology will be presented in this paper. This sce-

nario includes increased renewable capacity and energy efficiency improvement, without nuclear power plant construction.

3) *Hybrid:* includes the new nuclear capacity and spreading renewable production as well, based on the two previous visions.

The results of the analyses with *EnergyPLAN* of the different scenarios and their comparison can help answer the above questions and draw consequences of different directions of energy planning and policy in *Hungary*.

1.2. Official energy planning and policy in Hungary

The official *National Energy Strategy of Hungary* of 2011 (MINISTRY OF NATIONAL DEVELOPMENT, 2012) plans until 2030. It addresses structural changes in the energy system with increasing capacities of low CO_2 emission intensity, like renewable-based ones; spreading heat production from renewable resources; and increasing share of low emission transportation modes. From the three future energy demand scenarios, the middle one (called 'Joint effort') was selected by strategy authors for further calculations. This scenario includes slightly growing TPES reaching 1,147 PJ by 2030, and annually 1.5% increase in electricity consumption. Regarding power generation, three crucial efforts are stated: "the long-term preservation of nuclear energy in the energy mix; the maintenance of the current level of coal-based energy generation", and increase of renewable energy production "depending on the capacity of the economy, system controllability and technological development" (MINISTRY OF NATIONAL DEVELOPMENT, 2012). From six different energy mixes, the 'Nuclear–Coal–Green' was selected as favourable target, projecting 4,000 MW nuclear, 4,900 MW natural gas, 400 MW coal (lignite) and 2,200 MW renewable capacity by 2030.

However, this strategy should have been monitored and updated every second year which lags behind. MAVIR creates and updates projection of energy needs and capacities every year (MAVIR, 2014a). According to MAVIR's up-to-date projection, electricity needs will grow only 1.0–1.3% annually (in previous years, MAVIR also forecasted a 1.5% growth.). Depending on the market conditions, capacities are projected to increase from 8,600 MW (with 11.2 TWh import; delayed investments scenario) to 13,600 MW (with 8.0 TWh export; intensive capacity growth scenario) by 2030, from which 3,200–4,400 MW will be nuclear, 2,400–6,500 MW natural gas, around 100 MW coal, and 1,850 MW renewable, irrespectively of the scenario. These, more current projections of MAVIR are the basis of the *Official scenario* created in this research, detailed in *Chapter 2.2.2*.

Official Hungarian energy planning, while acknowledges energy efficiency and conservation efforts and aims of the European Union, concentrates mostly on building new power plants, claiming GDP growth will raise energy demand. Nuclear and coal-based power plant constructions are highlighted due to their strong and influential lobby groups. However, while energy efficiency, renewable energy sources and smart energy solutions appear in the *Energy Scenario* and official plans, in reality and in the media, they get only peripheral role (MOLNÁR, Cs. 2014). Since 2006, no wind capacity tenders were announced; therefore, no new turbines have been installed since 2011 (O'BRIAN, H. 2012); the long-promised new renewable energy feed-in tariff system, called METÁR (which would be highly necessary to reach the EU targets), has still not been introduced since 2011 (ROTHFUCHS, H. 2011); and new tax on photovoltaic solar panels were put in force from 2015 (DAILY NEWS, 2015).

1.3. Alternative energy vision

The long-term goal of *Energiaklub* is to phase out fossil and nuclear energy in *Hungary* to be able to realise a sustainable energy system in the next decades. Improving environmental awareness, energy sufficiency, efficiency and diverse range of renewable-based technologies will be the most important factors to outline a flexible, decentralised energy system. Besides energy safety and economics, social and environmental aspects are also important ones in energy planning decisions. For example, the 4th generation district heating systems, based on local energy sources, providing jobs nationwide will be important elements of the energy system.

The year 2030 can be seen as an intermediate station along the way to the long-term aims where new trends are getting stronger, but the fundaments of the energy system are still traditional. The reason for that is that the modelled scenario is not a normative, best-case scenario. While defining exact numbers and characteristics of the future alternative energy system of *Energiaklub*, desirable and, at the same time, realistic and easily achievable targets were defined as a first, basic alternative scenario. In the next *Chapter*, the details of outlining and modelling this scenario by 2030 will be introduced, along with the two other models based on official energy planning.

2. Methodology

This paper can be seen as a continuation of a research that started in 2011, creating and validating the first energy model for *Hungary* with the *EnergyPLAN software*, published in *Energy* (SÁFIÁN, F. 2014). The main characteristics of the Hungarian energy system, the status and results of alternative energy planning in *Hungary* were described there, as well as the *EnergyPLAN software*, which will briefly be presented in this chapter.

2.1. EnergyPLAN software

EnergyPLAN is an energy system analysis tool, which have been developed at *Aalborg University* (AAU), *Denmark*, since 1999. This software enables to build and analyse full energy systems (including all sectors, also transportation) of a year, hour by hour. It is working as a deterministic input-output model, optimising the energy system from technical or market-economic aspects. The main input demand of the model is yearly aggregated electricity, heat and fuel demands, renewable and nuclear energy production quantities and capacities, hourly distribution of electricity, heat demands and production curves. Costs and numerous options of regulation strategies can be also defined. The outputs are energy balance, annual energy production, fuel consumption, electricity import or export, and total costs. Serial analyses can also be made by a built-in application, where changes in CO_2 emissions, total fuel usage or critical excess electricity production (CEEP) can be investigated depending on variable capacities of certain renewable technologies. In this research, *EnergyPLAN* version 12.1 was used[1].

2.2. Model building

Based on the above presented visions, plans, and projections, exact input data had to be defined to model building in *EnergyPLAN* software. The model of *Energiaklub* for 2030 was used as the basis for the two other models; therefore, it will be presented in more details. In the Official and Hybrid models, where not indicated, all parameters are equivalent to the Alternative model. Some of the main inputs like electricity needs remained the same to ensure comparability between the models. *Chapter 2.2.2.* presents the parameters of the Official and Hybrid model, according to the official plans and projections. *Chapter 3.3.* summarises the main input data of the models.

2.2.1. Alternative model based on *Energiaklub*'s energy vision 2030

In the followings, the calculation and sources of the main inputs will be detailed, from which the model (and partly the other two models) were built.

2.2.1.1. Electricity demand

Since each electricity demand projection has been overestimated in the last decades, a new estimation was carried out. Based on the Hungarian sectoral electricity consumption data of Eurostat between 1990 and 2012, and European average figures of 2012 (EUROSTAT, 2016), sectoral-, and total electricity demand were conducted with trendlines, international comparisons and assumptions based on recent processes in economy and consumption *(Table 1)*.

[1] EnergyPLAN software, version 12.1. Aalborg University (www.energyplan.eu)

Table 1 – Electricity demand by sectors in 2012 and estimation by 2030
*Source: based on EUROSTAT (2016) data. (*of total electricity consumption)*

	2012 data (GWh)	2030 projection (GWh)	change (%)	trend or estimation method
Consumption in energy sector	3,719	3,809	+2.4	11.3%* in *Hungary*, 6–7%* in EU-28 in 2012; estimation of 9.5%* in 2030
Distribution losses	3,684	3,207	–12.9	11.2%* in *Hungary*, 7%* in EU-28 in 2012; estimation of 8%* in 2030
Industry	8,910	9,856	+10.6	exponential trendline from 1993 (end of industrial structural change)
Transportation	983	2,903	+195.4	custom calculations
Residential	10,620	11,682	+10.0	10% increase between 2012 and 2030
Agriculture, Forestry, Fishing	782	800	+2.3	remains on the same level with slight increase
Services	11,517	14,849	+28.9	polynomial trendline based on 1990–2012 (R^2 = 0,96; equals to 29% growth in 18 years)
Total	**40,215**	**47,107**	**+17.1**	**(equals to 0,88% growth annually)**

Hungary has significant energy saving potential due to high distribution losses and high level of the energy system's own consumption, compared to the EU-28 average *(Table 2)*. The economic growth of industrial sector will also indicate lower increase in electricity consumption due to improving energy efficient technologies. Transportation demand was calculated with a detailed calculator of *András Futó* (more details is presented in *Chapter 2.2.1.5.*), including 570,000 hybrid electric vehicles (HEV), 220,000 plug-in hybrid electric vehicles (PHEV), 40,000 pure electric vehicles (EV) with 25% share of smart charge—these numbers can be seen as conservative projections. During modal shift, 30% of freight road traffic (t/km) changes to freight train. These changes cause a huge increase in electricity consumption in electric transportation.

Table 2 – List of large and small fossil fuel-based power plants according to Energiaklub's vision of 2030. *Groups (according to EnergyPLAN): 1: heat producers; 2: small combined heat and power (CHP) plants; 3: large CHP (can run also in condensation mode); 4: condensation PP; 5: peak PP.*
Source: MAVIR (2014b)

Group	Power Plant	Capacity (MWe)	Efficiency (%)			Production (TWh)		Used primary energy (TWh)				
			Electric	Heat	Total	Electricity	Heat	Coal	Oil	Nat. gas	Other	Total
	Paks Nuclear	2,000	31.3	0.1	31.4	15.7	*0.1*				46.4	46.4
4	Dunamenti	408	54.0	0.0	54.0	1.2				2.3		2.3
4	Mátrai	500	35.3	0.3	35.6	3.2	0.0	8.1	0.0	0.2	0.8	9.1
4	Gönyűi	433	54.7	0.0	54.7	1.4				2.4		2.4
4	Csepeli	410	44.3	7.7	52.0	1.6	0.3		0.0	3.6		3.6
3	Budapesti	396	42.6	41.2	83.8	1.2	1.1		0.0	2.7		2.7
3	Pannon	85	29.0	15.0	44.0	0.0	0.1			0.0	0.4	0.4
3	Debreceni	95	34.5	41.7	76.2	0.2	0.3			0.7		0.7
2	Gas engines	600	34.2	43.8	78.0	2.6	3.3			7.6		7.6
2	Gas turbines	340	29.3	46.6	75.9	1.7	2.6			5.7		5.7
2	Steam turbines	50	28.0	35.0	63.0	0.2	0.4		0.2	1.0		1.2
5	New OCGT units	500	30.9	0.0	30.9	0.0			0.0			0.0
1	Ajkai	102	10.7	50.7	61.5	*0.0*	0.1	0.1		0.0	0.1	0.2
1	ISD Power	65	7.5	50.0	57.5	*0.1*	0.9		0.0	1.7		1.7

Regarding households, population degrowth, efficiency improvements, and new electronic instruments will shape the future needs, generating a 10% increase during the total period. The most significant electricity demand growth will happen in services sector where the strong trend of intensive growth will continue in the next decades as well, due to more air conditioners caused of climate change and wider services. By summing up the above, total electricity consumption will be 47.1 TWh by 2030.

2.2.1.2. Heat demand

Based on the previous researches of *Energiaklub*, investigating energy saving potentials in residential (FÜLÖP, O. 2011; FÜLÖP, O. – VARGA, K. 2013), public educational and office buildings (FÜLÖP, O. 2013) cost-optimality studies of energy efficiency investments (SEVERNYÁK, K. – FÜLÖP, O. 2013) and the *National Building Energy Strategy* (CSOKNYAI, T. *et al.* 2013), heat saving potentials were defined by 2030. Due to building refurbishments, heating system improvements, complex building renewals and new, efficient buildings, 23 TWh primer energy demand could be saved by 2030, compared to 2011. The total fuel demand for heat production is calculated to be 184 PJ (51.1 TWh) by 2030. Most savings can be realised regarding natural gas (–35%), residential coal (–55%) and firewood (–70%) consumption. The level of district heating supply will remain on the same level; however, it will include new, small, local, biomass- or geothermal-based district heating systems next to the existing ones, which will supply less heat caused by higher energy efficiency of buildings.

2.2.1.3. Large power plants and fossil-based small power plants

The power plants and their parameters were taken from MAVIR's most recent projections (MAVIR, 2014a), regarding large and small, fossil-fuelled power plants, creating a reasonable mix of the higher and lower rate power plant building scenarios. The list of power plants *(Table 2)* contains the existing nuclear power plant in *Paks*, while excludes *Paks II* and numerous power plants which are working today, but will be closed by 2030. *Mátrai coal-fired power plant* is not in the capacity list of MAVIR, but it is planned since years to build on the field of the existing *Mátrai coal-fired power plant* (VALASKA, J. 2011); therefore, it is also included in the model.

The power plants are grouped according to the *EnergyPLAN* grouping system (see first column and explanation of *Table 2*); the total capacity and average parameters (efficiencies, heat storages, etc.) are put in the model by these groups. Nuclear power plants and renewable power plants (except large power plants co-burning biomass) are presented in a different section. Heat production of *Paks nuclear power* plant (0.1 TWh) could not be indicated in the model. Furthermore, electricity production (<0.1 TWh) of *Ajkai* and *ISD Power plants* are neglected due to low efficiencies; these power plants were attached to Group 1 consisting of heat only producers.

2.2.1.4. Renewables

Renewable energy capacities and production were defined based on a wide research of related literature including researches of Hungarian sustainable energy potentials and future scenarios (ÁMON, A. *et al*. 2006; FISCHER, A. *et al*. 2009; SZAJKÓ, G. 2009; KPMG, 2010; MUNKÁCSY, B. 2011; BÜKI, G. – LOVAS, R. 2010; GREENPEACE, 2011; BARTHOLY, J. *et al*. 2013; HARMAT, Á. 2013; TÓTH, P. – CSÓK, L. 2014), Hungarian official strategies (MINISTRY OF NATIONAL DEVELOPMENT, 2012) action plans (NFM, 2011) and their background studies (REKK, 2011; PYLON, 2010) and international development curves (EUROBSERV'ER, 2010; EWEA, 2011; EUROBSERV'ER, 2014a & 2014b). Based on these, the first version of the model was outlined, with the aim of defining rather conservative, but easily achievable capacity targets by 2030. This version was published in January 2015, where the figures were affirmed or corrected by Hungarian renewable energy associations. The following list in *Table 3* presents the altered and validated list, used in this research.

Wind capacities will be 8.5 times more in 2030 than in 2014, according to the conservative calculations. Currently 330 MW are in operation, and during the last wind capacity announcement for 410 MW,

Table 3 – Renewable energy capacities and electricity production in Energiaklub's energy vision by 2030

Source: ENERGIAKLUB

Energy source	Capacity in 2030 (MW)	Power production (TWh)
Wind	2,800	5.40
Solar	1,400	1.82
Solid biomass	825	2.24
Biogas	750	1.62
Geothermal	67	0.47
Hydro	66	0.24
Total	**5,908**	**11.79**

during one year, 1,117.75 MW application was rejected due to cancelling the tender (B. HORVÁTH, L. 2013). Besides favourable solar potential, on-roof photovoltaic capacities of households started to almost double every year since 2009, growing from 0.46 MW to 68.13 MW by the end of 2014 (MEKH, 2016). The estimation of 1,400 MW by 2030 was confirmed by *Hungarian Solar Energy Association*. Solid biomass is already the most important renewable energy source in *Hungary*, but used primarily in large power plants. However, the new capacities of 825 MW will be small, local, perhaps community-owned combined heat and power (CHP) units. The first estimation of biogas capacity (350 MW) was more than doubled according to the *Hungarian Biogas Association*'s recommendation. *Hungary* has significant geothermal potential, but has severe technical barriers to utilise it; therefore, only pilot geothermal power plants will run by 2030. Without new, large-scale hydro power plants, only small units can be added to the existing energy system; therefore, hydro capacities will slightly grow by 2030.

2.2.1.5. Transportation

A detailed calculator of *András Futó* was used to define transportation demands based on trends between 2000–2010 of specific fuel demands, running volumes, vehicle stocks, etc. Regarding electricity, several targets were defined, from which most important are modal shift from road freight traffic to train traffic. Finally, 4.27 million private vehicles are calculated to run by 2030, from which 2.3 million petrol, 1.1 million gasoline-based (80% of private fleet), while next to 0.67 million hybrid and electric vehicles (PHEV, HEV), 0.2 million LPG/CNG cars will be on the roads. Average fuel consumption will decrease to 6.9 (petrol) and 6.1 (gasoline) litres/100 km, where the biofuel content will raise to 7%. Train usage will raise by 30% both regarding personal and freight transportation. Total fuel demand of transportation will be 34.0 TWh gasoline, 15.5 TWh petrol, 2.9 TWh natural gas and 0.5 TWh LPG, while in 3.1 TWh transportation electricity consumption 0.54 TWh accounts for hybrid and electric cars' consumption.

2.2.1.6. Distribution curves

Hourly detailed production and demand distribution curves play important roles in the models: besides the volume of energy production based on them, they indicate weather conditions (solar, wind production curves, heat demands), user behaviour (heat and electricity demand), and enable a particular analysis of the energy system. Therefore, coherent distribution curves are needed for one common year, with 8,784 data points for 366 days. In this case, 2011 was selected to this occasion, as for this year almost all the needed data series were available from measurements in *Hungary*; all data series listed in the followings are indicating that year.

Electricity demand and wind power production curves were downloaded from MAVIR (2015). This means, that no changes were made to indicate alterations in future electricity (or any other) consumption behaviour. District heating production measurements from a CHP unit of FŐTÁV (Budapest's district heating company) were used, also for individual heat and hot water demand (FŐTÁV, 2014). Solar production curves were generated from global radiation curves measured by *Hungarian Meteorological Service* (OMSZ) and *University of Debrecen* in *Debrecen Agrometeorological Observatory* (NAGY, Z. *et al*. 2008; 2010; OMSZ, 2014). Hydro production is simulated with a German river hydro distribution curve built in *EnergyPLAN*, since it provided better results on the validation (SÁFIÁN, F. 2014) than any own-created distribution curves, while production data were not available. For nuclear power production, distribution curve was generated manually based on the known maintenance periods of *Paks power plant*. Waste, geothermal energy and biomass production were considered as constant.

2.2.1.7. Balance and regulation

In *EnergyPLAN* model, technical simulation was selected (and not market-economic) as simulation strategy, where both heat and electricity demands were balanced (strategy No. 2). There are 10–10 GWh heat storage in total next to the group 2 and 3, including small and large CHP units. There is 4,000 MW of transmission capacity available for electricity import and export—however, during the analyses of *Chapter 4*, this is set to zero. Minimum grid stabilisation production share is 30%, small CHP stabilisation share is 50%. There is no regulation for CEEP or minimum running capacity of power plants.

2.2.1.8. Official and Hybrid models 2030

In order to have comparable models, only the most necessary changes were made when building the Official and Hybrid models: mainly power plant capacities. However, this way it is neglected, that Official (and Hybrid) scenarios are likely to be regulated in a different way from the renewable energy-focused Alternative model of *Energiaklub*; furthermore, user behaviour may vary as well. It is also very likely that in the official version, focusing on power plant building as a solution for growing energy needs (and not efficiency or energy saving improvements), energy needs can be expected to raise at a higher rate. However, electricity needs are the same in all models.

Regarding the *Official scenario*, power plant capacities are based on MAVIR's projections (MAVIR, 2014a), which means, that almost all fossil fuel-based capacities are the same with the Alternative scenario. The main differences are: 4,400 MW nuclear capacity; more peak power plant capacity (1,200 MW—have to be equal to the largest block of the country); and significantly less renewable capacities. In Hybrid scenario, wind and solar capacities calculated by *Energiaklub* are added to the power plants of Official energy model, therefore including 4,400 MW nuclear capacity as well. This way this scenario could show how significant nuclear power capacities can work together with significant renewable capacities. In these scenarios, a new nuclear power production distribution was generated, since in *Paks II power plant* (2,400 MW) 2 x 1,200 MW block will work, where a maintenance stop will cause only 50% power production compared to *Paks I*, where 4 blocks of 500 MW are working (75% production during maintenance).

2.3. Summary of main inputs of the three models

The models are the same regarding energy demands, distribution curves, regulation strategies, etc. Also, electricity demand will be the same: 47.1 TWh in all three models in this comparison. The main differences are in capacities, which can be compared in *Table 4*.

Table 4 – Power plant capacities by models (indicating groups according to the EnergyPLAN software; large CHP plants can work in CHP or condensing PP mode)

Source: Calculated by SÁFIÁN, F. (2016) with EnergyPLAN software

	OFFICIAL (MW)	ALTERNATIVE (MW)	HYBRID (MW)
Nuclear power plant	4,400	2,000	4,400
Condensing power plants (Gr. 4)	1,751	1,751	1,751
Large CHP plants (Gr. 3/4)	576	576	576
Peak power plants (Gr. 5)	1,200	500	1,200
Small natural gas CHP (Gr. 2)	830	990	830
Small biomass CHP (Gr. 2)	600	825	600
Small biogas CHP (Gr. 2)	120	750	120
Wind	850	2,800	2,800
Solar	90	1,400	1,400
Hydro	75	66	75
Geothermal	65	67	65
Total capacity	**10,557**	**11,725**	**13,817**

The Alternative model has almost 6,900 MW of decentralised, small power plants, from which more than 5,900 MW is renewable, approximately the same as the fossil-based capacities (including nuclear). In case of the Official scenario, there is only 2,630 MW decentralised capacity, from which 1,800 MW is renewable; the majority is still large (7,900 MW), centralised, fossil-fuelled (8,750 MW) power plant. Regarding Hybrid scenario, the capacities are more balanced with around 5,900 MW small and 7,900 MW centralised capacities, meaning around 8,750 MW fossil and 5,060 MW renewable power plants.

3. Results

The three models were run in *EnergyPLAN software*, simulating one-year run of the different models by 2030, but with weather and consumption circumstances from 2011. *Table 5* summarises the most important indicators from the results.

Table 5 – Most important results of model simulations in EnergyPLAN software

Source: Calculated by SÁFIÁN, F. (2016) with EnergyPLAN software

	OFFICIAL (TWh)	ALTERNATIVE (TWh)	HYBRID (TWh)
TPES	272.9	252.2	268.7
RES TPES share	6.9	13.4	8.6
RES electricity share	10.3	27.1	22.2
Import electricity	0.0	0.5	0.0
Export electricity	0.5	0.1	2.4
CO2 emissions. corr. (Mt)	35.2	40.8	31.7

The *Alternative model* has the lowest total primary energy source consumption, highest renewable share, and renewable supply is 27% of electricity production. However, it needs 0.5 TWh import electricity, and it has the highest CO_2 emissions of energy sector. This is due to the large utilisation of condensing power plants running on natural gas or coal (12.4 TWh production compared to 4.0 TWh in *Official scenario*)— as 2030 can be viewed as a transitional year of the transformation process. The *Official and Hybrid scenarios* have larger fuel consumption (even with the same renewable capacities) due to high nuclear production. *Official scenario* has half renewable energy production compared to the Alternative scenario, and renewable electricity generation is less than half of that; the figures are little higher in *Hybrid scenario*. The two latter models have low CO_2 emissions and needs no electricity import. On the contrary, there is a significant electricity export in Hybrid scenario.

4. Analyses

The aims of this research were to create an alternative energy scenario, which was presented above; and to analyse the effects of a new nuclear power plant on the future Hungarian energy system, focusing on renewable energy production. Therefore, three analyses were carried out for each scenario with *EnergyPLAN* software to investigate this issue:

1. A CEEP analysis. CEEP is a used indicator in energy system analyses to describe the integration scale of renewable energy sources into the electricity system (LUND, H. 2003).
2. 24-hours analysis of the highest CEEP production periods – what are the main reasons for CEEP production?
3. Analyses of production shares of different type of power plants – is it reasonable, realistic and sustainable, considering the energy system?

4.1. CEEP analysis

As electricity production of an intermittent energy source increases in an energy system, surplus, non-utilised electricity production grows. However, this growth is non-linear, renewable energy technology- and energy system-specific. The lower the excess electricity production is in a system with the same renewable electricity production, the better the integration and utilisation of renewable technologies are. This utilisation can be improved by regulated CHP plants, (smart-charged) electric cars, heat pumps, etc. (LUND, H. 2005)—however, these technologies are not significant in the author's models by 2030 yet.

For the analyses, all models were run in serial calculation mode, with the same changes applied in each model, following (LUND, H. 2003). Transmission capacity was set from 4,000 MW to zero, this way exportable excess electricity production (EEEP) will be appeared as CEEP as well. In normal regulation mode, CPH plants are taking part in grid stabilisation and ancillary services (stabilisation share of production is 25–30%), but in CEEP analyses this is set to zero as well. To ensure grid stability, the minimum of 350 MW running power plant capacities are available in every hour and at least 30% of electricity is produced by power plants able to supply ancillary services as well.

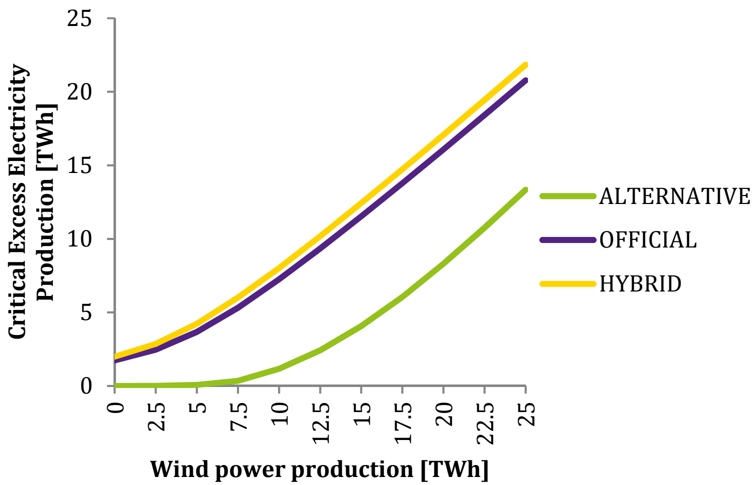


Figure 1 – Wind power and CEEP production in different models

Designed by SÁFIÁN, F. (2016)

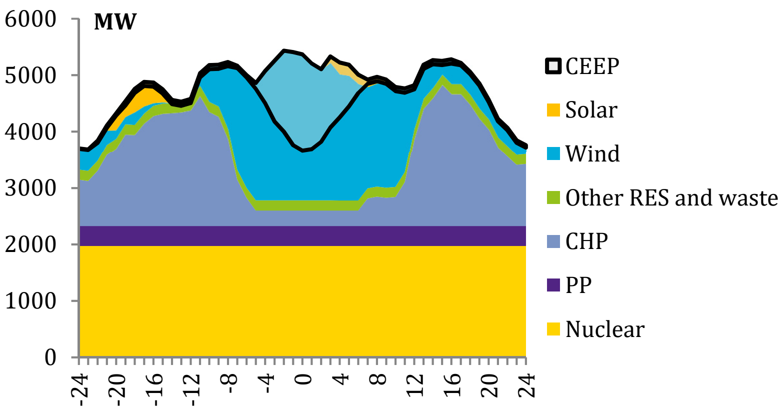
The results show *(Figure 1)* that the *Alternative model* can integrate wind energy production significantly better. Around the optimum point of 7.5 TWh wind energy production (equals to 3,885 MW wind capacity), CEEP is 4.7% of wind energy production in Alternative model, while 70.8% in the Official and 80.1% in the Hybrid scenarios. However, it is obvious, that in the latter two scenarios, excess electricity production is not solely coming from wind power, since there is 1.7 and 2.0 TWh CEEP at no wind power production as well.

4.2. Hourly analysis of CEEP production

To analyse the reason of CEEP production in the different models, the hour of highest CEEP value was selected, with 24-hour data before and after. This period was during the night of the 359–360th day of the year, in December. The following diagrams shown in *Figure 2* show the electricity generation of these two days by power plant groups (total production: top black curve), electricity demand (lower black curve), and with darker shadow, CEEP (area between the two lines).

In the case of the *Alternative model*, the excess electricity production is caused by low electricity demand due to night hours, and a windy night. However, this is not the case regarding the Official model: nuclear electricity production is higher itself in some hours of the night, than electricity demand; next to it, wind energy production is not significant.

ALTERNATIVE



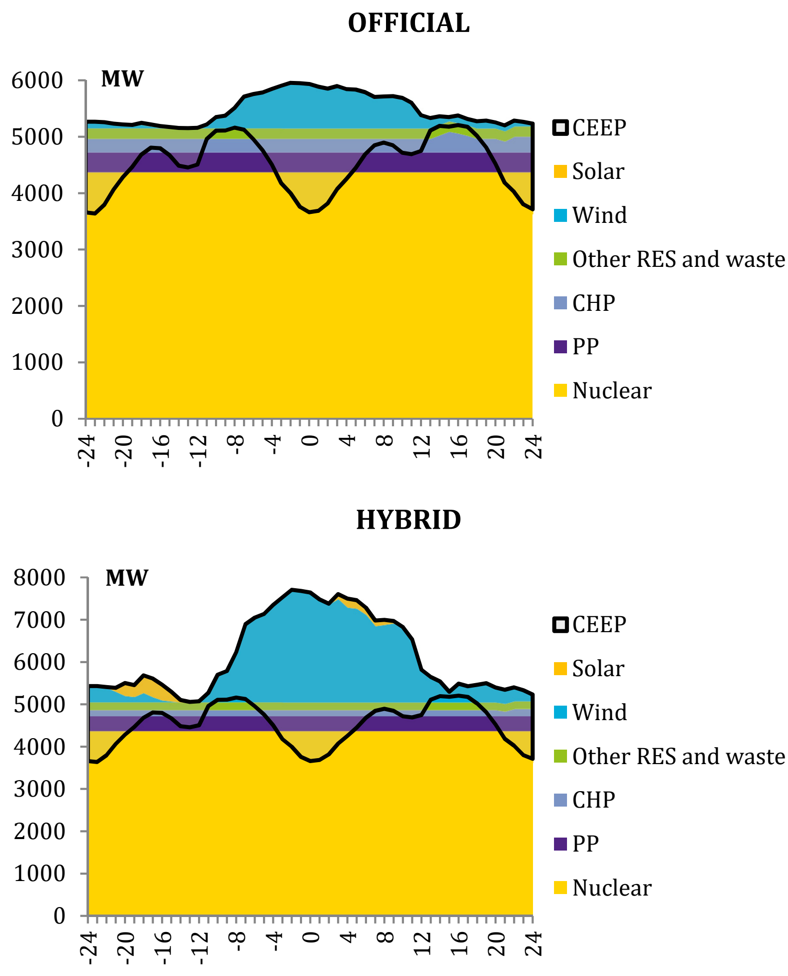


Figure 2 – electricity production, demand and CEEP in different models on the 359–360th day of the model

Designed by SÁFIÁN, F. (2016)

Based on correlation calculations between electricity demand and CEEP in Official model, it is clear, that the main cause of CEEP is not renewable energy production, but too high nuclear production compared to electricity needs, which mostly appears in winter months (corr. –0.64 on days with CEEP; corr. –0.87 on first 1000 hours of the year). Hybrid model sums up the two effects caused by wind power production and high nuclear power production.

4.3. Analysis of electricity production shares

It was already visible in the CEEP analysis in the *previous chapter* that the utilisation of different type of power plants alters significantly due to different nuclear and renewable capacities. However, in *Chapter 4.2.* the analysis was carried out with special regulation settings to be able to detect CEEP production. In this chapter, power plant production shares are presented in 'normal' circumstances as described in *Chapter 2.2.1*.

Figure 3 shows that electricity production of nuclear power plant(s) from only one physical site supplies almost three-quarter of electricity production in *Official and Hybrid models*, which arises security issues in itself. Intermittent renewable electricity share by 2030 is around 15% in *Alternative and Hybrid models* while only 3.7% in Official model by 2030. CHP (combined heat and power) and PP (power plant) production are in a critical situation next to large nuclear and renewable capacities – these power plant types are to be regulated (down) if needed. This can be seen on their production shares as well: they can produce almost half of total in Alternative scenario, only 20% together in Official and 11% in Hybrid. This would mean a positive transition of energy mix in another case; however, in *Hungary*, *Paks I* (2,000 MW) is expected to shut down step-by-step between 2032 and 2037. Therefore, PPs working in 2030 would be needed in the next decade as well, but low utilisation rates for the 6 critical years could result in PP shut downs during those years.

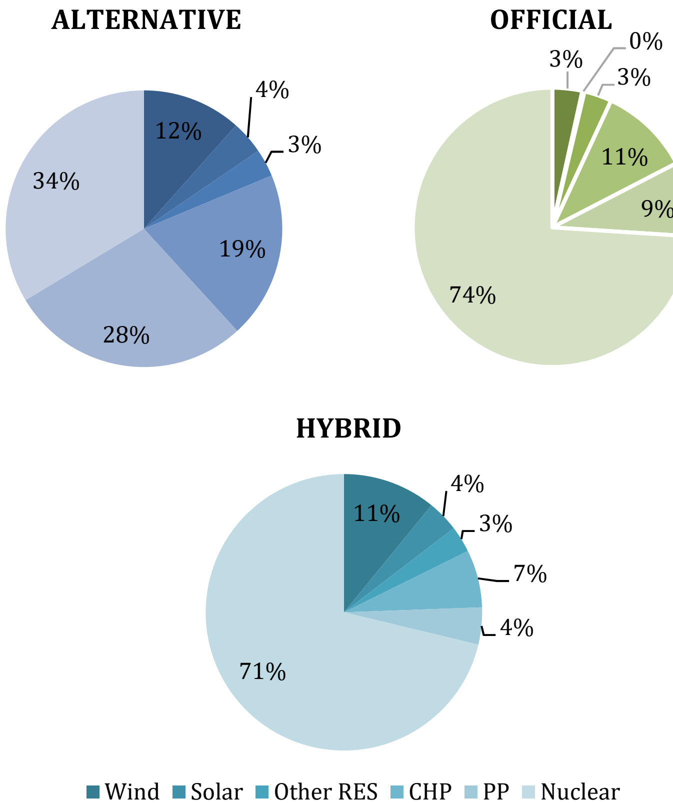


Figure 3 – Electricity production shares by power plant types in different models

Designed by SÁFIÁN, F. (2016)

As PP utilisation is more 'endangered' from this aspect, PP utilisation has to be highlighted. *Figure 4* shows the total capacity of PP (condensation power plants and CHP plants able to work in condensation mode), which is 2,327 MW, without peak power plants, and the utilisation of PPs by months.

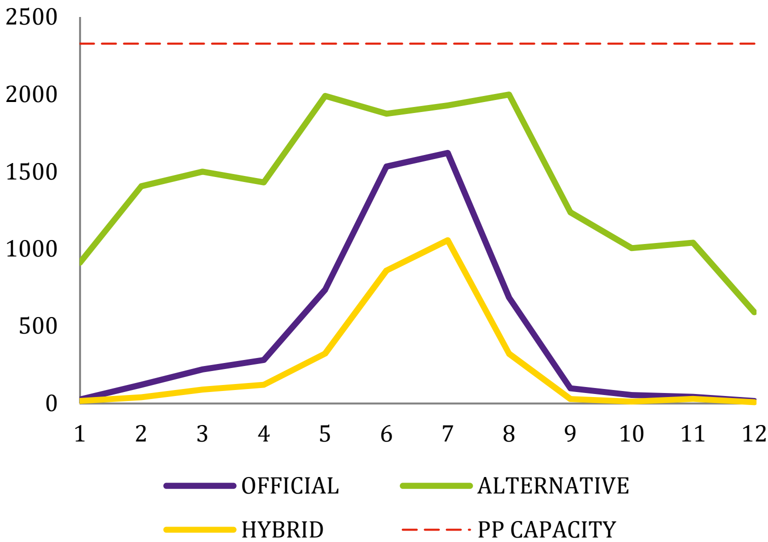


Figure 4 – Average monthly load capacity of condensational power plants in different models
Designed by SÁFIÁN, F. (2016)

The utilisation of PPs in *Official and Hybrid scenarios* is critically low, they slightly reach half of their capacity in a monthly average, while in the winter season, CHP plants are displacing them. The utilisation rate of PPs in Official scenario is 19.5%, which means only 1,710 hours, in Hybrid scenario 10.4% and 911 hours. These numbers raise the issue of uneconomic running conditions for power plants which could lead to shut downs. The *Alternative scenario* would utilise these power plants for 5,316 hours (60.5%), which could lead to normal running conditions based on average PP characteristics.

5. Conclusions

An alternative energy vision and model were outlined and calculated next to the official one. Simulation with *EnergyPLAN* software showed, that it is possible to run the energy system without a new nuclear power plan by 2030. Furthermore, according to the conservative renewable energy utilisation targets, 27% renewable electricity production share is reasonable by 2030, which is more than double compared to the Official scenario, where 2,400 MW new nuclear capacity is planned to be built instead of urging renewable-based improvements. This result implies, that *Hungary* has different viable options for energy system development, which have not been properly compared and discussed yet in public nor amongst experts; and that renewables would have more space in an alternative energy scenario than the official one.

CEEP and production share analyses showed, that excess production is significantly higher in Official and Hybrid scenarios. Hourly analyses showed, that not (solely) renewable energy production, but high nuclear power supply and low electricity demand are the main reasons of CEEP.

One can conclude, that nuclear power capacity will be oversized for 6 years of co-working of the two nuclear power plants, according to the Official scenario, which will be critical from the energy system's point of view. Nuclear capacity will be larger in itself in low demand hours than the expected electricity demand. The disproportionate nuclear power production and high baseload capacities arise serious issues regarding energy system regulation and renewable energy development, which can be expected as the followings:

- exporting electricity is the official solution for this issue, but the probability of CEEP due to large excess electricity production arises, especially during night, when export possibilities are unfavourable;
- between 2026–2032, due to the large nuclear electricity supply (and renewable production), other power plants will have to minimise their electricity production which is likely to cause uneconomic environment for CHPs and conventional power plants, while their existence would be essential after 2032–2037, when *Paks I* will be phased out;

- due to large nuclear electricity supply, preferred by TSO, will hinder other electricity production solutions for decades like 4th generation CHP district heating and renewable-based solutions;
- if TSO will not prefer nuclear electricity due to merit order effect or by preferring renewable or CHP production (and the nuclear power plant must be regulated down), financial return of the €12.5 billion investment by the state will be endangered. Therefore, there will be an interest against the development of other producers, like renewables;
- almost 75% of electricity production will come from one site, which arises security issues.

From looking upon a wider aspect, not only changes in the energy system, but also in the socio–economic framework will necessarily tend to hinder renewable solutions. For example, large amounts of research, development and investment costs will be channelled into nuclear industry, instead of diverse technologies. Furthermore, centralising the energy system on physical, but also on institutional level will hinder the development of renewable-based, decentralised local energy production.

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Environmental Limits to Sustainable Energy Production in Hungary

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Abstract

The aim of this paper is to calculate the sustainable portion of the renewable energy potential of Hungary, considering both ecological and technological limitations, in order to provide information for long term planning processes focusing on local energy solutions. In this research, the most important aspect is the multidisciplinary and spatial approach involving technical knowledge and branches of natural and social sciences. These novel aspects which have been mostly neglected in the management of centralised energy systems, emphasise the importance of locality as well as the necessity of involving new research areas, such as geography and new methodologies, for instance geographical information systems (GIS), which were used in this research to define wind, bio-mass and solar potentials. It was found that the sustainable potential (around

828.8 PJ/year after production losses) is very close to the recent energy consumption (963.4 PJ [KSH, 2016a]) of Hungary. This means that with increasing energy efficiency in renewable energy production Hungary's sustainable energy potential should be enough to sustain 100% energy autonomy from renewable energy resources in the future.

Key words

Sustainable energy; potential calculation; GIS; energy planning; multidisciplinary approach

1. Introduction

The progress towards sustainable energy transition is of utmost importance in the world since environmental consequences of the utilisation of fossil and nuclear energy resources have endangered the global ecosystem (LIOR, N. 2012; LI, F. G. N. *et al.* 2015). Conventional energy production and use determined by mainly technocratic and economic factors are the largest and still growing causes of massive local and global environmental problems. Greenhouse-gas emissions from the energy sector—representing roughly two-thirds of all anthropogenic greenhouse-gas emissions—have risen to the ever-highest level over the past century (IEA, 2015). Inside the sector another dominant problem area is nuclear energy, considering its unsolved waste management and the effects of nuclear accidents (SCHNEIDER, M. – FROGGATT, A. 2015). In the meantime, renewable energy technologies have been developed rapidly (OLABI, A. G. 2010; LIOR, N. 2012; OLABI, A. G. 2013) which represent a real alternative today.

Ecological footprint is, beside its simplifying factors, one of the most known aggregated sustainability indicators which can signal the environmental sustainability aspects of energy use in the societies. According to the *Living Planet Report* (LOH, J. 2002), the share of the energy footprint was 49.2% of the whole global ecological footprint in 1999. The global energy footprint increased from 2.5 billion to 6.7

billion hectares between 1961 and 1999, which means that it became the biggest and the fastest-growing component of the overall ecological footprint.

The latest *Living Planet Report* (McLellan, R. *et al.* 2014) published similar figures: in the European countries, the ecological footprint (4.5 Gha/capita) is much higher than the global biological capacity (1.7 Gha/capita). This report calculates carbon footprint instead of energy footprint, with similar methodology and message. According to this analysis, the carbon footprint was 53% of the total ecological footprint on global level. As for the EU-25, its energy footprint was 57.1% of the total footprint in 2001 (Wackernagel, M. 2005).

A detailed analysis was made for *Switzerland* by several governmental offices about the size and composition of the country's footprint (von Stokar, T. *et al.* 2006). According to this work, 67% of the Swiss ecological footprint was resulted by the energy sector—containing fossil fuels (35%), nuclear power (17%) and the embodied energy (15%). Moreover, the size of the whole ecological footprint is 3 times bigger (4.7 Gha/capita) than the country's biocapacity (1.6 Gha/capita)—mostly due to the significant size of energy footprint.

These developments hint at an unacceptably huge and wide environmental pressure originating from unsustainable energy production and consumption patterns. In the background, there is a defective energy planning and management practice that focuses firstly on economic, secondly on social aspects and underestimates or ignores the ecological consequences.

This situation necessarily draws the attention to alternative pathways that are analysed under the notion of energy transition and rapid decarbonisation. This new way of thinking firstly needs to be based on local solutions (Juroszek, Z. – Kudelko, M. 2016; Yanik, S. *et al.* 2016). Dealing with energy transition, nonetheless, requires a transdisciplinary approach (Personal, E. *et al.* 2014) which comprises environmental, social and economic aspects (Li, F. G. N. *et al.* 2015). That is the reason why this transition process is often understood as a co-evolution of socio-ecological (Berkes, F. *et al.* 2000), human-environment (SCHOLZ, R. W. 2011) or socio–technical systems (LI, F. G. N. *et al.* 2015). The facilitation of a proper energy transition pathway within these systems, especially from an environmental perspective, gained high priority. In this understanding, facilitation of energy transition should be started with a proper energy planning methodology—considering decisively the environmental dimension of sustainability. In this context, as a precursor of the planning process, the sustainably generated quantity, that is the sustainable energy potential of renewable energy sources needs to be assessed first. State-of-the-art energy strategies must consider these potentials, as limits of the system, in order to decrease the environmental impact of the energy sector.

In this understanding, sustainable energy sources are provided in the long run without irreversible environmental, social or economic consequences. According to this definition, waste incineration, nuclear and fossil energy generations are per se considered as not sustainable processes, because of the following reasons: *a)* waste incineration has a huge waste demand which is in contradiction to the principal of waste prevention; *b)* fossil fuel based technologies create huge greenhouse gas emissions while carbon capture and storage technologies are not proven to be reliable in the long-run; *c)* the final disposal of nuclear waste is unsolved in the entire world and may cause major accidents. However, the utilisation of renewable energy sources does not necessarily mean a sustainable energy production. In this field, it is also important to consider environmental consequences and add some ecological constraints concerning biodiversity, nitrogen and carbon budget and climate change (ROCKSTRÖM, J. *et al.* 2009).

This paper, as a case study, focuses on a Central European country, *Hungary*. In the first part, a methodology developed for assessing sustainable energy potentials will be introduced, using a relatively simple concept, in order to be able to use it in any other geographical areas. That will be followed by the calculation of the most relevant renewable energy potentials of *Hungary*, mentioning the methodological challenges too. Finally, the results are compared to similar outputs from the literature and conclusions are drawn.

2. Research concept: sustainable renewable energy potentials in the light of regulation

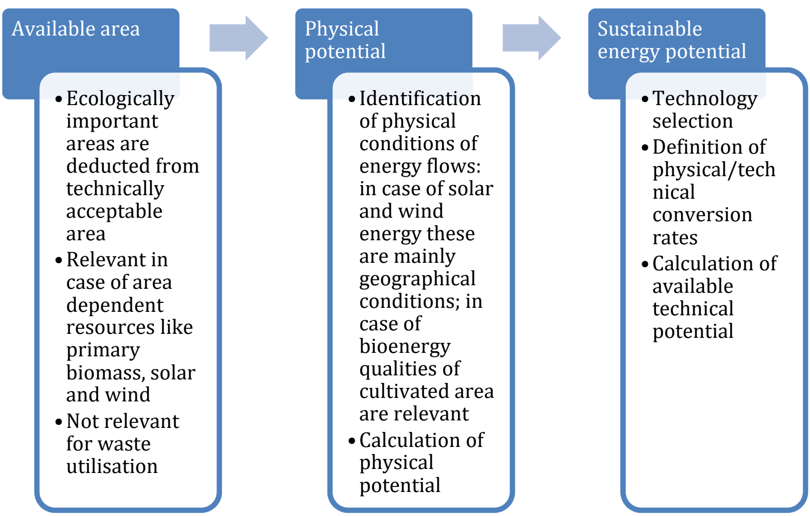
On the one hand, it was an important goal to use a relatively simple methodology assisting practical energy planning procedures. On the other hand, workable sustainability constraints had to be defined. For this purpose, the idea of embedded systems (CATO, M. S. 2009) and strong sustainability criteria were invoked (AYRES, R. U. *et al.* 1998; VAN DEN BERGH, J. C. J. M. 2014) that are common in environmental economics. The idea of embedded systems visualised by the three circles model articulates that both society and economy are dependent on and embedded in the overarching ecosystem highlighting biophysical constraints. This refers to the fact that limitless use of resources from the ecosystem is not possible and it destroys the carrying system which results in the ultimate collapse of the carried systems too. This emphasises the inequality of the three pillars: ecosystem, society, and economics (PEARCE, D. *et al.* 1989; CONSTANZA, R. – DALY, H. 1992) too.

Concerning renewable energy use in the context of the three circles model reveals the problem of scale which is a decisive factor of sustainability when using these resources. Practically, this means that area for harnessing renewable energy resources is limited and often excluded from the ecosystem. Thus, there exists a competition among society and the rest of the ecosystem for these resources. To resolve this problem while keeping in mind the ultimate role of the carrying ecosystem the use of the precautionary principle and the concept of strong sustainability should be considered. The conditions set by the precautionary principle and by the strong sustainability can be satisfied by setting the highest priorities to the ecological system and maintain its resilience in every way. Maintaining this criterion is one of the biggest challenges of humanity, since humanity must manage a transition from less area-dependent resources, for example fossil fuels, towards much more area-dependent renewable energy resources in a limited world.

Based on the ecological constraints, a methodology was developed for assessing sustainable energy potential intends to improve—or at least to conserve—the given ecological conditions, preventing any deteriorating long or short term processes. For defining sustainable energy potential to satisfy these requirements, the methodology used in this paper is a hierarchically structured set of barriers for each renewable energy technology. A strongly spatial approach was used, where in the first step the available area of renewable energy production must be defined in a way that it does not induce any environmental deterioration. This, of course, is not relevant for technologies using secondary and tertiary wastes. In the first instance the ecological requirement is guaranteed by the exclusion of any protected areas, including ecological corridors, from the area suitable for energy production purposes *(Figure 1)*.

Figure 1 – The general process of assessing sustainable energy potential

Edited by K*OHLHEB*, *N. (2016)*



If this is satisfied by the current regulation in force, it defines the available area. If not, it is defined by the ecological constraints. Based on the physical potential in the available area suitable for sustainable energy production, technical potentials are calculated using technological conversion rates. The area available for sustainable energy production can be fine-tuned by some important assumptions listed below:

1. Usage of already anthropogenic/industrialised areas are preferred, where the installed technology does not disturb human population;
2. To the usage of ecologically less valuable territories are given higher priority over the green/natural areas with high natural value.

Spatial calculations were made within the environment of ArcGIS 10.3 software. One of the biggest barriers of the work was the lack of accessibility of GIS data. In most of the cases data were provided by the given authority or research institute, since only few relevant spatial data are available for public.

When calculating the technical potential from the available area, besides the physical conditions of the area and the technical conversions rates, the following sustainability aspects are considered:

1. Exploitation of wastes and by-products always have priority over primary resources;
2. Energy efficiency improvement excluding unnecessary conversion steps and transport distances have priority.

In the following, the above described methodology for sustainable renewable energy potential assessment will be detailed in practice through the case of the Hungarian potential calculations. After the assessments, the results will be compared with Hungarian renewable energy potential calculations from the literature. Finally, based on this discussion, conclusions will be drawn related to the current renewable energy developments in the country.

3. Sustainable potential of solar energy

In *Hungary*, the legal regulation is not sufficient in the field of solar applications from an ecological point of view. On the one hand, regulations do not exclude green-field investments, even though this non-exclusion conflicts with the priority set above for maintaining biodiversity. In this approach, biological activity of the target area was important to protect resulting only brownfield areas and existing infrastructure (rooftops of buildings, parking lots, hypermarkets, etc.) to be acceptable for solar energy investments. On the other hand, some of the cities have strict regulation against solar applications in order to protect the historical urban landscape, which seems a contradiction, as equipment necessary for the traffic of modern vehicles are not excluded from the very same areas.

To calculate the sustainable solar energy potential, the first step is to determine the suitable area and the technology. The latter are the photovoltaic (PV) and the photovoltaic/thermal hybrid solar collector (PV/T) systems *(Figure 2)*.

Figure 2 – GIS-analysed orthophoto of Esztergom showing the south facing and flat rooftops to calculate solar potential

Source: MUNKÁCSY, B. et al. (2008)

As for the spatial aspect, firstly, in this research greenfield sites are not considered for solar applications, because existing technologies demand remarkable space and the result in a negative impact on biological activity and diversity.

Secondly, using GIS methodology in cases of settlements, it is necessary to calculate the surface areas offered by the existing building stock. A thorough GIS-based assessment of orthophotos of 17 settlements including 2 cities and 15 villages (MUNKÁCSY, B. *et al.* 2008) resulted in the following outcomes. Considering the area of flat roofs together with roofs facing to South (with a maximum 45° East or West deviation), the ratio of the proper building stock varies between 21 and 84%, as the average ratio for the whole area is 53%. The size of the suitable roofs varies between 36 and 115 m^2 per building, the average size per building is 53 m^2. Extrapolating the figures of the sample area at national level, the result is between 82 and 105.5 km^2 (94 km^2 in average) south-facing and flat roof area. This value needs to be corrected with the ratio of the urban fabric category represented in the *Corine Land Cover* database, as the urban fabric is 7.13% in the sample area of this research; meanwhile the same sort of area is 4.67% in *Hungary* in average, which is about the two-thirds of the value of the sample area. Using the correction factor, the final figure is 61.6 km^2, as suitable roof surface for solar applications in the whole country.

Thirdly, using the figures of some existing European PV-applications, like the solar train tunnel near *Antwerp* (width: 14.3 m) and several solar noise barriers along highways (width: 2 metres on one side of the road, 4 m on both sides), it is possible to refine the earlier published 11.11 km^2 figure (FARKAS, I. 2010). Considering the whole 8,000 km train network, and a 14.3 m tunnel width, it would be possible to cover 114.28 km^2 area with PV systems. As for the 1,400 km highway system, using a 2-m-width noise barrier on both sides of the road, 5.6 km^2 area would be utilisable by solar panels. Consequently, the existing traffic infrastructure could provide, as a potential, almost 120 km^2 surface for PV applications.

Fourthly, the shopping infrastructure including all their parking sites can also provide significant areas, as there are around 80 larger hypermarkets and 6,000 smaller local shops all over the country. Taking into consideration only half of their parking areas, as there are also underground parking areas and parking garages, another 4 km^2 can be added to the potential areas.

Fifthly, calculation of the planned elements of infrastructure by 2050 is also needed. According to the *National Development Policy Concept* (VARGA, M. 2013), there are 1,300 km highways and 800 km railways in need to be built. As for the planned highways, their south-facing noise barriers could provide 5.2 km^2 suitable area for solar applications (considering 2 m noise barrier height on both sides of the road). Regarding the planned railways, using the same methodology as the existing 50,000 m^2 PV tunnel system (3.92 MW) near *Antwerp*, it would be possible to utilise another 11.4 km^2 surface area.

Sixthly, the expanding 'average floor area per capita' also needs to be taken into account which means that growing building surfaces lead expanding roof areas suitable for solar applications. In *Hungary*, this increase was 5% between 2000 and 2010 (IEA, 2015). The recent 30.2 m^2/capita is much smaller than the EU-15 average (42.9 m^2/capita), so in this research there was assumed a (ENTRANZE, 2008.), therefore 25% expansion between 2000 and 2050. This factor results another 15 km^2 increase of the possible solar areas.

Table 1 – Potential areas for solar energy applications in Hungary and their sizes

Source: MUNKÁCSY, B. et al. (2016)

Type of surface area or other factors	**Size of surface (km^2)**
Roofs in settlements	61.6
Existing linear infrastructure	120.0
Parking areas in commercial zones	4.0
Expansion of the linear infrastructure by 2050	16.6
Increase of building area/capita by 2050	15.0
Total	**217.2**

In summary *(Table 1)*, using the different elements of the existing and planned infrastructure, almost 217.2 km^2 potential area can be considered as suitable for active solar applications in *Hungary*. Using a state-of-the-art PV technology (7 m^2/kW), it is possible to install 30,885 MW active solar capacity without any disturbance to green areas. The estimation of the average yearly power production was based on optimal (1,150 kWh/kW/year) and suboptimal (1,000 kWh/kW/year) predictions of the PV yield-estimation calculator developed by the *European Commission Joint Research Centre*. Using the suboptimal moderate value, 30.9 TWh/year (or 111.25 PJ) electricity can be predicted by 2050, a slightly more than the recent domestic power production (29.4 TWh or 105.7 PJ) in *Hungary* in 2014 (KSH, 2016c.). However, utilising the same area, this electricity production could be much higher using future technologies. Using the photovoltaic/thermal hybrid solar collector (PV/T) technology, it would be possible to increase the electricity production by 25%, moreover, these systems are also able to create heat (250 kWh/m^2/year), mainly hot water, which can be used in settlement areas. The available surface areas (buildings and parking areas) for solar applications in settlements cover 80.6 km^2. With this technological shift, it would be possible to produce another 3 TWh (10.8 PJ) electricity, as a surplus, by 2050. Additionally, utilising the same surface area, these PV/T systems could produce 20,150 GWh (72.5 PJ) heat.

4. Sustainable wind energy potential

The calculation of sustainable wind energy potential of this research also begins with defining the available area. In this case, the existing legal and technological regulations proved to be sufficient for a sustainable production. The *Environmental Ministry* (KvVM, 2005), published a list of excluded areas, creating strict environmental limits for wind energy investments. These are as follows:

a) protected natural areas (national, local, and international level)—including the ecological network, that prevents protected areas from fragmentation;

b) protected landscapes (national and county level);
c) Environmentally Sensitive Areas;
d) forests;
e) hydrographical elements;
f) roads, railways and airports;
g) transmission lines (it is a primary condition of these kind of projects; but in this context, the grid is a vulnerable element of the infrastructure).

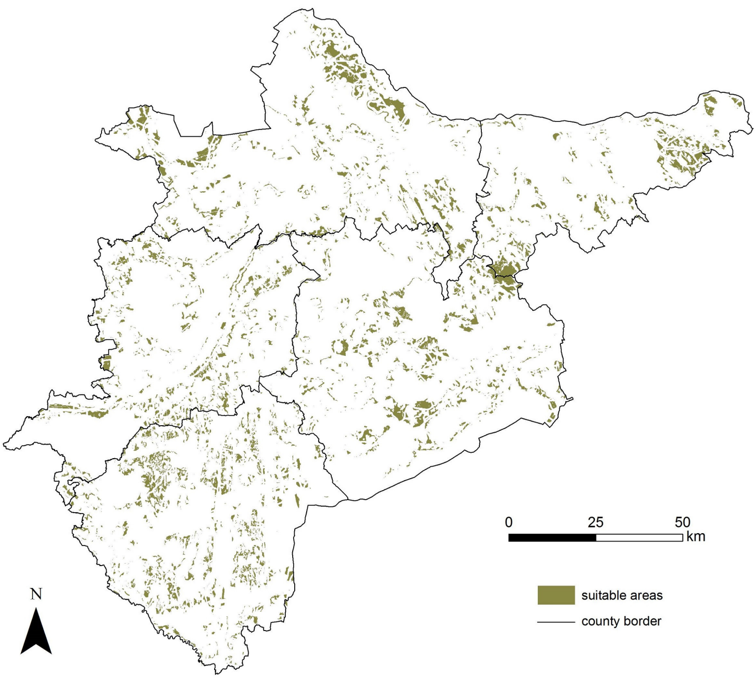


Figure 3 – Suitable areas for sustainable wind energy utilisation in north-western Hungary
Edited by Harmat, Á. (2016)

Around the excluded areas there are buffer zones with distances which vary between 0 m and 1,000 m depending on the type of the areas. These restrictions are covering all the territories with the highest biodiversity and ecological values. Hence, it can be stated that, due to the regulation, aspects of sustainability are taken into consideration sufficiently *(Figure 3)*.

Using GIS application, all these limitations can be implemented and excluded from the technically suitable area in the country. The deduction of these areas restrains the potential areas to 5,396 km^2, which is only 5.8% of the total land area of *Hungary*—it also means that 94.2% of the land area is excluded, strictly considering the existing regulation.

The opportunities in *Sweden* were analysed by a GIS-based research. It was estimated that up to 69% of the total land area was excluded due to the constraints given by biodiversity and ecosystem services, in the form of areas of national interest for nature, culture and recreation values, as well as single houses with buffer zones (SIYAL, S. H. *et al.* 2015). According to a similar research of the *German Federal Environment Agency* (LÜTKEHUS, I. – SALECKER, H. 2013), using also a GIS methodology, this value is 86.2% in the case of *Germany*. In the case of *Austria*, due to the regulation, 93% of the land area are under restrictions and only 7% of the land area can be utilised for wind power production (GASS, V. *et al.* 2013). Comparing the above-mentioned values, 94.2% excluded area indicates a strict legal background in the case of *Hungary*.

In the next step, a proper technology was chosen. In the authors' analyses, the state-of-the-art horizontal axis wind turbine technology, developed especially for low wind sites, was used. These turbines have a moderate space demand and exceptionally high EROEI value. Involving ecology experts, it is possible to decrease their environmental pressure to a reasonable level (WANG, S. – WANG, S. 2015). For the analyses, the most important parameters are the capacity and the power curve. Because the Hungarian wind energy development has been blocked by political reasons (MVM, 2006; NFM, 2012), it is not possible to find proper local information, therefore it was necessary to use international data sets from regions with similar wind climate. According to the values of the *German Energy Agency* (DEUTSCHEN ENERGIE-

AGENTUR GMBH, 2010) the so-called land requirement value can be varied between 7 and 10 ha/MW, considering the state of the art turbine technology. Calculating with the less favourable 10 ha/MW land requirement value, 10 MW wind turbine capacity can be installed per 1 km^2. Adopting the GIS calculated 5,396 km^2, as the potential area, the Hungarian sustainable wind energy potential is around 54,000 MW. To calculate the electricity production of that huge capacity, it is possible to use the real-life capacity factor of the Hungarian wind energy sector. These values are between 20–25% in *Hungary* (MAVIR, 2010; MSZT, 2010). If the basis of the calculation the worst value, that means that 54,000 MW wind turbines could produce 94.6 TWh (340 PJ) electricity, which is three times higher than the recent domestic power production (29.4 TWh or 105.7 PJ) in the country.

5. Sustainable solid biomass potential

In case of solid bioenergy potential only forestry biomass and short rotation coppice (SRC) were taken into consideration.

5.1. Forestry biomass

In *Hungary*, 20.8% of the country area is covered by forest, namely 1929 thousand ha in 2014 (NÉBIH, 2015). In the period between 2004 and 2014, the average annual net growth of the forested area was 13 million m^3, the yearly logging was 7.3 million m^3 (NÉBIH, 2015). The amount of the natural mortality and the logging is less than the annual net growth, therefore the growing stock increases with 3% per year. That means that forestry is controlled by relatively strict technical regulation based on the annual and ten-year forestry operational plans, which in the authors' understanding, ensures sustainability, at least from a quantitative point of view. The potential calculated with the factors is presented in *Table 2*. The total gross logging data was determined as the average of the logging data from 2012 to 2014.The rate of the firewood from the total gross logging is available in the statistics only as aggregated data (54.5 %—average of 2012–2014); therefore, this rate was applied for the three timber-type group. Since the logging data are for fresh wood, the moisture content was determined in 50%, according to (Röder, M. *et al.* 2015), and the energy content was collected from Biomass Energy Centre (2016). In total, the gross calorific value is 30.7 PJ.

Table 2 – Factors determining solid bioenergy potential

Sources: [1](NÉBIH, 2015); [2](BIOMASS ENERGY CENTRE, 2016)

	Total gross logging[1] (thousands m^3/yr)	**Firewood from the total logging[2] (thousands m^3/yr)**	**Energy content (with 50% moisture content)[2] (GJ/m^3)**	**Gross calorific value (PJ)**
Hardwood	4,552.3	2,481.0	8.5	21.1
Softwood	1,580.5	861.4	6.0	5.2
Pine	1,162.7	633.7	7.0	4.4
Total	**7,295.5**	**3,976.1**	**21.5**	**30.7**

5.2. Short rotation coppice

The determination of energy potential from plantations was calculated using GIS database, too. The focus of the investigation was only arable land occupied by intensive cultures since using these areas for less intensive cropping like woody short rotation coppice (SRC) could improve their ecological services by conserving soils, enhance soil organic content balance and mitigate carbon emissions (Rowe, R. L. *et al.* 2009). The arable land was identified as the 211. Category—non-irrigated arable land in the national land cover database with the scale of 1:50,000.

Legal limitations exist only for the plantations of black locust *(Robinia)* on protected natural area and Natura 2000 sites (FVM, 2007). These limitations were considered as not sufficient for a sustainable SRC production. Thus, in the first step, arable land—where limitations of the current land-use are needed for protective purposes—were identified. The GIS database of the *National Agro-Environmental Program* was used for this purpose. This GIS database, with the integration of 28 parameters of agricultural production and environmental sensitivity, provides a value from 0 to 200 indicating an environmental sensitivity-agricultural suitability measure for each 1 ha grid cell of the whole country. In (ÁNGYÁN, J. *et al.* 1999) areas with a value less than 100 were ranked into the protection zone, between 100 and 125 as extensive agricultural zone, and with a value more than 125 as intensive agricultural area. The extensive agricultural zone was identified as suitable areas for the further steps. In the next step, suitable areas were identified for willow, *Robinia* and poplar (these are the approved SRC species by law (FVM, 2007) using soil parameters of GIS database like pH, lime condition of the soil, physical soil types, soil types and sub-types, water management parameter, and compaction of the productive soil *(Figure 4–5)*.

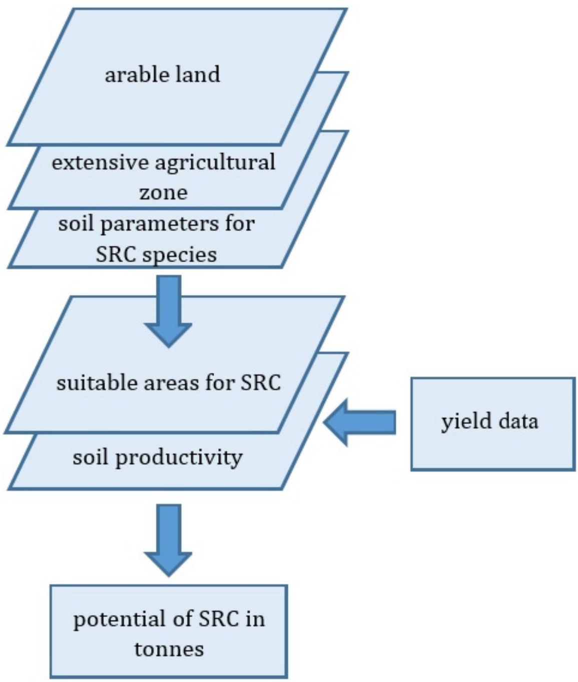


Figure 4 – Process of determining SRC potential
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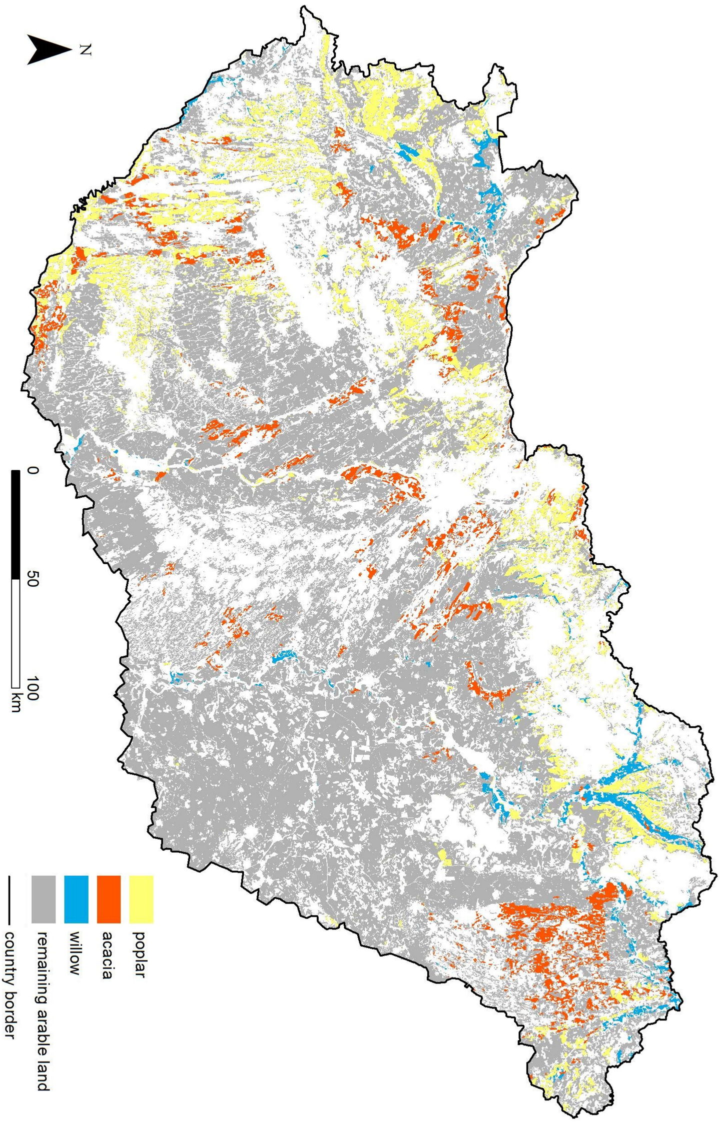

Figure 5 – Suitable areas for SRC plantations in agricultural areas
Edited by HARMAT, Á. (2016)

In the next step, the intersection of the suitable areas with the zone of extensive agriculture were selected yielding 0.96 million hectares for potential cultivation, which takes up 49.8% of the extensive agricultural zone. The exclusion of the area would not cause issues in the security of food-supply on national level, since only 1.5 million hectares of the total 4.3 million hectares of arable land are needed to secure the average current diet in *Hungary* (KOHLHEB, N. *et al.* 2009). In the final step the yield calculation was based on empirical yield values of the experimental plantations in *Hungary* (BARKÓCZY, ZS. – IVELICS, R. 2008). Here yield data—defined by the minimum and maximum measured yield for the three species—was differentiated by the soil productivity class for each 1 ha grid cell. According to the calculations, the average yield was 17 t/ha (fresh mass) and the total yield was 15.87 million tons on the whole designated area. With the heating value of 7 MJ/kg (IVELICS, R. 2006), the total energy content is 111.1 PJ. This, together with the forest based potential, amounts 141.8 PJ. This can be used in cogeneration units with 80% efficiency producing 34 PJ electricity and 79 PJ heat. Using high efficiency heating appliances working with 90% efficiency, 127.6 PJ heat can be produced. The exploitation of this resource only for power production would gain only 42.5 PJ with 0.3 efficiency ratio. So, this alternative does not satisfy the criteria for energy efficiency.

6. Potential of biofuels and biogas

Because of the well-known sustainability debate about biofuel, the calculation of this research has determined the biofuel potential as the minimum compulsory share of the total fuel (10%) (EUR-LEX, 2009), which is 12 PJ. According to (EUR-LEX, 2015), maximum 70% of the potential would be from crops grown on agricultural land.

6.1. Biogas potential

In the calculations following the ecological principles laid down above (favour wastes instead of primary resources), primary resources that consume valuable area either from the ecosystem or from food production were not considered. So, the Hungarian biogas potential was assessed considering only secondary and tertiary resources. In the first step, the available residues are accounted, for example manure, meat processing wastes and human residues as sewage, food wastes and landfill. Of course, the first step, namely calculating the available area was not relevant, when assessing biogas potential from residues. In the next step the utilisable share of these residues was assessed. In this step the usually collectable share was determined. This was made concerning usual size distribution of animal husbandry units and usual agricultural practices in bedding and in waste management.

To assess biogas potential from manure, the produced amount of feedstock was calculated first. In the approach of this research, the most important manure type (solid manure) was considered that also incorporates bedding materials, like straw and stover, that are crop residues. In case of grazing animals, like horses and sheep, smaller fraction of manure was collectable (approx. 50%), meanwhile for dairy cow and mast pig a higher share is possible (80% and 90% respectively). Only a fraction from the collectable amount of manure is utilised in biogas plants, since not every animal husbandry unit is able to build a biogas plant, mainly due to too small animal density. In the final step, according to the share of dry matter, organic matter and biogas yield ratios, the producible biogas and its energy content was calculated.

Table 3 – Biogas potential of manure

Sources: [1](KSH, 2016b); [2](FVM, 2008); [3](INSTITUT FÜR ENERGETIK UND UMWELT GGMBH, 2004)

	Number of animals[1]	***Specific manure production[2]***	***Dry material[3]***	***Organic dry matter[3]***	***Specific biogas yield[3]***	***Collectable share of manure***	***Share of manure treated in biogas plant***
	(pcs)	*(t/pcs/yr)*	*(%)*	*(% of DM)*	*(Nm3/t ODM)*	*(%)*	*(%)*
Cattle	821,000	9.923	0.25	0.72	255	80%	70%
Pig	3,124,000	2.184	0.25	0.78	360	90%	70%
Horse	62,200	4.888	0.25	0.72	255	50%	40%
Sheep	1,190,000	1.560	0.32	0.71	255	50%	40%
Poultry	37,895,900	0.021	0.32	0.71	350	80%	70%

Based on the calculation given in *Table 3*. 12.27 PJ manure based biogas energy can be produced in *Hungary*.

The tertiary wastes as slaughterhouse offal, DDGS from bioethanol production, food wastes, sewage and sewage mud were also considered. Here, also the utilisable share is assessed and then the special biogas yields are applied, since these gases often have different methane shares than those from manure *(Table 4)*.

Table 4 – Biogas potential of secondary residues and by-products

Sources: DDGS: Distiller's dried grains with solubles; [1]MUNKÁCSY, B. et al. (2016); [2] VADAS, T. 2012; [3]HANSEN, C. L. 2011; [4]MUNKÁCSY, B. et al. (2016) based on BAI, A. et al. (2002); [5]gross calorific value of biogas at 60% methane content (WELLINGER, A. 1991)

	Amount of wastes[1] (t/yr)	Biogas yield (Nm^3/t)	Energy content (MJ/Nm^3)	Utilisable share (%)
Slaughterhouse offal	**372,264**	900.00[2]	21.5[5]	50%
DDGS	**706,963**	106.50[3]	26.0[3]	50%
Food wastes	**4,506**	680.00[2]	21.5[5]	50%
Sewage mud	**1,059,832**	14.80[2]	21.5[5]	50%
Landfill	**20,087,407**	35.04[4]	15.74[4]	2%
Sewage, m^3	**600,571,382**	0.10[4]	21.5[5]	100%

According to *Table 4*, 6.29 PJ energy is embodied in the tertiary residues and by-products that could be used for biogas production. Altogether secondary and tertiary residues comprise 18.57 PJ renewable energy potential in *Hungary*. Currently the country produces only 3.2 PJ.

20% of the amount of 18.57 PJ biogas has to be used for heating the fermenters (BESGEN, S. – KEMPKENS, K. 2004). The rest, 14.85 PJ can be used with 80% efficiency in a cogeneration technology producing 5.9 PJ heat and 5.9 PJ electricity per year. Another way of utilisation would be upgrading and/or cleaning of biogas enabling a local direct heat production with approx. 90% efficiency. This gains 13.36 PJ heat energy.

7. Discussion

The preceding chapters of this paper focus on sustainable solar, wind and biomass energy solutions and contain new calculations for these potentials, since available sustainable energy has not been evaluated on a country level in *Hungary* ever before. In this part the goal is to compare the results with other calculations from the literature. As it appears, there were barely a few researches in this field except for biomass, which is broadly considered the most important renewable energy source in *Hungary*. In the case of hydropower and ambient heat potentials, data from literature was used, to get a complete picture of possibilities of sustainable energy in *Hungary*. Comparisons are made mostly on the level of technical and social-economic potential.

7.1. Solar potentials

Earlier calculations carried out by technology experts (PÁLFY, M. 2005; FARKAS, I. 2010) state that *Hungary* has theoretically more than 9,000 km^2 area where PV panels could be installed, and 4,000 km^2 area where PV installations should be favourably built. Approximately 90% of the latter value is agricultural area, 54.27 km^2 south-facing surfaces of the building stock (43.16 km^2) and suitable areas along railways and roads (11.11 km^2). Using the favourable surfaces, 400,000 MW PV capacity could be installed, which could produce 12 times more electricity than the electricity consumption in *Hungary* (PÁLFY, M. 2005). It is important to underline that these calculations mention almost 20 times bigger areas than the sustainably available (217.2 km^2) assessed in this study.

7.2. Wind energy potentials

The national level wind energy potential calculation, made by technology and meteorology experts and accepted by the relevant branch of the *Hungarian Academy of Science*, was published intensively during the last decade (HUNYÁR, M. 2004; BOHOCZKY, F. 2008; SZALAI, S. *et al.* 2010). These works were based on the same initial research that neglected several types of restricted areas, and contained overlapping. That can be explained by the facts that earlier research was conducted without environmental expertise such as nature conservationists and was accomplished without geographers and GIS methodology. The calculated 65.3% rate is a result of a simple addition which does not contain some types of restricted areas, as national and county level landscape protection zones or Nature 2000 areas. The incorrect methodology and the lack of knowledge in the field of landscape and nature protection produced an irrelevant and very high end-result (148 TWh or 533 PJ).

7.3. Bioenergy potentials

There have been a number of studies dealing with solid bioenergy potential. FISCHER, G. *et al.* (2005) concluded that in *Hungary*, SRC (mainly willow, poplar, and reed) could produce 327.6 PJ energy. Completed with the available forestry potential, altogether 1,777 PJ solid bioenergy potential is exploitable in the country. VAN DAM, J. *et al.* (2007) also calculated a physical potential of 400–1,200 PJ by the end of 2030. In this calculation, however, less suitable areas were excluded from potential areas. DE WIT, M.– FAAIJ, A. (2010) estimate 500 PJ bioenergy potential that can be achieved mainly by energy plantations by the end of 2030. The *European Environmental Agency* (EEA, 2006) in its model based approach, already considered environmental constraints like conserving extensively cultivated areas, excluding 3% set-a-side from cultivation, intensification of forest harvest on protected areas and the necessity of forest residues being kept on site. They conclude that by 2030 on arable land and in forest 146.6 PJ primary biomass theoretical potential can be produced, meanwhile the residue potential amounts 83.8 PJ.

Hungarian studies also estimate similar theoretical potential, for instance 203–328 PJ (IMRE, L. 2006), and 188 PJ (NFM, 2014). The study of (POPP, J. – POTORI, N. 2011) estimates theoretical potentials of 47.5 PJ for firewood and 39.8 PJ residue potential that can be used by firing processes, altogether 78.3 PJ. This potential was calculated by keeping the current land-use patterns, meanwhile the calculations of FISCHER, G. *et al.* (2005) assumed a massive change of land use favouring bioenergy production.

Compared to these results, the total 141.8 PJ theoretical potential represents a moderate value; however, it is slightly larger than the estimation made by POPP, J. – POTORI, N. (2011). This is due to their calculation which did not consider an increase in energy plantations, which, therefore, gained 111.1 PJ in the model. However, POPP, J. – POTORI, N. (2011) calculated with a slightly higher firewood potential than the model of this research, respectively with 47.5 PJ and 30.7 PJ. The study of POPP, J. – POTORI, N. (2011) also calculates technical potentials that are in case of cogeneration, 35.1 PJ for heat and 22.3 PJ for electricity. These are also smaller numbers than this research's results due to the above mentioned conservative approach of SRC production.

The residue potential degradable in anaerobic fermentation was estimated at 77.6 PJ by BAI, A. (2007) and 157 PJ by POPP, J. – POTORI, N. (2011) also estimated the biogas technical potential and calculated 118 PJ. This value is more than five times larger than the estimation of this research. This is due to two reasons. Firstly, in the calculation of POPP, J. – POTORI, N. (2011) the manure potential is 33.6 PJ while result calculated by the authors of this paper was only 12.27 PJ, because considerable fractions of manure due to less favourable animal density were excluded from the authors' calculation. Secondly, the calculation of POPP, J. – POTORI, N. (2011) takes into account a considerable amount of potential stemming from energy crops which were excluded for ecological reasons.

7.4. Hydropower potential

As *Hungary* has no favourable geographical settings (the rivers are either slow-flowing or in the mountains have low streamflow), significant hydropower potential was not taken into consideration. The theoretical potentials that are defined in the Hungarian literature (SZEREDI, I. *et al.* 2010; GŐŐZ, L. – KOVÁCS, T. 2011; TÓTH, P. *et al.* 2011) are approximately 1,400 MW, producing 7,446 GWh/year (14.22–27

PJ/year), and the technical potentials are 1,000–1,040 MW, 4,590 GWh/year. 80–90% of the potentials are connected to the two main rivers, *Danube* and *Tisza* (SZEREDI, I. *et al.* 2010), but utilising their potentials would cause large environmental consequences. Taking this into account, only a fraction of the above technical potential could be considered sustainable, consisting of small and micro hydropower plants of 10(–20) MW (IPCC, 2012); furthermore, rebuilding existing dams or installing, upgrading or fully reconstructing micro and pico hydroelectric stations can add further approx. 40 MW to the potential (SZEREDI, I. *et al.* 2010). Based on the assessments on these potentials, the sustainable hydropower potential was defined to be 2 PJ.

7.5. Potential of ambient heat

The ambient heat can be deep and shallow geothermal, as well as hydrothermal and aerothermal. The traditional and most well-known resource in *Hungary*, is the deep geothermal energy. Its potentials are influenced by geological conditions which results in outstanding heat resource in the *Carpathian Basin*. In the calculations, the approaches can be different, therefore the figures of the theoretical potential vary between 264 PJ and 102,000 EJ. The most respected figures of the technical potential are published by MÁDLNÉ SZŐNYI, J. *et al.* (2009), namely 65 PJ for deep and 35 PJ for shallow sources, respectively. With the reinjection of pumped groundwater, these last figures can be considered as sustainable potentials.

The potentials of hydrothermal and aerothermal heat pumping are more complicated to estimate, as the quantity of these ambient heat sources are practically inexhaustible. Their sustainability depends on the environmental characteristics of the used electricity. Namely, the ambient energy can be considered sustainable if the power production is based on sustainable renewable energy applications. According to a software based sustainable energy scenario (MUNKÁCSY, B. – KRASSOVÁN, K. 2011), in 25–35 years, as a surplus of the demand, 13–14 PJ sustainable electricity could be converted into 55 PJ heat in *Hungary*.

7.6. Sustainable energy potential in general

Table 5 summarises the sustainable energy potentials in *Hungary*. According to the calculations carried out by the authors of this paper, 828.8 PJ sustainable renewable energy potential could be made available in the country. This is a very promising number compared to the current primary energy use (963.4 PJ [KSH, 2016a]) is a very promising number, because the difference can be easily saved by energy efficiency and sufficiency measures.

Table 5 – Summary of sustainable energy potentials, concerning conversion losses in the production phase

Calculations by MUNKÁCSY, B. et al. (2016)

	Heat (PJ)	Power (PJ)	Transport (PJ)
Solar	122.5	72.5	0.0
Wind	0.0	340.0	0.0
Solid biomass	79.0	34.0	0.0
Liquid biofuel	0.0	0.0	12.0
Biogas	5.9	5.9	0.0
Hydro	0.0	2.0	0.0
Ambient heat	155.0	0.0	0.0
Total	**362.4**	**454.4**	**12.0**

8. Conclusions

In the last 10–15 years, there has been a lot of debate over the quantity of renewable energy sources in *Hungary*. The reason for this is that only a few good quality partial results were published, but the overall final outcomes have been missing so far. In this research's calculations, using strict sustainability and technological limitations, the country's overall sustainable technical potential resulted in 828.8 PJ, concerning conversion losses in the production phase. This number highlights that even under strict constraints renewable energy resources are significant in *Hungary*, since this number is very close to the recent primary energy supply (963.4 PJ in 2014), which was topped in 2005 (1,166 PJ) (KSH, 2016a).

In order to evaluate these figures correctly, it is important to consider the huge energy efficiency potential in particular and the immense resource efficiency potential in general, as it was introduced by some researchers in the 1990s (VON WEIZSÄCKER, E. U. *et al.* 1998). A less explored but at least as important area is the potential of sufficiency. Alternative energy strategies contain 40–60% decrease in energy consumption by 2030 (IDA, 2006; CAT, 2013). This means that using economic regulation as well as education, it would be possible to decrease the energy consumption significantly, in this country, and throughout *Europe*. Thus, a 100% energy autonomy could be covered by endemic renewables in *Hungary*, however, this seems to be a temporary solution only. The reason for is that there are other developments challenging renewable energy autonomy, for example the emerging industry of biorefinery which creates an additional market for biomass feedstock other than combustion.

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Energy Resources and Energetic Challenges for the United Kingdom in the Shadow of Brexit

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Abstract

The aim of this article originally was to discuss energy-related challenges in the United Kingdom, reflecting especially on a post-Brexit era. The topic, however, quickly evolved into a thorough energetic overview of the British Isles and it involves the entire analysation of the locally available energy resources including both non-renewables and renewables. Whilst the paper is focusing on the availability, utilisation and energetic importance of all of these local resources written in a school textbook style, it also ventures into understanding the reasons behind their decline or growing usage and how and why these have changed over the last few decades researched academically. It also attempts to compare energetic situations, such as electricity generation, to other European countries and focuses on the importance of global co-operation, and international efforts to tackle, for example, environmental issues including climate change.

Key words

Energy resources; energetic challenges; international co-operation; United Kingdom; Brexit

People hate scientists. There is no use in beating about the bush here. The scientist is in danger of becoming the scapegoat for the helplessness which the public feels. And if an immense revulsion of public feeling does lead to the destruction of the scientific tradition, then the world may again enter a dark age as it did after the Goths destroyed Rome. It is not impossible that the whole mechanical and intellectual society which we know could be abolished by a great wave of fanaticism.

BRONOWSKI, J. (1956)

1. Introduction

On the 23rd June 2016, the people of *Great Britain and Northern Ireland* were invited to a referendum on their country's membership of the *European Union*. The rhetoric and credibility of the campaign on both ends still remains questionable; the results next morning, however, showed 52% to 48% in favour to leave the *Earth*'s most successful political, commercial and cultural integration (THE GUARDIAN, 2016a). Despite the non-representative 4% difference, so far it seems that the *United Kingdom*'s departure has now become a reality which can build up questions on a high number of challenging issues. Energy economics and environmental concerns are just two of the most important among these.

During this referendum campaign left and right could follow a large number of social media pages and groups, daily papers, and political debates broadcasted on the television or radio, mostly run by experts or actual scientists; and one could also see hundreds of contributors from the public, including fictional experts, dedicated pro or anti-EU journalists, and fake-news generators, some of them claiming the *United Kingdom* to be fully independent producers on frankly everything including, among many other challenging areas, food production, fishing, mining, manufacturing, and approaching this by adapting models similar to *Norway*'s, *Iceland*'s or *Switzerland*'s. In this process, from a geographic point of view, the absence of logic and rationality of information adaptation, analysation, synthesis and evaluation can be identified which scientific seriousness is one of the major factors that inspired the author to prepare this paper in his own research field and to discuss facts regarding energy economics focusing on the natural givens of the *British Isles*.

The research activity of the author has now been stretching for a decade and mainly focuses on the geography of energy resources and their connection to locality, sustainability and environmental awareness; in the shadow of *Brexit*, and several other European nationalism-filled irrationalities (for example the proposed ban on wind energy projects in *Hungary* (277/2016. [IX. 15.] decree of the government—WOLTERS KLUWER [2016]), these terms need to be put into the focus more than ever before.

2. Aims of study

In this article, a thorough analysis on the *United Kingdom*'s energy resources and their availability, utilisation and economics will be presented, and those geographical facts are also highlighted that should be taken into account when discussing these resources' locality & globality, sustainability and integration among countries. International comparisons will also be made to see how some of the other *European* countries (especially *Norway*, *Iceland* and *Switzerland*) are performing in the same area. Two of the author's own models will also be employed (*Need* and *Co-operation*) to help explain certain facts regarding (for example) local and global integration, and international co-operation. The bases of this research set on traditional regional geography which examines the social and economic spheres on the principles of physical geography; therefore, there will cliché explanatory parts be also presented to develop general understanding.

3. Research methods

GAILLE, S. (2016) has published an article on *LinkedIn* on the impacts of the energy industry that could follow *Brexit*. The article published on a social media platform is only mildly thought-provoking, but it can still encourage researchers to deepen their own thinking and analyse the problems related to energy sustainability right from their roots. This current paper is mostly a simple but thorough analytical review of previously researched primer and secondary sources, but the different energy-related contents are now analysed separately and then synthesised and evaluated in the aim of forming a complex piece of writing from geographic point of view, and by employing two models. According to this, the reader will find:

1. General definitions in both energetics and sustainability which were mostly sourced from specialist books or phrased by the author.
2. Historical overviews of the energy resources and their local uses which were also traced in books, but journal papers and online databases were also searched to collect data.
3. Statistics on how important these resources are or how their utilisation changed over certain periods which were tracked in national statistics websites and other company databases. The data collected are presented in charts and diagrams that were made in Microsoft Excel.
4. Models to help understand the connection among certain factors, for example crude oil–petrol–transportation. These and other images were designed by using CorelDRAW X6 and SmartDraw.

4. Energy resources

A few years ago, a paper by the author of this paper was published in this *GLS* series on what energy is and what energy resources mean (BOKOR, L. 2013). According to the information presented in that article, it is worth sweeping the dust off some definitions and present them again in a compressed, but updated form here in this work too.

Everything that exists in our *Universe* is composed of either *matter* or *energy*. The interaction of these two parts is essential, because energy is what makes matter change through time (physically and/or chemically), which causes the shaping processes of our planet (STRAHLER, A. H. – STRAHLER, A. N. 2002). Energy is nothing more than stored 'work or force', which is re-released under certain conditions (GULYÁS, J. *et al.* 1995). This appears in different forms, such as thermal, electric, nuclear, and mechanical (BREUER, H. 2002). The forms of energy may be divided into three main groups: kinetic energy, potential energy, and chemical energy (STRAHLER, A. H. – STRAHLER, A. N. 2002). The forms of energy can be traced back to one of the four fundamental interactions of physics (fundamental forces/interactive forces): gravitation, electromagnetism, strong nuclear, and weak nuclear (HOLICS, L. 2009).

The energy itself is invisible, rather than a factual, objectified material. This is typically transmitted by the energy source. However, this is already a more evident material that is always a source of energy stored in a characteristic *energy bearer*. This latter principle can be anything, as everything is abundant in stored energy (so-called subatomic energy) that can be handled or seen (EDDINGTON, A. 1935). From the point of view of, and in the earthly dimensions of our geographical approach, the *Earth*, in this sense, is one of the largest energy bearers. It bears different types of *energy sources* that can be objectified in materials (for example hard coal), or in the direct or indirect results of physical processes and phenomenon that cannot be detected with a naked eye (for example wind). Its nature and manifestation vary by geographic dimensions, that is to say, most of the energy bearers can conclude in the existence of more energy bearers *(Figure 1)*.

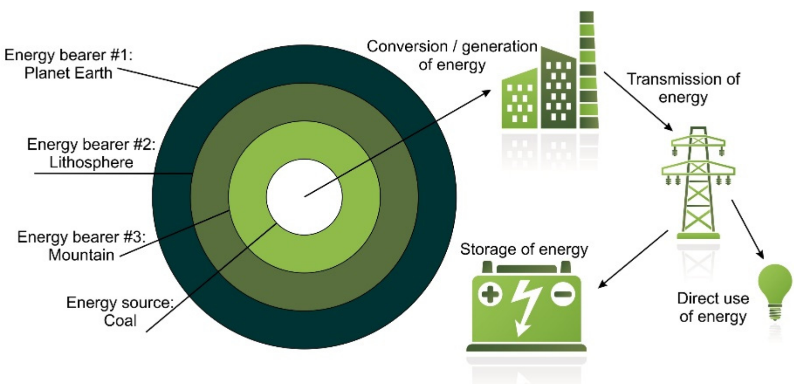

Figure 1 – A Simplified Example of the Spherical Structure of the Energy Resources
Edited by BOKOR, L. (2016)

This *spherical structure* may include the whole lithosphere or a single mountain range that bears various energy sources. There can—for the modern society's needs and use—be thermal energy or electric energy transformed from. The principal difference between the *energy bearer* and the *energy source* is that the source can be exploited for its electric power and thermal unit, but the energy bearer does not function as a source. The *energy carrier* is, according to ISO 13600, either a substance (energy form) or a phenomenon (energy system) that can be used to produce mechanical work or heat, or to operate physical or chemical processes (ISO, 2007). The energy carrier is a product and can directly be used in demand of energy, for example batteries, petrol.

It may be difficult to distinguish among the bearer, the source, and the carrier; therefore, to make their terms clearly understandable, the approach taken has to be simplified: in this sense, the bearer is, for example, a mountain, where the source (for example black coal) can be found; and the carrier is, for example, the electricity itself that is transformed (produced or generated) from the source and is either directly used (for lighting homes) or stored for further use in a particular device (for example a battery).

Energy resources can be anywhere on the planet, but the type, quality, and availability of the source specific to one locality of the planet is limited to the area and its natural givens, and which clearly defines what people can do in that region where they live. This is known as potential. On a larger scale, instead of people, one can also refer to cities, regions or countries and see with what they are naturally provided, as this is the core thing to understand how their economies are based on those resources and also, how they can be linked to other activities. This will also make us understand how some of the economies that are lacking in certain resources need a wider international integration (co-operation) to be successful. First of all, let us discuss primary energy sources, and some information of their production and consumption in regards to the *United Kingdom*.

The primary energy resources (or primary energy or PE) are the major types of sources from where energy derives. They can either belong to non-renewables (non-constants) or renewables (constants). The purpose of the energy resources is to provide an input to a system which in a more understandable way means, for example, filling up our car with fuel (*1/* transportation) placing wood in a log burner to generate heat and warm interior spaces (*2/* heating), or burn black coal in a conventional power station to generate electricity (*3/* electricity generation). It is now easy to see that without trees one cannot place wood in the log burner or without coal one cannot generate electricity in a power station. And, after all, one can also see that if one were unable to generate electricity, it would not be able to run an extensive industry which would have a significant effect on the economy. But, once again, there are other solutions in an area other than just wood and coal. These resources, their availabilities and conditions in the *United Kingdom* are presented in this paper.

5. Production and consumption of primary fuels in the United Kingdom

Primary fuels mean fuels without energy conversion and transformation processes (for example into heat, electricity or mechanical work). When one talks about primary energy, it normally refers to domestic (indigenous) production, so what a country can produce by itself. The *Total Primary Energy Supply* (or TPES) includes the balance on imported and exported energy resources (and some other data related to trade and waste of energy too). The TPES is important as it highlights the balanced amount of imported fuels in a country's energy mix which also links to the country's dependency on non-domestic resources (DONEV, J. n.a.).

According to the *UK Energy in Brief 2015* (NATIONAL STATISTICS, 2015), the domestic production of primary fuels changed significantly between 1980 and 2014 *(Figure 2)*. The information that is presented in this chart clearly shows that the *United Kingdom*'s primary energy production is still dominantly composed of fossil energy resources (especially crude oil and natural gas, the coal's importance is becoming more and more insignificant) whilst the share of the renewable energy resources carries on being relatively small[2], but their importance is certainly growing and in electricity generation, in some cases, have already outcropped the coal (VAUGHAN, A. 2016). In the total production, the primary fuels have been in decline since the early 2000s whilst the renewables are increasing (NATIONAL STATISTICS, 2015).

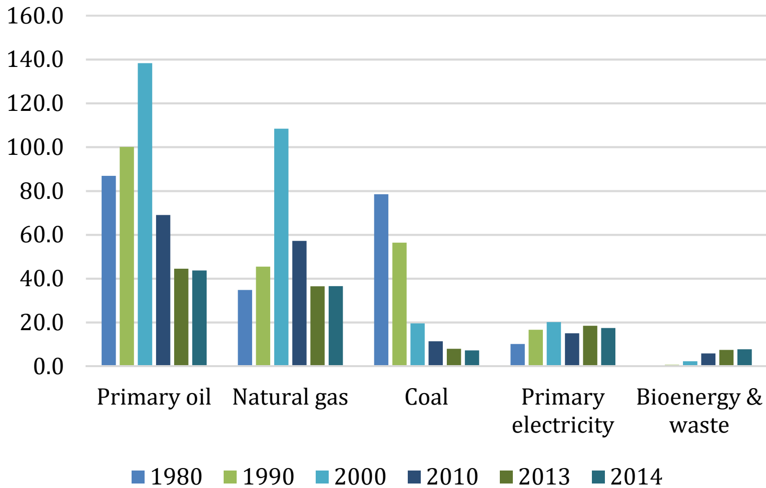

Figure 2 – Domestic production of primary fuels in the United Kingdom between 1980 and 2014 in Million tonnes of oil equivalent
Source: NATIONAL STATISTICS (2015)

Figure 3 shows the correlation between the primary energy production and consumption. It can clearly be seen that in the period between 1980 and 1990, the *Britain*'s production was synchronised with the consumption which means that it was used as much as the country actually needed and all the domestic production equalised the domestic consumption whilst there was sufficient amount for export too. Between 1990 and 2005, the country was still able to compete with the

[2] In *Fugure 2*, renewables are merged into the last two categories of which primary electricity (more about it in *Chapter 6*) is consisting of wind, solar and natural flow hydro, plus includes nuclear too.

cheaper imported resources which resulted in higher production than the country was required. The peak value, that is shown in the chart around 2000, marks a period when the production was the highest and increased rapidly mainly due to the growth of oil and gas (NATIONAL STATISTICS, 2015). Since the early years of the 21st century, the domestic production has declined dramatically which mainly affected the fossil resources (coal and hydrocarbons) and in the last 5–6 years, it has been importing more than producing domestically (locally). To understand the decline in the overall production–consumption relationship, a closer look at the different types of energy resources and an insight in their decline will be required.

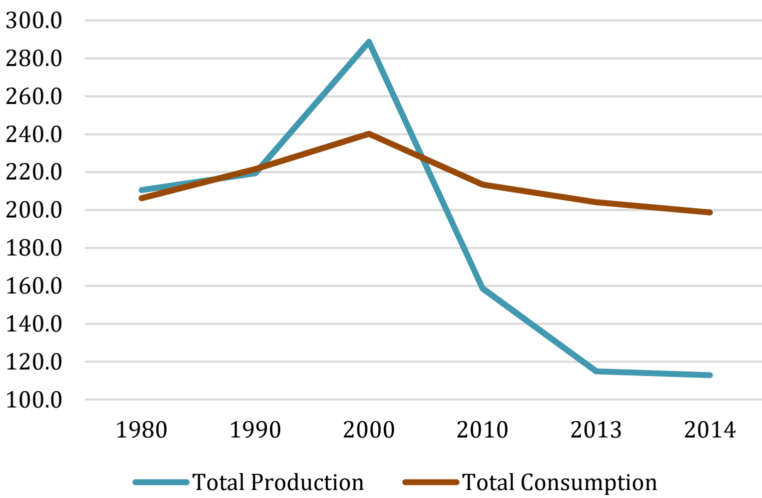

Figure 3 – Primary energy production and consumption in the United Kingdom between 1980 and 2014 in Million tonnes of oil equivalent
Source: NATIONAL STATISTICS (2015)

The task now is to see with what energy resources the *United Kingdom* is provided by nature (this is the primary energy source) which can be converted to be a secondary energy source, which is also known as an energy carrier. One will also see how their roles and importance changed throughout history and will receive explanation on their present decline or success. The research will concentrate on the major primary energy resources beginning the journey with the non-renewables (coal, crude oil & natural gas, and nuclear), renewables (solar, wind, hydro, tidal, and wave, biomass, and geothermal). These categories may consist smaller sub-sources too.

The TPES which defined by IEA (n.a.) is majorly made up of domestic production + imports – exports; therefore, when it comes to the total primary energy supply of one certain area, the indigenous production that is based on the resources found in the area and the export/import balance, has to be addressed; it will also be pointed out how the import/export effect the economy, but will not discuss at an overall level. After the primer sources have been discussed, an overview of the electricity production will be carried out, because that is deliberately the most important product of energy resources which has a major impact on the whole economy and in generally on the everyday lives of people.

5.1. Non-renewables

5.1.1. Coal

One of the most traditionally and widely used energy resources that has been respected and had a high significance throughout the history of mankind, for over thousands of years. One of the major type of energy sources that has also had a definite impact on the development of societies and economies (FREESE, B. 2006).

The coal is a type of a sedimentary rock with combustible properties. Its quality and heat content (normally presented in kJ/kg) are defined by the conditions that have formed them and according to this, there are several types of coals from lignite (brown coal) to anthracite (the hardest and most metamorphic coal beside graphite) (WOODCOCK, N. 1994). The coal has organic origin (mostly died vegetation) and takes thousands to millions of years to form. During its formation it conserves the energy and other physical materials; when it burns, it releases a high amount of chemicals and substances which makes this energy resource one of the most CO_2 intense and least environmentally friendly (ADB, 2009).

Nearly all of the coal reserves of the *British Isles* occur in carboniferous rock (formed about 358.9 to 298.9 million years ago) deposits, with 86–88% average carbon content which makes this type a high quality natural fuel (McLean, A. C. – Gribble, C. D. 1985). According to the statistics of UK Coal (2011), the country is abundant in coal, the reserves are estimated to 3,196 million tonnes of which 2,344 is accessible underground and 856 on surface. No surprise then why the *UK* has had the potential to build an extensive industry and economy based on coal. However, this type of energy resource is primarily used to produce electricity (nationwide) and heat (domestic) which, due mainly to environmental reasons, has been in decline for decades since renewable energy sources enjoy more widespread use due to their more environmentally friendly properties (Bian, Z. *et al.* 2010).

Until the 1950–60s, coal was the main energy source in the *British Isles* which fits into an international trend at that time. Ever since its downfall began, it has resulted in closures of coal mines and the domestic production decreased rapidly. Currently, there are a small number (26) of surface coal mines operating across the country and extracting coal for energetic purposes—the last deep mine, *Kellingley*, was closed down in 2015 (BBC News, 2015). The closure of coal mines, therefore, are direct effects of the decreasing economically accessible fossil and the increasing use of renewable resources, and also a change of lifestyle and standards of people in the early 21st century.

Locally thinking, the huge coal reserves are important for *Britain*, but the mines are inevitable due to current international market forces. The most easily accessible deposits are used up; therefore, mining and machinery has become expensive and less environmentally friendly (Waugh, D. 2000). Coal mining and consumption have significant effects on directly the local and indirectly the global environment (Bian, Z. *et al.* 2010); therefore, if other, environmentally more friendly and economically exploitable local sources are available, they need to be put in favour to coal. This so called 'green type' of using alternative energy resources has caused the significant drop of coal usage which in 2016 many times resulted in 12-hour long electricity production without the input of the coal-fired power stations (THE GUARDIAN, 2016b). Moreover, building an energy reliance on coal is not sustainable in a long run, because, on the one hand, it is being a fossil fuel means that reserves can and will run out in a certain period of time; and, on the other hand, it is not worth running an economic sector that is based on coal whilst the other part of the world is changing their economic structures and becoming coal-free, which means coal keeps losing its value and importance in the economies and the energy systems.

The currently extracted coal in the *United Kingdom* is principally addressing domestic electricity production in conventional power stations. The more widely harness of renewable energy resources since the early 1990s, however, decreased the need of coal in electricity production *(Figure 4)* and, according to recent trends, it stagnates at around 30% in the total electricity production (refer to *Chapter 6*).

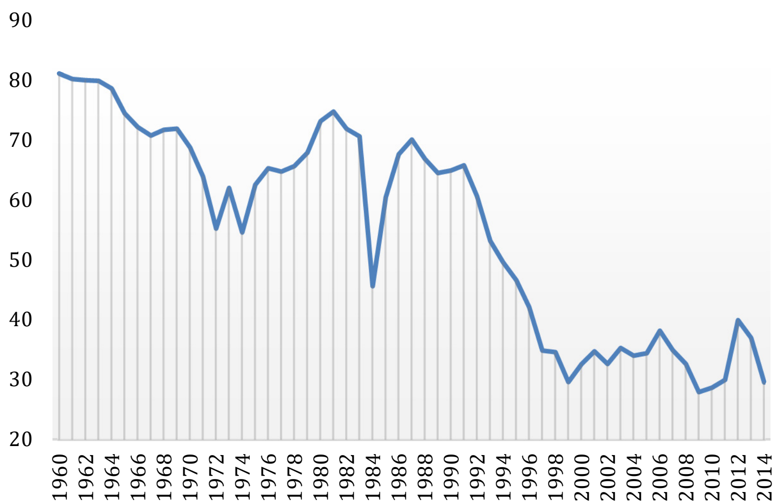

Figure 4 – The coal's decreasing share in the electricity mix in the United Kingdom between 1960 and 2014

Source: THE WORLD BANK (2014)

Coal will, however, remain a quasi-important energy resource of the future generation both at nation level in electricity generation and in domestic use to generate heat for homes. Once the power station technology becomes more advanced and environmentally friendly (carbon capture and storage, or one of the newest discovery on how CO_2 can be turned into ethanol [YAHOO, 2016]), the coal might have the chance to be once again a significant type of energy resource, but this chance, in line with the more and more efficient and environmentally friendly emerging technologies and other alternatives, is very small.

5.1.2. Hydrocarbons

Hydrocarbons refer to a group of compounds of organic origin that mainly consist of hydrogen and carbon. They are naturally occurring and majorly found in crude oil. When geography of energy talks about hydrocarbons, it normally refers to a group including crude oil and natural gas. These two are currently the world's most primer energy resources. They have had a dominant role since the second half of the 20th century and their importance is still highly significant in the second decade of the 21st century. Crude oil and natural gas have shaped our society and lifestyle; without them the world would look majorly different as it is now (in both a positive and a negative sense).

Crude oil is the leading resource of our society. The most common (and well known) products of it are fuels, for example petrol, diesel, kerosene, which have a central role in transportation as a 'food for our cars'. However, other petroleum products are widely present in the economy as industrial activities use crude oil and other hydrocarbons to produce a wide range of items that have key roles in our society, for example plastics, lubricants, packages, medicines and plenty more 'ingredients' that are used to produce other items. Our modern society relies on crude oil and will carry on being an important energy resource in the future. This importance will, however, have to decline as burning off fuels (for example carbon dioxide [CO_2] and sulphur dioxide [SO_2] emissions) and environmental contamination related to the petrochemical products (for example plastics) have a significant environmental impact which has to be more seriously addressed. Also, the extraction of crude oil (mining) is one of the 'dirtiest' in regards to all the other energy resources that have been involved in a high number of ecological disasters since the beginning of the 20th century that had local or, due to the *Earth*'s physical cycles (for example hydrological), even global environmental effects (the most notable oils spills incidents are, among many others, the *Exxon Valdez* in 1989, and the *Deepwater Horizon* in 2010—USCG, 2011).

Natural gas plays a key role as a domestic energy resource in cooking and heating homes; and it is also one of the major energy sources of electricity generation in thermal power stations. In Britain, this latter one currently represents 29.1% in the total share (more information at *Chapter 6*). Natural gas and crude oil have the same origin, but their chemical compositions are different. Whilst the burning of crude oil (and coal) is one of the most carbon dioxide, sulphur dioxide and greenhouse gas producer, the natural gas has more environmentally friendly properties (EIA, 2016) which is why gas-fuelled vehicles (public buses) are considered to be 'greener' than the ones fuelled by petrol or diesel.

Crude oil and natural gas are both formed over millions of years buried deep; therefore, they have to be extracted from underground reservoirs. In the case of their availability, an extensive amount of hydrocarbons is found in the sedimentary rock basement of the *North Sea* (for example in *Dogger Bank*). These reservoirs became economically exploitable in the 1970s, after the Middle east oil crises. Let us, however, bear in mind that hydrocarbons are finite resources which means, according to the amount of extraction, sooner or later the reservoirs will run dry. This means, setting an entire economy's reliance on indefinite resources cannot be sustainable on a long run, but *Britain*'s dependence is and will be highly significant on it (CRITCHLOW, A. 2015). This realisation comes along with the modern environmental awareness that puts the renewable energy resources in favour and also that imported oil and oil products are becoming cheaper. One of the key characteristics of the *North Sea* crude oil is, compared to the middle east oil, being 'sweeter[3]', better quality (PETROLEUM, 2015), but its extraction is more expensive due to the technology that it requires to bring the 'black gold' up to the surface. Since the last production peak in 1999, the crude oil and gas production in the *UK* have been in decline (THE ECONOMIST, 2015)—*Figure 5*.

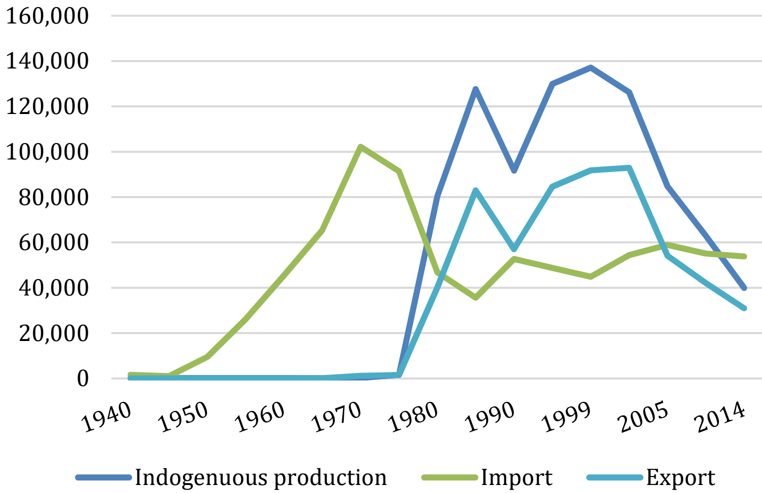

Figure 5 – Crude oil production in the United Kingdom (excludes oil products) between 1940 and 2014 (in thousand tonnes)
Source: DEPARTMENT OF ENERGY & CLIMATE CHANGE (2016a)

5.1.3. Nuclear energy

Atomic power, through the process of nuclear fission to generate electricity, is without doubt the most and the least supported type of electricity generation method at present times. On the one hand, it provides a low carbon power production in which case makes this option one of the greenest amongst all; but, on the other hand, it poses many threats and, in case of an accident, the contamination of the environ-

[3] Sweet crude oil means its sulphur content is below 0.5%. Sour crude oil has sulphur content greater than 0.5%.

ment and living systems may be highly significant. A nuclear power station accident is a potential hazard, if we understand that the planet is one integrated organic entity which is connected via several geographical spheres: for example, the atmosphere or the hydrosphere are global systems which means that an accident in *Japan* can affect the world oceans just as well the global air systems (as it happened in *Fukushima* in 2011).

It is not the aim of this research to decide whether nuclear energy is a good or a bad choice of energy generation method, but it has to be seen that a nuclear power station has affects not only during its operating time, about 30 years, but over millions of years even after the power plant has ceased. The aim now is to highlight facts according to its utilisation in the *UK*. In the *European Union*, according to *Figure 6*, 14 out of 28 countries generate electricity with nuclear power stations which makes the *EU* moderately dependent on it, approximately one-quarter of its electricity to be precise (WNA, 2016d).

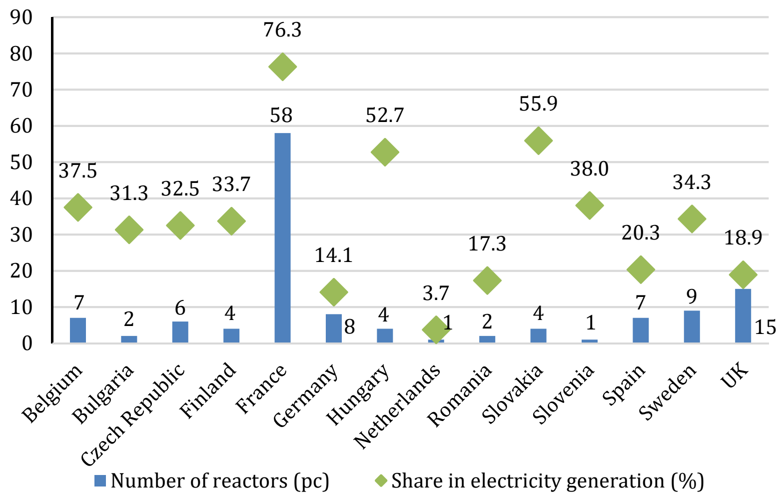

Figure 6 – Number of nuclear reactors in the European Union and their shares in the electricity generation (2016)

Source: WNA (2016d)

Within the *EU*, after *France* (58 reactors and 76.3% share), the *UK* has the largest number of operating reactors (15) which in 2015 provided about 21% (WNA, 2016a) of the country's total generated electricity. Smaller countries by size and population, such as *Hungary* and *Slovakia* with 4 reactors each produce a sizeable amount of electricity with nuclear power stations (WNA, 2016b; 2016c) *(Figure 6)*.

According to some sources, the *United Kingdom*'s nuclear power stations are planned to be gradually shut down in the next few decades (ENERGY-UK, n.a.; ALDRED, J. – STARKEY, N. 2013), however, in regards to some other sources, there is no sign the *UK* would abandon this method of electricity generation as there are new power plants planned (4) and proposed (7) to be in line by 2025 and 2045 – the most recent is the controversial *Hinkley Point* (MASON, R. 2016). At present, a full closure of the country's nuclear power stations would raise questions how or from what sources the 'missing' amount of electricity would be generated (which is currently $^1/_5$ of the total electricity mix).

One of the major difficulties with nuclear energy is the fact that it is not a resource. Nuclear energy is a result of methods when, through nuclear reactions, energy is released from a certain type of energy source. In the case of nuclear power stations, the resource is normally uranium, sometimes plutonium—highly radioactive elements (BGS, 2010). The other difficulty is, therefore, how to supply the power stations with uranium, which is the major energy resource to generate the electricity from? Also, what happens with the exhausted, but highly radioactive parts? Earlier *Hungary* and *Slovakia* were mentioned where both countries have a significant dependency on imported uranium, mainly from *Russia* (WNA, 2016b; 2016c). This fact makes both of these countries strongly dependent on imported fuel and also makes their electricity generation majorly reliant on one source in the mix which does not provide these countries with sufficient energy security (KRAEV, K. 2016).

Focusing on the *United Kingdom*, although there are some minor occurrences mainly in different locations across *Scotland*, in the *Pennine* area, and in *Cornwall*, uranium is not currently mined (BGS, 2010;

WNA, 2016a). The uranium is imported from a range of countries, but the country's other nuclear facilities (conversion, enrichment, fuel fabrication, reprocessing and waste treatment) are self-sufficient (WNA, 2016a). The energy mix in the *UK* still shows a diverse range of resources that are used in electricity generation. In this regards, about 20% share in electricity generation may easily be replaced by other alternatives (mostly renewables), but viewing this from the aspects of politics, it is certainly a challenging energy endeavour.

5.2. Renewables

Nowadays, it is very common to discuss the role of renewable energy resources when environmental awareness and energy security come into focus. These terms are certainly inseparable. As seen in the previous chapters, the conventional energy resources, in a way or another, are in a decline in the *European Union* and so as in the *United Kingdom*, but a global trend in favour to the 'green' energy resources can also be observed. Global climate change, global warming, CO_2 issues, SMOG, air pollution, and other similar issues, are examples that are mostly related to mining and burning of non-renewable energy resources. Coal, crude oil and natural gas are commonly known as fossil fuels. They, however, are of organic origin, but their solid matter takes millions of years to form; the release of their stored energy through emission mean a direct impact on the environment which can reach global scales. Also, since they are finite resources, the modern economy cannot have the time and 'patience' to wait millions of years for them to renew; therefore, in contrast to them, renewable energy resources can be powerful alternatives. In fact, one of the major triggering factors of the wider use of renewables and the more and more spreading green philosophy is the unavoidable decline of conventional energy resources.

Most of the *Earth*'s physical forces provide access to the energy that they 'store': solar (sunshine), atmospheric (wind) and hydrospheric (water) phenomenon (hydro power in general, wave & tidal energy), bioenergy and geothermal have significant energy potential. In the following, only these major resources are discussed.

Regarding *(a) solar energy*, the potential in the *British Isles* compared to the Mediterranean is significantly less. However, solar radiation is available even in the polar regions, therefore as being a local source, it is worth investing in the harness of this type of energy resource. Other countries in the *European Union*, such as *Germany*, *Denmark*, *Sweden* and *Austria*, have developed the solar technology (including photovoltaic and active solar heating) to high standards which guarantees efficiency and stability at high degrees—and generation even in cloudy weather. The solar energy's international success has certainly encouraged its utilisation in the *UK* too, as from 4,040 GWh in 2014, the electricity generation of solar photovoltaics increased to 7,561 GWh in 2015 which is an 87% change (GOV, 2016). Solar energy is an alternative to fossil resources and its greatest importance could be achieved locally as a domestic generator of electricity and heat which could potentially contribute in lessening the household energy expenses which could even lead to domestic energy independence. Their installation on the rooftops of houses could also help save the impact on other greenfield areas as one of the biggest issues with solar power stations is the large land area they require. The extra electricity generated could be feed into the national grid which would also bring extra money into both the local government's budget and the household.

The utilisation of *(b) wind energy* is one of the most successful throughout *Europe* (apart from some areas such as *Hungary*—GREENFO [2016]). There are countries already in the *EU* where wind represents the highest share in the electricity production (for example in *Denmark* where the composition of electricity generation from wind is 74.5% including the production of on and off shore farms which represents 42.1% in the total electricity generation—ENERGINET [2016]). One of the most important factors in efficiently harnessing the energy of wind is the access to the constant wind resources. Geographically talking, the more western a country in *Europe* is situated, the more and better quality wind potential it has. This means, the closer it lies to the *Atlantic Ocean*, the easier it can access the western winds that dominates in *Europe*, especially its western part of it. The *British Isles* are at the gates of this corridor which means the *UK* has one of the greatest potential of wind energy to harness everywhere on *Earth* and considered to be the best in *Europe*. However, whilst in *Denmark*, wind represents almost half of the electricity production, in the *UK*'s mix it is approximately 15%. Its appreciation has, however, become rapidly increasing in the recent years and it is now one of the most successfully developing sector. By the end of 2015, 14,291 MW worth of installed capacity of wind turbines had been harnessing wind across the *UK* on and offshore generating 17,423 GWh electricity (GOV, 2016)—*Figure 7*.

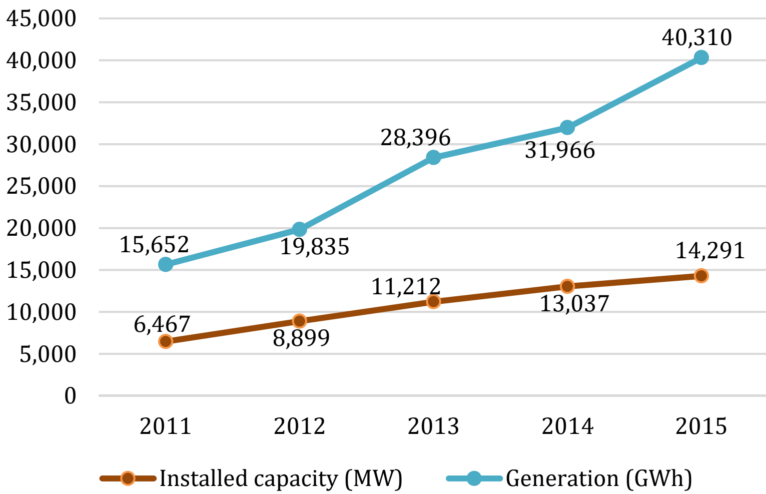

Figure 7 – The development of wind energy in the UK

Source: GOV (2016)

One of the main issues with wind energy as a variable resource (the same as with solar power) means the electricity generation is timely dependent and also largely defined by its properties in a given time (for example speed). Wind energy is, therefore, only an alternative to fossil resources but an efficient addition to the mix of diverse range of energy resources.

As it is going to be presented in the next chapter, *(c) hydro power* is the renewable energy resource that has been utilised in electricity production for the longest time in history and has major importance in many of the European countries and in their economies. It does not have much impact on the *UK*'s electricity production as its total share in the mix was 3.2% in the end of 2015 which also includes the shoreline tidal and wave systems (GOV, 2016). The total installed capacity has not changed much in the past decades and it is consistently holds around 1,759 MW that produced 6,289 GWh electricity in 2015. Compared to solar and wind, hydroelectric power stations are able to provide electricity in a continuous manner, but they require certain geomorphologic conditions to operate efficiently. According to BHA (2016), the *UK*'s hydro potential would allow to double the current capacity, but installation of new plants at new sites onshore raises potential environmental concerns (BOKOR, L. 2012). In this regards, the role of new and emerging technologies that concentrate on harnessing the energy of seas has increased rapidly in the recent years. Electricity generation by wave and tidal streams are more predictable than wind or solar, and according to the *UK* government's sources, they could represent up to 20% of the *UK*'s current electricity demand (GOV, 2013).

Overall, geographically the *UK*'s renewable energy resources (solar, wind and hydro) are excellent alternatives to fossil resources, because the *British Isles* geographical situation makes this possible. Even though the solar energy potential is much less than in southern *Europe*, the *UK* lies in the gateway of the *Earth*'s most powerful wind resources and hydropower from the seas, which have immense local importance due to an island situation.

According to *Figure 8*, the overall energy generation from renewable sources in the *UK* is currently based on the increasing utilisation of all locally available solar, wind, and in a small scale, hydro (including wave and tidal) resources. Based on the GOV (2016) statistics, the total generated electricity in 2015 was 83.6 TWh which is an increase of 29% compared to 64.6 TWh in 2014. The overall share in the country's electricity generation has increased from 19.1% (2014) to 24.7% (2015). Since the *UK* government introduced the *Renewable Obligation scheme* (RO) in 2002 *(England & Wales)* and 2005 *(Northern Ireland)*, and also the support system through *Feed in Tariff* (FiT), the electricity generation from renewable sources have *increased rapidly (GOV, 2016).* The pie charts, however, shows that, despite the *British Isles* excellent potential of all three major renewable resources, the *UK* still relies and increases the share of bioenergy (70.7%).

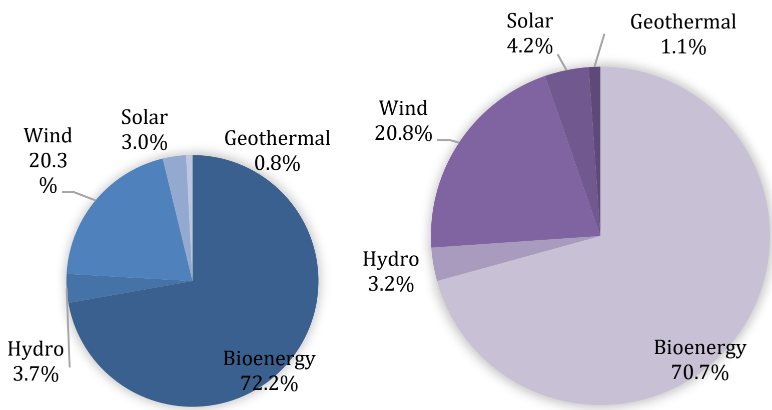

Figure 8 – The mixture of renewable energy sources within the electricity production in the UK in 2014 (left) and 2015 (right)

Source: Department of Energy and Climate Change, 2016b; GOV (2016)

Bioenergy (biomass) (d) has the highest share in renewable energy fuel use *(Figure 8)*, but that 72.2% (2014) and 70.7 (2015) share do not correspond with one resource only. In fact, when it comes to bio-energy, it is common to refer to plant biomass (24.2%/25.3%), landfill gas (12.3%/9.7%), domestic wood (11.5%/11.4%), transport biofuels (9.2%/6.00%), waste combustion (4.2%/6.2%), industrial wood (3.4%/4.7%), anaerobic digestion (2.8%/3.4%), sewage gas

(2.5%/2.2%), animal biomass (1.9%/1.6%) and co-firing (0.2%/0.2%). Bioenergy, therefore, refers to a diverse range of, mostly, organic matters. The more variety it comes from, the more diverse options there are to utilise them as bioenergy can be used to produce heat (burn wood), fuel (rapeseed oil for bio-diesel), and generate electricity (burning gas).

According to the *British Geological Society* (BGS, n.a), despite the *UK* is not volcanically active (like *Iceland* or *Japan*), there is still a substantial *geothermal (e)* resource. *Shallow geothermal source* means access to the top 10–15 m of the ground by heat pumps (aerothermal heating), but this is technically still solar energy as sunshine heats up the top layers of the ground which means constant temperature throughout most of the year. *Deep geothermal energy* (geothermal gradient in the *UK* is 26°C/1 km) has been tried at numerous sites (for example *Eden Project* in *Cornwall*), but their importance has not been addressed successfully yet, even though, according to the *Renewable Energy Association*, the *UK* has a high potential of geothermal energy which could provide approximately 20% of the electricity. At the moment, the importance of geothermal is only 1.1% in the total primary energy mix (GOV, 2016).

6. Electricity: a wider view

So far, the primary energy resources of the *United Kingdom*, their origin, and the impact they have on the local (domestic) economy have been discussed. It has also been shown that the energy resources are important for the industry and to run the country's economy. There are many energy resources that are primarily used in certain sectors, for example, crude oil is majorly used to produce petrol and other petrochemical products. But the majority of energy resources are used to generate only electricity which, as an energy carrier, is then used to produce other things. For example, currently the entire economy and life fundamentally rely on electricity: in factories everything is based on precise machinery, car manufactory, IT industry would not even exist without it: internet, services, online banks, stock exchange, Face-book, Twitter, etc.; everything is electronic and digital. Public services, for example, hospitals need a lot of electricity and energy safety. And the diversity of its use make us more dependent on it day after day (televisions, smart phones, electric cigarettes, electric cars, and the world is becoming more 'electrified') (LEKSHMI, S. 2010). Electricity has extended the economy and its sectors and nowadays relies on one another: from primary production (crude oil extraction) → secondary production (manufacture, assembly) → tertiary production (transport, advertising, warehousing, selling). And besides these there are the intellectual (quaternary) and educational levels (quinary) which has gained more and more significance in the past few decades (BIS, 2012). Without electricity, the lives known cannot be imagined anymore. This can also be seen in how the *UK*'s economic sectors have redistributed in a half century *(Figure 9)*.

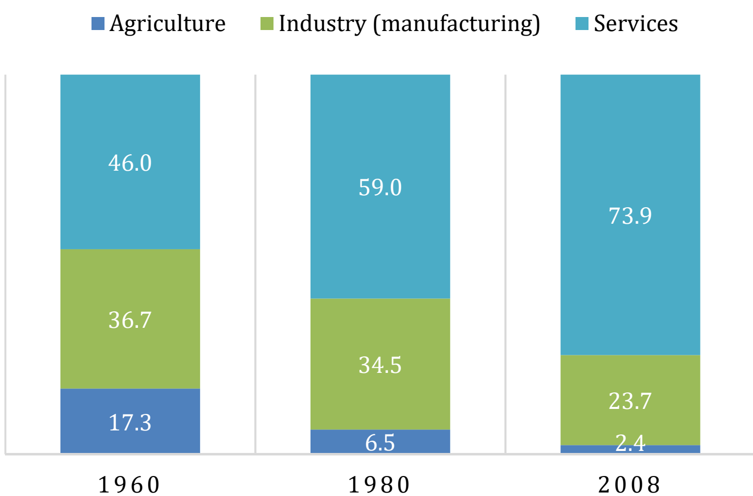

Figure 9 – The United Kingdom's industrial market economies, distribution of labour force (percentage)

Source: GRIFFITHS, A. – WALL, S. (2011)

This is a global trend which also means that the integration among the planet's continents have got a strong bond which is increasingly recognised in the countries that are situated in a certain region. These are mostly economic integrations as multilateral free trade areas, such as the EFTA in *Europe* or the NAFTA in *North America*, but there are already more developed integrations that go much beyond economy, such as the MERCOSUR in *South America*, or the *European Union* which is one of these regional integrations and the most successful of them on the planet. In this system electricity also has a key role as production and consumption are strongly connected among the European countries and the future's idea is the establishment of a common *European super grid* (JEFFERIES, D. 2014). Moreover, electricity is the cleanest and most environmentally friendly energy carrier which can be produced directly from 'clean' energy resources; therefore, one of the most important aims of the human civilisation should be to reduce the fossil resources and to establish energy systems mostly on electricity provided by the *Earth*'s infinite resources. Its generation, therefore, needs to be continuously secured and they have to be done along with certain environmental requirements which means the electricity generation has to provide us with a sufficient amount whilst keeping the environment clean and healthy. For this latter reason, the electricity has to be transmitted from resources that are widely available in the country. This is when the energy resources for electricity generation is provided locally. Nowadays, however, the resources for electricity production may travel thousands of miles (see the availability of primary energy) which might be tolerable as long as it is based on equal trading deals and conditions, and not results in dependency and the extensive use of fossil resources. This responsible co-operation is shown in the *Co-operation Model* (BOKOR, L. 2013). This idea (responsible co-operation) makes globalisation a 'domesticated pet' of locality which is a useful interaction among other locations with different conditions and properties. The interaction by making a global network is the only option that can make a locus work quasi independently with other local hot spots which can also help tackle global problems at larger scales *(Figure 10)*. The co-operation is stronger and more efficient when each individual locus situated near to each other.

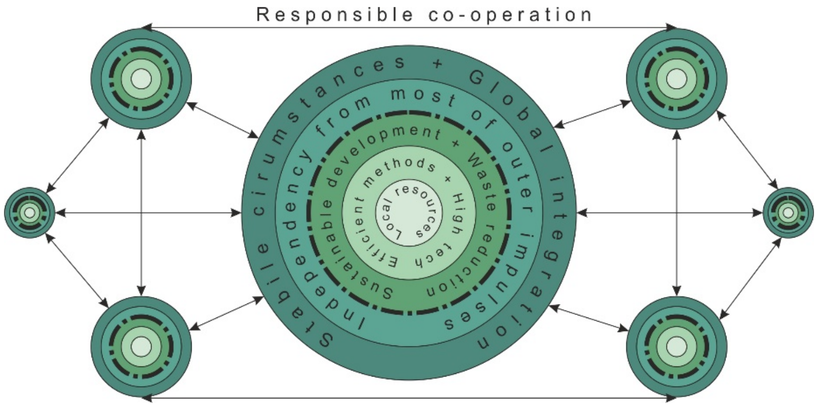

Figure 10 – The Co-operation Model
Based on Bokor, L. (2013)

According to Bokor, L. (2013), the term of 'producing electricity' is not fully accurate when one understands that energy itself is stored in a certain material (for example in coal) which only has to be released from that given energy resource by transforming it into a different form. The conversion of energy can be performed in many different ways depending on what one wishes to use that energy for and what type of energy is particularly needed. When it comes to electricity, electrical power is normally generated with a turbine of some type, but the type of energy resource can place electricity generation into two main categories in regards to how naturally it becomes electricity. According to Øvergaard, S. (2008): "*In the UN manual electricity from nuclear, hydro, wind and geothermal sources is labelled primary. The OECD/IEA/Eurostat manual states that; »Electricity is produced as primary as well as secondary energy. Primary electricity is obtained from natural sources, such as hydro, wind, solar and tide and wave power. Secondary electricity is produced from heat of nuclear fission of nuclear fuels, from the geothermal heat and solar thermal heat and by burning* *primary combustible fuels such as coal, natural gas, oil and renewables and wastes«".*

Now let us have a look at how the *UK* produces electricity. Based on NATIONAL STATISTICS (2016b), *Figure 11* shows the dominance of fossil fuels (coal, gas, and oil) which in 2015 was as high as 53% in the whole mixture. According to the previous observed years, their overall share, however, is in decline.

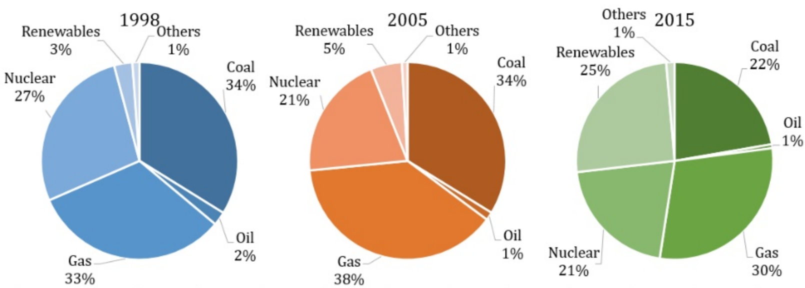

Figure 11 – Electricity generation in the United Kingdom in 1998, 2005 and 2015 (%)

Source: NATIONAL STATISTICS (2016b); Edited by BOKOR, L. (2016)

The coal at the end of 2015 represented 22% which has dropped significantly within the last 10 years (from 34%) and will very likely carry on falling out as an energy resource in the future for electricity generation. Nuclear has its share at 21% which has not changed much in the recent decade. It is promising to see the increase of renewables in the share which dominantly consists of wind and bioenergy, but there is an increase in the use of solar energy. The presence of other renewables, including hydro, is very little. It is worth having noted here that THE GUARDIAN (2016c) article headlines "Record 46% of *UK*'s electricity generated by clean energy sources in 2015" is misleading as they merged renewables with nuclear energy and classed the second one as 'clean' whilst forgetting about the significant environmental hazards that atomic energy poses.

Figure 12 shows how the electricity generation and supply and the significant downhill from 1998 to 2015; *Figure 13* presents how the generated electricity is consumed among the British sectors at national level.

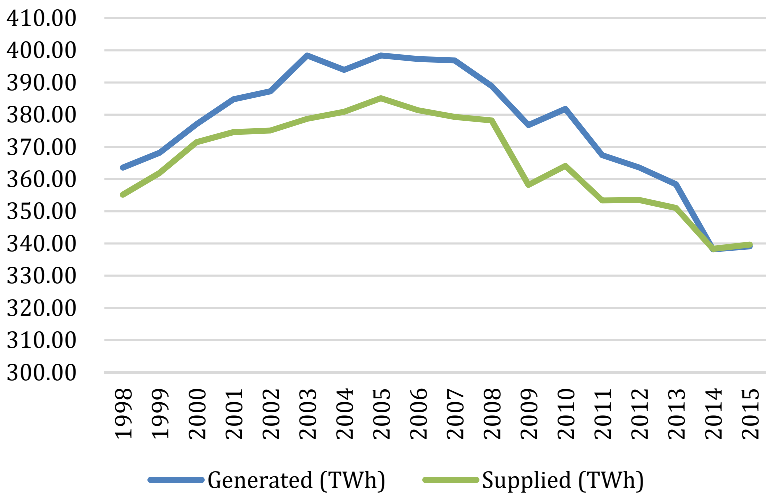

Figure 12 – Electricity generation and supply in the United Kingdom between 1998 and 2015 (in TWh)

Source: NATIONAL STATISTICS *(2016b)*

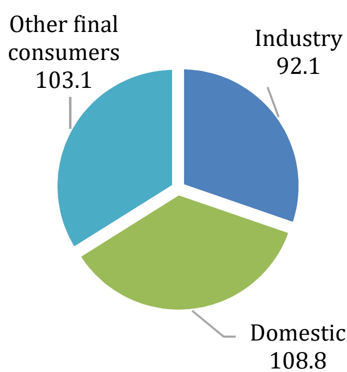

Figure 13 – Electricity consumption in the United Kingdom by sectors in 2015 (in TWh)

Source: NATIONAL STATISTICS *(2016a)*

In the following, it is worth comparing the above with some of the other European countries. Also, when this comparison is carried out, let us stick with the electricity production only, because these parameters tell us sufficient information about how a country is provided with energy resources and, therefore, other economic situations can be linked. It is not the aim to analyse consumption thoroughly, and the reason that this chapter only discusses and makes comparisons to electricity generation is enough to show links to local energy dependency or independency. For example, if a country's electricity is dominantly generated from hydro, that links to the dominance and sufficiency of local energy resources, while a largely mixed structure with fossil fuel dominance links to insufficiency and higher dependency of import fuels.

Throughout the *Brexit* campaign, the leavers frequently used *Norway* as a possible way for the *UK* to follow, so here it is *(Figure 14)* *Norway*'s electricity pie chart:

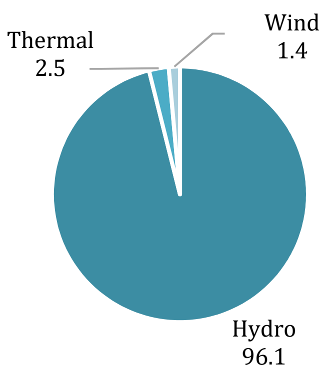

Figure 14 – Electricity generation in Norway (2013)
Source: SSB (2015)

Figure 14 shows information on what methods *Norway* uses to generate electricity. The data is as of 2013 (SSB, 2015), but if a similar chart is analysed now or ten years earlier, it would, without doubt, have looked the same with an overwhelming dominance (96.1%) of hydroelectric power. And, it is very likely that this mixture will not change any soon in the future. The answer behind the predominant share of hydro power based on at least two, but very important, factors and both are geographic: *1) Norway* is situated in the oceanic climate region and *2)* it is a largely mountainous country with high peaks, steep hillsides, deep valleys and fjords. The first information tells us that the country receives an immense amount of precipitation every year (above 1,000 mm), the second tells us that the country's natural givens are fully suitable for harnessing the power of the rivers. Basically, the *UK* and *Norway* are very similar in their physical features, but whilst the first one's mountain municipalities share 25.21%, the second one's 91.84% (EUROPEAN COMMISSION, 2004). As of today, *Norway* has access to over 4,000 river systems, and has over 900 fully operational hydro power plants with the installed capacity around 30,000 MW (produces about 125 TWh electricity) which makes *Norway* the 6th largest hydroelectricity producer on *Earth* (GONZALES, D. *et al*. 2011; WIKIPEDIA, 2016).

It is also an important fact that *Norway*, since the discovery of the *North Sea* and *Barents Sea* hydrocarbon fields, the country's economy has been dominantly set on the trade of crude oil and natural gas. Their domestic use is very little and both are mainly used in transportation (fuels) and household supplies (cooking and heating). According to CIA (2016), whilst the production in 2015 was estimated 1.568 million barrels per day[4], the refined petroleum products consumption was only 225,200 bbl/day (the production in the *UK* in 2013 was 771,800 bbl/day, the refined petroleum products consumption in 2014 estimated to 1.505 million bbl/day). According to INDEXMUNDI (2016), the domestic use has been constant since 1980 whilst the production peak period was in 2000 when, on a daily basis, 3,222 thousand barrels of crude oil was produced, principally for export purposes. That is where *Norway*'s richness comes from which is the overall result of the naturally available energy resources, the size of the country's consumption basis and excellent trade policies in place (such as fishing).

[4] An oil barrel (USA) which is abbreviated bbl.

The situation regarding electricity generation and the reliance of energy resources in *Iceland* is very similar to that of *Norway*'s *(Figure 15)*.

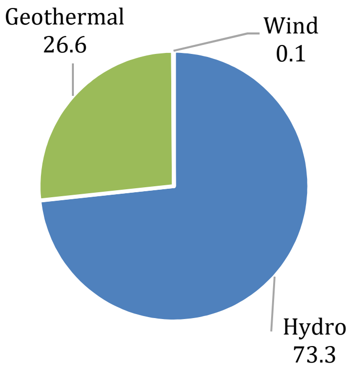

Figure 15 – Electricity generation in Iceland (2015)
Source: OS (2015)

The harness of hydroelectric power has been the most traditional since the main island, according to its terrain and climatic conditions (also oceanic), has a vast amount of water to utilise. The share in mix has just recently dropped down to 73.3% which is due to the more diverse and logical use of geothermal energy. *Iceland* is an active volcanic island where the energy of *Earth* can easily and sufficiently be accessed without any modification. All the energy production then is consumed by only a small number of people which is about the same as a middle-size city in the *UK*. *Iceland*, according to its natural resources, is able to supply its electricity production from 100% domestic resources. One would now raise the fact that *Iceland* does not require international co-operation, but in 2016, exclusion from global happenings would not make *Iceland* one of the richest (by GDP) and most developed countries on the planet. This country still has to be part of international trade and research networks.

The third country one could hear about many times through the *Brexit* campaign is *Switzerland* whose energy usage and electricity generation is significantly different to those in *Norway* and *Iceland* (and also in the *UK*) *(Figure 16)*.

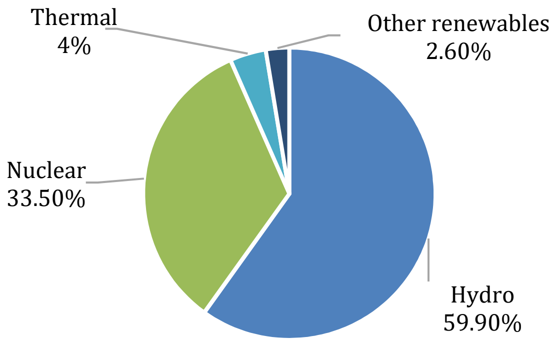

Figure 16 – Electricity generation in Switzerland (2015)

Source: SFOE (2016)

The country is, however, situated in the middle of the *Alps* where a high number of fast and powerful rivers can be utilised for energetic purposes. *Switzerland* has a very strict environmental regulation in place which does not allow the use of conventional power stations, therefore the rest of the electricity is predominantly produced by nuclear power stations.

Several other European countries and their primary energy use or electricity production could be looked at which would show a different reliance according to their natural givens. It is however a good idea to have a look at *Germany*, a country with similar size of economy, land area and population to the *UK*, how and in what ways produces electricity *(Figure 17)*.

Having an analytical look at the pie chart, one can see an example of a traditional, strong, continental economy. The coal is still very dominant, but the energy share shows a diverse range of energy resources. The best way to be quasi independent or secured on energy resources when a country has a continental situation if a country develops the energy mix as diverse as possible, which means: the more type of energy sources is being used, the better and safer the country's electricity production is.

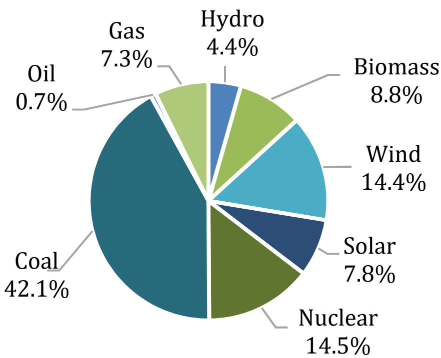

Figure 17 – Electricity generation in Germany (2016)
Source: FRAUNHOFER ISE (2016)

In *Germany,* this means a wider and more efficient reliance on locally available renewable energy resources including dominantly wind, biomass, solar and hydro energy which currently sums up 36.9% in the overall share. Never underestimate the importance of the total share of renewables, *Germany* (and the *UK* too) is still dependent on fossil resources and they need a wider integration with other energy suppliers to run their country and economy effectively.

As an extra addition, *Japan* is one of the non-European examples that has a very dependant energy economy which, according to 2013 statistics, includes 32.42% coal, 14.43% oil, 38.68% gas, 0.9% nuclear[5], 7.52% hydroelectric, and 6.04% other renewables in its energy mix whilst the country's production, according to its naturally available fossil resources, are very limited (FEPC-DP, 2016). Also, the country is isolated from mainland grid integration and, despite its rich renewable resources, *Japan* only uses 2% of these for electricity generation (BER-

[5] Note that after the *Fukushima accident* (2011) caused by a series of earthquake and tsunami, *Japan* shut down all of its nuclear reactors (54) and only 2 have been approved to restart since 2012 (BERRAHO, D. 2012). Before the great shut down, nuclear energy represented about 30% in *Japan*'s electricity generation.

RAHO, D. 2012). After the *Fukushima accident*, as a result of nuclear phase-out, the Japanese government has started moving towards the renewables and by 2030, it aims to achieve about 22–24% of its share in the energy mix (FEPC-DP, 2016).

7. Summary and conclusion

It is important to rule out the principal differences among these charts, shown in *Chapter 6*, based only on electricity generation of the *United Kingdom*, *Norway*, *Iceland*, *Switzerland*, *Germany*, and additionally of *Japan*; and even more important to understand the 'whys' and 'hows' in the overall energy economics. It is understandable that an area without suitable terrain will not be able to provide a country with the possibility to build efficient hydroelectric power stations. But, *Europe* is a large continent where a significant number of locally accessible renewable resources is available. If the charts are analysed at national levels, the *Need Model* (BOKOR, L. – NEMES, V. 2014) helps show what this dependence means if the *UK* is compared, for example, to *Norway (Figure 18)*.

The *Need model* shows how a local entity should rely on its local resources to be independent, but if this is not possible, and in most countries' cases it is not, then a wider co-operation is required between or among those places who have the same or similar energetic conditions. In this case, being part of a larger economic body with a significantly larger land mass is the only rational answer. If this model is set against electricity generation *(Figure 18)*, *Norway* produces 100% of its demand from domestic resources (SSB, 2015) which indicates positive sustainability, energy use and efficiency, whilst the *UK*'s dependency on imported fuels is predicted to increase in the next decade (in 2015, the import dependency was 38.6%—DEPARTMENT OF ENERGY AND CLIMATE CHANGE, 2016b) means negative local sustainability. This growing reliance is unavoidable even if the demand is set to shrink (MORISON, R. 2016); therefore, the *UK* needs international co-operation to provide its economy with the necessary resources. In the event of *Brexit*, *Britain* would, however, face higher energy import prices which would potentially drive up domestic energy prices (KAHYA, D. 2016). This is why the *UK*'s *Need Model* is negative, but the *Co-operation Model* indicates that this could still be shifted towards positive sustainability. The answer is a wider international integration and not separation. Most of the energetic challenges that affect a certain locus (a country for instance) are eventually political negotiations too which means, naturally provided and locally available resources and their domestic utilisation is always a subject of current political decisions. These decisions are not always rational and not always focus on those that would make a country's energy systems independent.

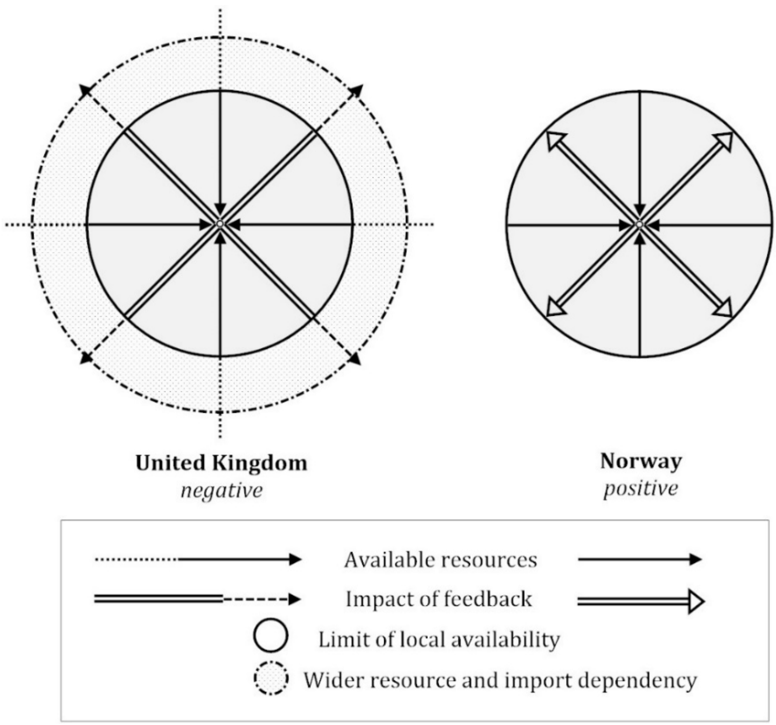

Figure 18 – The Need Model adapted to the UK and Norway according to their electricity generation reliance

Based on BOKOR, L. – NEMES, V. (2014), edited by BOKOR, L. (2016)

The energy economics of the *Earth* (including all the economies) has been increasingly shifting towards the use of renewable energy resources. The answers may be simple: the easily accessible fossil energy resources are in decline, mostly because their extraction is not economically sustainable any longer (because the easily accessible resources have already run out) and due to known environmental concerns and their evident contribution to global climate change. In this progressive system, energy resources (especially wind and solar) will be increasingly favoured and this is the only way for *Europe* to become more independent on import fuels from outside the continent which is the definite result of the reduction of fossil fuels. The *European Union*'s physical geographical properties indicate that the entire continent could move towards and be by 2050 a decarbonised, reliable and efficient, largely renewable energy resources-based power system (PwC, 2011). But one has to see that the members of the *European Union* have to stick together to create a sustainable energy network and the key part of this is a wider integration and the independent use of the 'constant' resources available (shared) among the (currently) 28 member states.

8. Further researches

As it was presented in the case of *Japan*, the energy structure of an economy can change significantly, if an unaccepted event happens. The *Fukushima accident* has had a major impact on the Japanese, which has spiralled implications globally onto other energy economics. The energy structure of these other local formations may change overnight which has to be frequently analysed and updated. The author of this paper is planning to carry on developing a measuring method (which started a few years ago as a co-operation—BOKOR, L. – NEMES, V. 2014) to emphasise differences, for example between the *United Kingdom* and *Norway*, by employing indexed data which will give more understanding to the *Need* and *Co-operation models*.

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Analysing Website Communication of Green Hotels with Respect to the Use of Renewables. How can they Increase Competitiveness?

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Abstract

The significance of competitiveness has increased in the last decade; therefore, the application of adequate marketing tools has gained major emphasis in the hotel industry. Despite the increasing role of website communication in the hotel industry worldwide, there has been little interest in the relationship between renewable energy usage and hotel competitiveness from the viewpoint of website communication.

The aim of this study is to analyse how the different forms of the available renewable energy are utilised in Hungarian hotels. Moreover, the study explores to *what extent the utilisation of renewable energy is communicated at the hotel websites in the Hungarian hotels.*

Following the right marketing strategy is a solution to stay competitive in the industry by means of attracting and retaining guests and distinguishing the hotel firm from their rivals. The hotel websites play an essential role in hotel marketing, the website content and the features are significant management decisions. As a result of the website content analysis, it can be stated that only 2 of the investigated 91 green certified hotels in Hungary communicate the utilisation of renewable energy and apply this fact as a competitive advantage on the hotel website. From the viewpoint of website communication, non-green hotels pay more attention to advertise and communicate their green attitude and renewable energy utilisation than the green certified hotels based on the research results.

Key words

Renewable energy; green hotel; hotel competitiveness; website content analysis

1. Introduction

The concept of sustainability has become a key issue in environmental management in the 21st century (DYLLICK, T. – HOCKERTS, K. 2002). Challenges in energy management and planning are considered as major technical and economic problems by the society in regards to the global environmental crisis (MUNKÁCSY, B. 2013). The tourism industry is also faced by this problem, consuming natural resources, such as water and energy, and producing a significant amount of waste. CHAN, E. S. W. – WONG, S. C. K. (2006) stated that the lodging industry is the most environmentally harmful hospitality sector, and 75% of its environmental impact can be attributed to the exaggerated consumption of non-durable goods, energy and water, enhanced by emission released into the air, water and soil (BOHDANOWICZ, P. – MARTINAC, I. 2003).

The concept of sustainability has been adopted by most countries since the *Rio Earth Summit Conference* in 1992 (KIRK, D. 1998), for example the *European Union* has also set targets for 2020 and 2050. The hospitality industry is responsible for 2% of the world's greenhouse emission, and therefore it plays a crucial role in contributing to the 2020 energy targets (TSOUTSOS, T. *et al.* 2013). However, while on the one hand, emission of tourism industry is harmful for the environment; on the other hand, it is one of the most dynamically developing sectors, and the development would be related to the utilisation of the newest forms of technology, including renewable energy sources. Renewable energy sources include, for example, solar energy and wind energy or alternative hydroelectric power (for example energy of sea currents and waves, high and low tide).

There is a strong correlation between the development of economy and the efficiency of available energy used (CHEN, Y. – CHEN, Y. 2012). As for the hospitality sector, architects, designers and environment-conscious managers now focus on creating more sustainable buildings and the implementation of renewable energy sources which can be regarded as a competitive advantage for the hotel. Hotel competitiveness is influenced by several factors, including location, price and physical environment which have been the subject, according to a number of studies (PHILLIPS, P. A. 1999; MOREY, R. C. – DITTMAN, D. A. 2003; BARROS, C. P. 2005; LOCKYER, T. 2005). Despite that all these factors are closely related to the energy consumption of the hotels, researchers have not investigated the relationship between the application of renewable energy and hotel competitiveness so far. It has already been stated that if a property is located in a low energy region, it is more complicated and complex to obtain energy which might be reflected as a conclusion in the prices of the services offered (KRARTIA, M. – HAJIAHB, A. 2011, TSOUTSOS, T. *et al.* 2013). If a hotel uses renewable energy, it is usually visible from outside, the roof or façade is covered with solar panels or solar cells, or the visitor can find smaller and larger wind turbines nearby. Renewable energy utilisation can enhance hotel competitiveness by several factors: on the one hand—the high cost of investment not taken into account—these are long-term savings, on the other hand, renewable energy can be regarded as a useful element which can be part of the marketing communication, representing commitment to sustainable development and thirdly a factor which has a strengthening effect on the physical environment and the design of the hotel.

In this research, we were searching the ways and methods how the green hotels in *Hungary* apply the renewable energy opportunities provided, and how and to what extent this is communicated through their websites. Another aim was to investigate and to find the answer to how the effort for the use of renewable energy is related to the known factors of competitiveness in the Hungarian hotel industry.

2. Green approaches in the hotel industry

2.1. Green certifications and labels

Recently, environmental awareness has gained a significant market, and several certifications and labels are awarded representing the given accommodation's commitment to a consciously sustained environmental operation. The different definitions, *green hotel, eco-hotel, eco-friendly hotel, environment-friendly hotel, etc*. are sometimes confusing and not explained for the tourists/guests/consumers. Most of the hotels worldwide are available online and they are interested in representing their green approach to their future guests. On the basis of the eco-labels that certify hotels about their green practices, there are a little bit more than 50 active types off different certifications available in worldwide comparison. These certifications aim at distinguishing the different green attitudes, products and services, however, some brands create and establish their own green programs and labels. Standard- and green label issuing associations can be classified into several groups depending on the region (JUDY, L. *et al.* 2007; ZHANG, H. S. – LIU, Z. L. 2010). In *Hungary*, the *Hungarian Association of Hotels and Restaurants* (MSZÉSZ) is responsible for making the decisions and appointing each consecutive year the green hotels based on their criterion system. In the analysis, the websites of the certified green hotels appointed by the *Hungarian Associations of Hotels and Restaurants* are examined since 1995.

2.2. Green hotel definitions

In explaining the term 'green hotel', different definitions are available depending on the business or the field of industry (green practices, hotel programs etc.), and the academic literature. ENZ, C. A. – SIGUAW, J. A. (1999) stated that operating a green hotel is not only a good practice, but also a good business. Environmentally friendly hotel operations are the waves of the future. Some hotel owners are convinced that operating a hotel in an environment-friendly manner is the right thing to do, others will act in the same way simply because of the increasing governmental regulations (ERDOGAN, N. – BARIS, E. 2007).

According to LEE NI (2002), a green hotel is a hotel which provides facilities and services with the idea of environmental protection. For example, during the construction of a new hotel, try to use recycled material. A growing number of hotels join the green movements to reduce harmful impacts on the environment, and in doing so they eventually increase their profitability (for example cost savings and customer attraction/retention) (WOLFE, K. L. – SHANKLIN, C. W. 2001; PIZAM, A. 2009). WOLFE, K. L. – SHANKLIN, C. W. (2001) also indicated that 'green' refers to actions that decrease the negative impacts on our environment (for example recycling, eco-purchasing). Similarly, according to the definition of *Green Hotel Associations* (GHA, 2016), a green hotel is an eco-friendly lodging property that has implemented various green practices, sound and environmental-friendly programs to protect the environment and reduce operational costs. In particular in green hotels, the following items are quite commonly used, practiced and served: durable services, cotton towels and linens, donations to charity, well-educated staff about green practices, energy conservation, environmental cleaning, eco-friendly/organic foods, fresh air, water recycling/conservation, recycling bins, towel re-use program, etc. The *Green Hotels Association* defined a green hotel as "a hotel which saves water and energy in a constructive manner and reduces solid wastes to maintain our environment" (JUDY, L. *et al.* 2007, p. 467.). ERDOGAN, N. – BARIS, E. (2007) defined green hotel as "a hotel that evaluates surrounding ecological condition before starting construction and tries not to aggravate impacts on environment" (ERDOGAN, N. – BARIS, E. 2007. p. 609).

In conclusion, a green hotel's goal is to introduce the idea of environmental protection into either hotel hardware or software in order to save energy and reduce waste. Software in hotel industry refers to the people who provide the service and the operational process; hardware on the other hand refers to the main facilities and constructions. The core spirit of green hotel aims at reducing environmental impacts and energy consumption while providing products and services to customers. Based on the above, a green hotel can be defined as a hotel, the managers of which save water and energy, reduce wastes and environmental impacts through the participation of staff and customers. A green hotel needs to promote the idea of environmental protection through operating recycling, separate waste collection (CHEN, Y. – CHEN, Y. 2012), and utilising solar energy, wind energy, biomass energy, hydro power. For example, hotels can plant real flowers and plants and provide related ecological travel options for their customers.

2.3. Green hotels and consumer behaviour

To achieve general and environmental competitiveness on the global tourism market, the hotels must increase their performance to satisfy environmental requirements. Environmental protection continually attracts public attention (CHAN, E. S. W. – WONG, S. C. K. 2006), and people gradually recognise the environmental damage caused by business (MANAKTOLA, K. – JAUHARI, V. 2007). The increasing public concern stimulates the implementation of environmentally responsible management in the hotel industry, too (WOLFE, K. L. – SHANKLIN, C. W. 2001).

More and more customers prefer green products/services and environmentally responsible companies that meet the green requirements of the customers, as exemplified, for example, in their willingness to pay for eco-friendly products/services (VANDERMERWE, S. – OLIFF, M. D. 1990; ROBERTS, J. A. 1996; CHEN, Y. – CHEN, Y. 2012). This green consumerism has brought about modifications in purchasing methods, manufacturing processes, and operation procedures, including ecologically conscious decisions in various business segments (D'SOUZA, C. – TAGHIAN, M. 2005; CHEN, Y. – CHEN, Y. 2012).

Consumers make product choices based on which combination of product attributes best meets their needs according to dimensions of value, cost and prior satisfaction (KOTLER, P. 1997). Tourism is identified as one of the most promising growth sectors in world economy. Therefore, tourism firms need to be more innovative in the future. As with many other products, hotel products have become more segmented by the market and there has been recent innovations in design which have changed the external and internal appearance of the hotels (DURNA, U. – BABUR, S. 2011). Interesting hotels in ship, plane, fish, ball, castle, or jail designs have appeared in different tourist destinations of the world. Also, findings in psychology confirm the role of hoteliers and hotel designers; psychologists have determined that the physical environment has an effect on human behavior and this branch of psychology has become known as environmental psychology (COUNTRYMAN, C. C. – JANG, S. S. 2006). Using the premise of environmental psychology, KOTLER, P. (1997) determined that physical environment influences the behavior of indivuals in consumer settings. In a study conducted by DUBE, L. – RENAGHAN, L. M. (2000) about the top ten attributes determining the price selection of hotels, respondents ranked physical aspects and room design of the hotel as the third and fourth determinants of their decision.

2.4. Green labels in the hotel industry

The development of eco-labels provides information on the sustainable initiatives of the hotels and supports the consumers or the future guests in decision-making. Several types of effort can be made by the hotel management industry through the application of the best available practices and technological innovations without decreasing the comfort and convenience of the tourists. The hotel industry is conscious of this new trend and has set new policies (BARROS, C. P. 2005, CEROVIC, L. – DRPIC, D. 2014). Various guides are designed to be practical tools for daily implementation. As consumers become more willing to pay extra for green products (KAPELIANIS, D. – STRACHAN, S. 1996, LAROCHE, M. *et al.* 2001), it is anticipated that a green image will play an increasingly critical role in their decision-making process and purchase intentions (PRENDERGAST, G. – MAN, H. W. 2002).

2.5. Green practices as a form of competitive advantage

The hotel industry has always been open for the new innovations that influence their performance in a positive way. The green practices and the implementation of green technologies represent a new developmental paradigm in tourism and hospitality industry, providing possibilities to minimise harmful effects to the environment, which is a basic precondition in the modern development of tourism (CEROVIC, L. – DRPIC, D. 2014).

The 'green' hotel business is a growing niche because not only do these establishments distinguish themselves from the similar non-green hotels, but they also fulfil a need in the market for less environmentally damaging hotels. Marketers in the hotel industry are striving to increase their firm's competitiveness (for example earning recognition and increasing customer retention) through the greening of their firms, thereby eventually enhancing their hotel firms' profits (MANAKTOLA, K. – JAUHARI, V. 2007).

Being green is a competitive advantage not just for the hotels but for many companies. Being green on the other hand has different perspectives from the viewpoint of the companies, guests and governments, depending on the location of the hotel and the surrounding community. The word 'green' means being environmentally responsible or sustainable with the aim to minimise environmental impacts in purchasing, operations and management. In this way, the health and well-being of the guests and the staff is enhanced, reducing waste, toxicity and overall costs.

A green hotel does not only mean compromising on guest satisfaction or the performance of products and services. Any environmentally responsible product or service must work well or it is of no value, so guests should be as satisfied with the green features in a hotel as with more conventional ones. Being green is often associated with the incorrect assumption that green products are necessarily more expensive. Many environmentally responsible products and procedures, in contrast, can be purchased or applied quite economically, especially if cost is considered over the full life cycle. The competition of the hotels has created an energy-spending environment, on the supply side with providing more and more for their guests, and this type of attitude has resulted in a careless behaviour also on the demand side. The end of the energy-fullness times and the fear of facing by the end of non-renewing energy sources forced the hotel industry for acting.

A great number of hoteliers have adopted the green hotel label also as a marketing ploy to attract customers (PIZAM, A. 2009). MANAKTOLA, K. – JAUHARI, V. (2007) indicated that by marketing its green activity, a hotel can increase competitiveness by positioning itself distinctively in the competitive arena. Improved public relations, a better relationship with the local community and greatest financial and marketing advantages can also be the benefits obtained through hotel environmental management (KIRK, D. 1998).

3. Hotel competitiveness

3.1. Definition of hotel competitiveness

BARROS, C. P. (2005) stated that the competitiveness of a country derives from the performance of its enterprises, among others the hotels that contribute to the community's economic, social and cultural development. According to TSAI, H. *et al.* (2009), productivity is a key element of hotel competitiveness. IONCICA, M. *et al.* (2009) marked that the concept of competitiveness is subdivided on two sub-concepts: comparative advantage and competitive advantage which can be investigated in the case of hotel industry as well.

From the viewpoint of the competitive advantage-based view, economics and ecology are compatible, and superior environmental performance leads to above-average industry profits (RUSSO, M. V. – FOUTS, P. A. 1997). Based on this concept, corporations with proactive environmental programs have a competitive advantage because their better reputation resonates favourably with stakeholder groups such as customers, employees, and the public in general. Other factors that contribute to the competitive advantage based on environmental sustainability are developed technology (GROENEWEGEN, P. – VERGRAGT, P. 1991) and sharper political point to influence public policy.

3.2. Hotel competitiveness indicators

A hotel competitiveness indicator expresses the extent to which the hotel is able to provide services which are available for sale while providing satisfaction for the guests, employees and management/ownership at the same time (JUHÁSZ, L. 2010). According to this statement, the various dimensions: leadership performance, environmental output, internal capabilities and performance output are highlighted. A conclusion is drawn, that reaching high business profit does not mean full competitive advantage on the market. If the guest wishes are guaranteed and the guest satisfaction is high without adequate revenue this fact is still not enough for a firm to possess competitive advantage on the market. Special indicators (GESPER[6], GOP[7]-level, GOPPAR[8], REVPAR[9], TREVPAR[10]-results, etc.) are in use for the ability to increase in profitability, guest segments, harmony of specialisation, level of personal cost and the profitability of the invested capital all contribute to the competitiveness of a hotel.

The *Hotel Competitiveness Monitor* (as defined by JUHÁSZ, L. 2010) includes various factors and indicators contributing to the level of hotel competitiveness *(Figure 1)*. These four main dimensions are leadership performance, environmental output, internal capabilities and performance output. Sustainability is present in the dimension of environmental output, but the indicators of green attitude and environmentally friendly approach can be observed in all dimensions.

[6] Guest Night Per Revenue
[7] Gross-Operating Profit – result of the business activity
[8] Gross Operating Profit Per Available Rooms
[9] Revenue Per Available Room
[10] Total Revenue Per Available Room

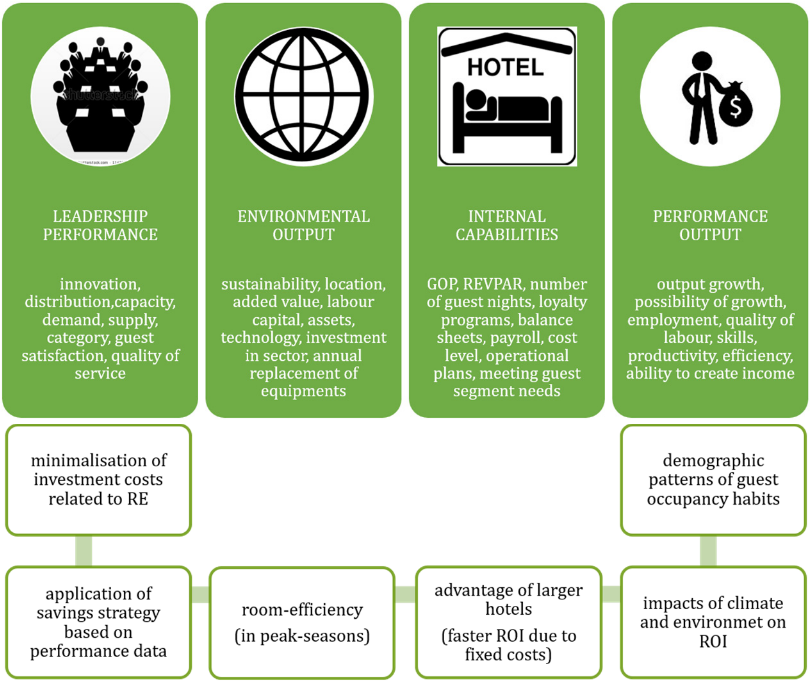

Figure 1 – Hotel Competitiveness and Renewable Energy Monitor
Source: based on JUHÁSZ, *L. (2010) and* JUHÁSZ-DÓRA, *K. (2015)*
Edited by JUHÁSZ-DÓRA, *K. (2016)*

Based on this monitor, a hotel utilising any form of renewable energy can be competitive, if the investment costs related to renewable energy are minimised. The implementation of renewable energy sources can be regarded long-term savings, if the high cost of investment is not taken into account. The hotel performance must be recorded before and after the utilisation, and future forecasting has to be made regarding the expected results. After implementation, these recorded results have to be analysed with respect to the analysis of room efficiency and seasonality of the hotel for example. A number of facts can be stated regarding the utilisation of renewable energy by hotels. Hotels possessing more rooms have the advantage that due to the fixed costs, the return on investment is faster than in the case of hotels possessing less rooms. Moreover, the climate and the environment in which the hotel property is located has an impact on the return on investment and, as a consequence, affects hotel competitiveness as well. The demographic pattern of the guest occupancy habits also influences the competitiveness of a hotel based on the indicators of the hotel competitiveness monitor. Furthermore, financial support from the *European Union*, governmental or institutional funds, personal impulse of the management, the attitude of the property owner towards sustainability also have an effect on the implementation of renewable energy, therefore it has a long-term impact on the competitiveness of a hotel.

4. Research methodology

The aim of this study is to investigate how green hotels in *Hungary* utilise and apply the available renewable energy opportunities provided, and how and to which extent it is communicated via the hotel websites. The novelty of this paper is the application of the method content analysis of the hotel websites. The main focus is to reveal to which extent the utilisation of renewable energy can be a competitive advantage for Hungarian hotels.

The rapid development of the internet usage has dramatically changed the world which also has an effect on the tourism industry. In the early decades of the 21st century, the role of online marketing is emerging and website communication is increasing which also have an impact on the lodging industry, due to the changing lifestyle of the customers (LIAO, C. P. – SHIH, M. L. 2006; ANDERSON, C. 2012). A hotel website plays an essential role in property marketing, the content of the website and the presented features are significant management considerations. The management and owners of the hotel properties try to find out which decisions result in long-term success and competitive position in the hotel market. A website offers a business possibility, not only a platform to promote products or services, but also another platform to generate revenue by attracting more customers

(Chiou, W. *et al.* 2010). Therefore, the effective website evaluation has become a point of concern for business practitioners and academic researchers. Academic researchers have long advocated the importance of assessing website effectiveness. Lu, M. – Yeung, W. L. (1998) were pioneers in this field, proposing a framework for evaluating website performance, in which the usefulness of a website is estimated, based on its functionality and usability. As a newly emerging research area, website analysis and evaluation has no global definition or framework yet (Ting, P. *et al.* 2013).

The utilisation of renewable energy can be regarded as a competitive advantage, but several hotels do not take into account this opportunity as a marketing tool. The presence of renewable energy application in the marketing communication activity, on one hand, is a competitive advantage, and on the other hand it demonstrates an environment-conscious attitude and is also a long-term economic decision.

The applied research method of this study is website content analysis. First, the hotel websites were analysed, and then secondary data were collected. The online webpage of the *Hungarian Association of Hotels and Restaurants* were analysed in May 2015. The investigated period was every second year between 1995 and 2015, because in *Hungary* green hotels are classified in every second year. The sample number altogether is 91 hotels of *Hungary* which have been appointed green hotels in the last decade by the *Association of Hungarian Hotels and Restaurants*. The *Hungarian Association of Hotels and Restaurants* launched activities to protect the environment to encourage domestic hotels since 1993. The first competition was organised in 1994 by the Association, and since then in every two years some new hotels are appointed as green hotels. The successful candidates have obtained a two-year right to boast with the 'Green Hotel' logo. The sample number was reduced from 101 hotels due to the fact that some hotels of this sample have been purchased or become under the operation of a management company or have been closed during the last decade.

Website content analysis involves choosing certain concepts for examination and analysing their presence at the studied websites. The data coding technique we applied includes three steps: firstly, analysis of photos and videos that indicate applications of renewable energy at the hotel website. Secondly, presence of logo or any other type of indication of the financial supporters for the investment in the renewable energy project. Thirdly, by analysing the website content, searching for the words ‘renewable energy’, ‘alternative energy’, ‘geothermal energy’, ‘solar collector’, ‘biomass’, ‘heat pump’ (also in English and in Hungarian language) at the hotel websites *(Figure 2)*.

Step 1

- for photos/videos indicating the applications of renewable energy sources

Step 2

- indication of the institutional support/governmental fund, financial supporters of the investment in renewable energies

Step 3

- analysis of website content, searching for the words: renewable energy, alternative energy, geothermal energy, solar energy, biomass, heat pump

Figure 2 – Applied research method: Hotel Website Content Analysis

Edited by JUHÁSZ-DÓRA, K. (2016)

Due to the globalisation and the change in the consumer habits, global trends can be experienced also in the hotel room sales technique. The internet use and technological developments have greater influence on the hotel market than ever, and most of the hotel rooms are sold through online booking (ANDERSON, C. 2012). Therefore, from the viewpoint of competitiveness, the website is regarded as a significant online marketing tool that a hotel can boast with, and which is available for the future customers and also for the competitors.

5. Research results

The authors investigated whether the Hungarian green hotels that apply renewable energy utilise this fact as a competitive advantage and present it at their website as a marketing tool *(Table 1)*.

Table 1 – Selected green hotels in Hungary applying various forms of renewable energy based on the website evaluation in Hungary
Edited by JUHÁSZ-DÓRA, K. 2016

Name of the hotel / Location	Form of RE utilised	Notification on the website (Yes/No)	Year of implementation	Number of rooms	Category/ Hotelstars Union	Year of green hotel classification
Airport Hotel Stáció / Vecsés	Geothermal energy, solar collectors	No	2010	75	4*	2011
Art Hotel Szeged / Szeged	Solar collectors, geothermal energy	Yes	2014	71	4*	2015
Danubius Hotel Helia / Budapest	Solar collectors	No	2000	262	4*	1999
Hotel Silvanus / Visegrád	Heat pump, solar collectors	Yes	2003	151	4*	1999
Hunguest Grandhotel Galya / Galyatető	Biomass	Yes	2013	129	4*	N/A
Zichy Park Hotel / Bikács	Heat pump, solar collectors	No	2008	47	4*	2007

Based on the studied 91 green hotels in *Hungary*, it can be concluded that only six of them utilise any form of renewable energy, and only two of them, the *Art Hotel Szeged* and *Hotel Silvanus*, present this fact as a form of competitive advantage, also by communicating this fact at the hotel website. *Art Hotel Szeged* and *Hotel Silvanus* take a competitive advantage of the utilisation of renewable energy in a way that the photo of the solar collectors is displayed at the website. The application of the form of renewable energy is a long-term investment, it is a design-architectural solution, moreover it can also be regarded as a competitive advantage for the environment-conscious future guests.

As we found through the website analysis that most of the certified green hotels do not apply any forms of renewable energy *(Table 2)*, we tried to find the reasons why. If the solar hours are compared and checked against which hotels apply this energy-saving method, these solutions, the utilisation of solar energy are only applied when the hotel management/ownership receives any form of support from the Hungarian municipalities. It is an interesting finding that these assets communicate the utilisation of renewable energy, because they have to return the support received.

Table 2 – Hotels without green certification applying forms of renewable energy based on the website content analysis in Hungary

Edited by JUHÁSZ-DÓRA, K. 2016

Name of the hotel / Location	Form of RE utilised	Notification on the website (Yes/No)	Year of implementation	Number of rooms (r) and apartments (a)	Category/ Hotelstars Union	Green hotel (Yes/No)
Auguszta Apartman Hotel and Youth Hostel / Debrecen	Solar collectors	Yes	2013	262 (r)	3*	No
Aqua-Lux Wellness Hotel / Cserkeszőlő	Solar collectors Geothermic energy (heating with thermal water)	No	2013	17 (r) 16 (a)	4*	No

Arany Bárány Hotel Zalaegerszeg	Solar collectors	Yes	2012	54 (r)	3*	No
Balaton Hotel Siófok Siófok	Solar collectors	Yes	2013	120 (r) 12 (a)	4*	No
Erdőspuszta Club Hotel Debrecen	Geothermic energy	No	2013	29 (r)	4*	No
Hotel Kapitány Wellness és Konferencia Hotel Sümeg	Solar collectors	No	2012	154 (r)	4*	No
Medves Hotel Salgótarján	Heat pump, biomass, solar collectors	Yes	2012	50 (r)	2*	No
Tó Wellness Hotel Bánk Bánk	Heat pump, solar collectors	Yes	2011	58 (r)	4*	No
Vinum Hotel Kiskőrös	Solar collectors	Yes	2014	27 (r)	4*	No
Zenit Wellness Hotel Balaton Vonyarcvashegy	Heat pump, solar collectors	No	2011	35 (r)	4*	No

In regards to the hotels without certification, several indicate the application of renewable energy on their website as a form of competitive advantage. One assumption is that the not certified hotels aim at representing their attitude towards sustainability; even though they are not certified or classified, they aim to express their attitude towards sustainability.

Another interesting fact is that most of the green hotels do not represent the renewable energy utilised on their website. Possibly, some hotels already holding the green certification aware of their competitive advantage on the market, and they do not need to present their green-attitude towards the hotel market and the future guests any more.

6. Conclusions

Since the onset of the internet in the early 1990s, the potential of the *World Wide Web* in the field of business has also been recognised. The rapid development of the internet has dramatically changed tourism, and also hotel industry. The internet can serve as a marketing tool in the hotel industry, the hotel website being a platform where future customers, competitors and other participants of the tourism market can receive information about the hotel firm. Therefore, the continuous improvement and adequate choice for the website features is an important decision of the hotel management. Due to changes in consumer behaviour, competitiveness via the internet has become an important factor; therefore, hotel websites have an important role in the decision-making of customers.

The aim of this study was to analyse the hotel websites from the viewpoint of renewable energy utilisation in the Hungarian green hotels in the last decade. The study explored to which extent the utilisation of renewable energy is communicated at the hotel websites of the investigated certified hotels by means of website content analysis. The investigated period is every second year between 1995 and 2015. 91 appointed Hungarian green hotels were studied (of which 54 are located in *Budapest* and 37 countryside). The research method was website content analysis *(Figure 2)*, the authors were searching for videos, photos, logos and also some expressions in the hotel description related to the utilisation of renewable energy.

In the long term, the use of renewable energy can be regarded as a competitive factor for the hotel assets: in *Hungary*, we found that mostly solar cells are applied in the case of thermal complexes and hotels. Only one green hotel, the *Silvanus Hotel Visegrád* represents the utilisation of renewable energy at its website. It was an interesting result, that from the viewpoint of website communication, non-green hotels pay more attention to advertise and communicate their green attitude and renewable energy utilisation than the green certified hotels.

It is obvious that in the future more emphasis should be put on the institutional, governmental support of renewable energy in hotel industry because it utilises a large amount of energy. The management of the hotel companies, hotel associations and the government of the country should collaborate, and create concepts to find the best ways how to obtain the forms of innovative solutions in hotel industry.

Based on the research results and the review of the related literature, it can be confirmed, that the application of renewable energy is significant from the viewpoint of hotel competitiveness. In the future, the authors aim at finding the reasons why the hotels applying forms of renewable energy do not use this fact as a competitive advantage. Another research aim is to increase the number of analysed hotels, widen the research database, and include not only certified green hotels, moreover check the attitude of the hotel management and owners towards green solutions and the utilisation of renewable energy in the hotel assets.

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Landscape Factors that Influence the Planning of the Renewables. The Case of Wind Energy Utilisation in Slovenia

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Abstract

The meeting of the climate targets largely depends on the successful expansion of the renewable energy (RE) production facilities. While technical solutions are available and political support is prevailingly secured, the main limiting factors seem to be social; either the competition for space with other land uses, or the opposition of local communities to host a renewable energy facility. The change of landscape is one of the more often used arguments for this opposition. Using the example of wind power plants in Slovenia as a case study, this paper identifies the landscape factors which should and could be considered, and discusses *how these could be employed in planning the RE facilities. While certain factors seem to be unambiguously concluded from the literature as well as the presented cases, such as adapting the scale of the facility to its environment, or using the already degraded or poorly used sites; others are too diverging to allow any concluding guidelines. Nevertheless, the process factors, such as a transparent and trustful governance of the process and a fair distribution of cost and benefits as perceived by the local community, seem to prevail over the adequacy of planning and design solutions.*

Key words

Renewable energy; wind power plants; landscape change; Slovenia

1. Introduction

Being one of the main climate change mitigation pillars, the production of energy from renewable resources gained considerable political support in the last decade(s). The *European Union* (for example the *EU Renewable Energy; Council Directive 2009/28/EC*) and its member states have set ambitious targets regarding the share of energy produced from renewable resources, supported by (mostly financial) instruments. For *Slovenia*, this means a 40% share of RE in the electricity production by 2020 (AN OVE, 2010; ELES, 2012). Currently, the share of the renewable energy sources represents 33% in the Slovenian energy production, and the majority of that is secured by hydro power. As most possibilities for the hydroelectric power production in the country have already been exploited, the bets for the future are largely on solar, biomass and wind energy. The highest increase in the period 2009–2014 has been in solar power (243 MW of new installations), followed by biomass, while the new wind energy facilities have been marginal with 3 MW. Although, the first initiative for a wind power plant dates back in 2000, only two turbines (at different locations) have been put in operation since. The dynamic of the expansion of solar plants can be almost entirely explained by economic motives (level of subsidies). On the contrary, the reasons for the slow development of wind power production are more complex. The main factors to be considered are: a lack of resource (wind), conflicts with other users (including nature conservation), bad management and policy implementation, and (lack of) public support (EKINS, P. 2004).

The contemporary definitions of good governance (including planning) involve criteria such as a sound evidence (knowledge) base, in addition to accountability, transparency and participation. The role of experts to provide these is significantly different, and not always effective. If we focus on the role of planners, STEINITZ, C. (2012), provides the framework of different *models* representing the type and form of knowledge, used in different stages of the planning process (*Figure 1a* and *1b*).

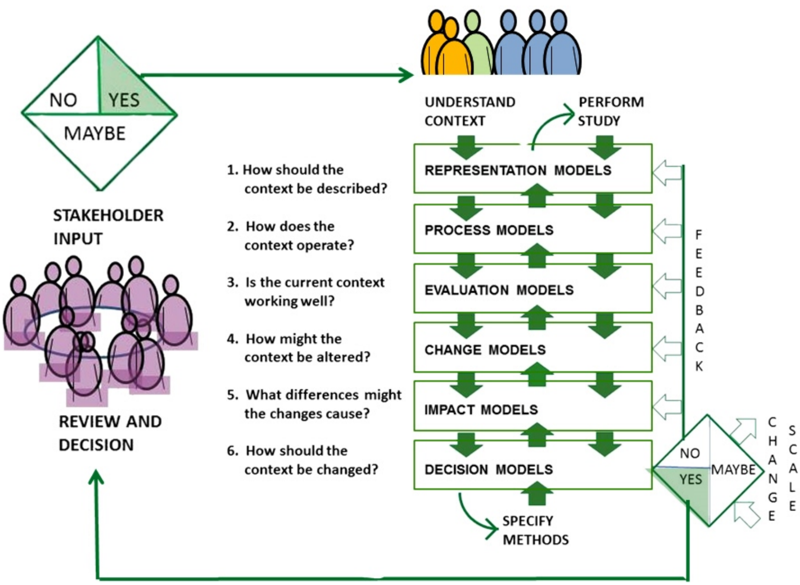

Figure 1a – Planning process and knowledge inputs
Source: STEINITZ, C. (2012)

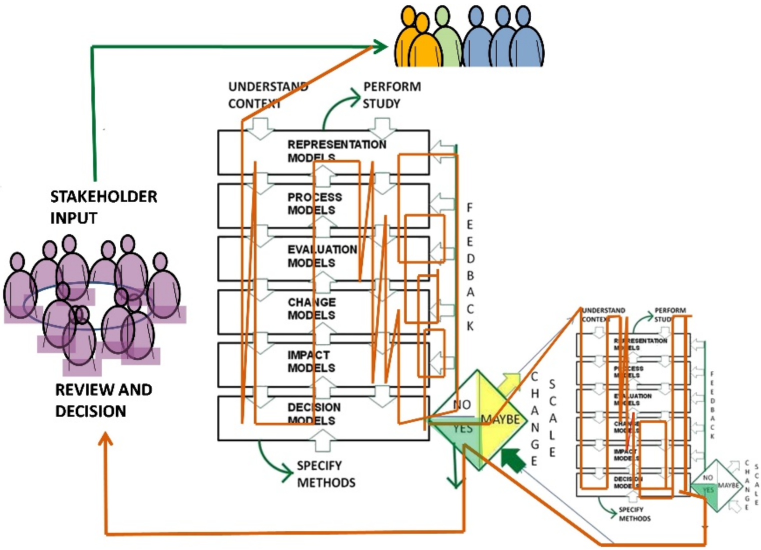

Figure 1b – Planning process and knowledge inputs

Source: S*TEINITZ, C. (2012)*

These steps and models require several iterations *(Figure 1a)* and, in reality, often feedbacks, skips and repetitions of certain steps *(Figure 1b)*. The second ('scoping') loop, which is critical for designing the planning process, should be taken from the bottom up, starting with decision models. In this stage, the process designer (team) should answer the following questions: How is the decision taken? By whom? Is there more than one decision-maker? What are their attitudes, are they conflicting? What will be their decision based on? What will they need to know? (STEINITZ, C. 2012). The set of studies, defined by answering these questions may be quite different from the set based on what experts think is important from the perspective of their expertise.

2. Knowledge support for wind power planning

In terms of planning the wind energy production facilities (wind power plants, WPPs), the first question is the presence of the natural resource (representation and process models) and its quality (evaluation models). Although, the wind power technology has considerably advanced in the last decades, the amount of wind is still the limiting factor. In Slovenia, the highest and most stable speeds of wind are along the mountain ridges, and these areas are presently the only ones with any reasonable wind potential *(Figure 2)*.

Although these sites have considerable natural limitations (altitude, difficult access, steep slopes, landslides and erosion), their estimated energy potential by 2050 is 600 MW or 1,000 GWh (AN OVE, 2016).
The construction of WPP involves considerable changes in landscape due to the wind turbines as well as the electricity transmission lines. The information on the anticipated changes can be provided by the change and impact models. The restrictions due to the conservation of (other) natural resources such as the agricultural land, forests, visual amenities or water resources, are examples of such models which indicate that the impacts exceed the thresholds. Change of landscape is often (among) the main concerns as it abruptly interferes with place attachment of local communities and visitors (MCPARTLAND, S. 2012).

In the case of WPP in *Slovenia*, the biodiversity concerns and the (protected) habitats present important restrictions. The restrictions for development as designated by the nature conservation areas (national, regional and landscape parks corresponding to UNESCO level II–V) are not very high with a 13% share of the total area. On the other hand, the share of the protected habitats by the *Natura2000* is the highest in the *EU*. It covers almost 38% of the land, a fair share of which are the internationally important bird areas. A comparison of these areas *(Figure 3)* with the areas of high wind potential, shows a high overlap and indicates a potential for conflict.

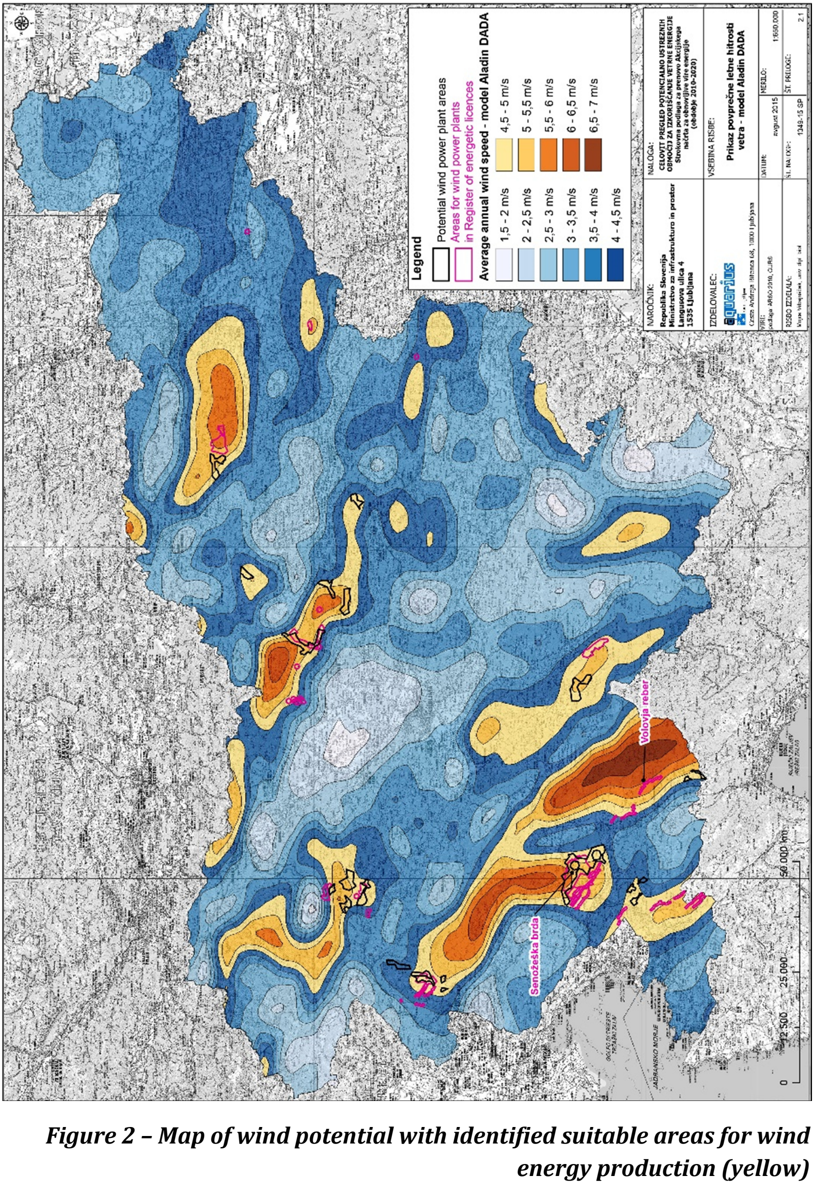

Figure 2 – Map of wind potential with identified suitable areas for wind energy production (yellow)

Source: MLAKAR, A. et al. (2011)

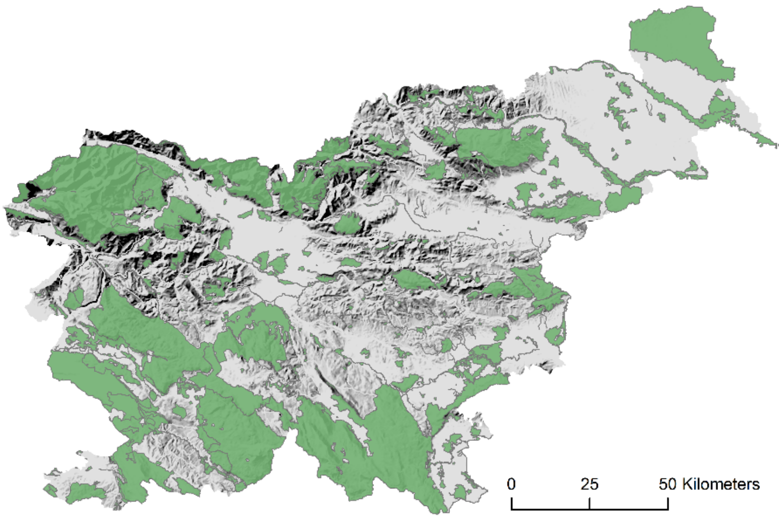

Figure 3 – Nature2000 areas in Slovenia
Source: NATURA2000.SI (2013)

At this point knowledge support ends by providing sound, evidence-based, objective information. However, the information can be interpreted in a variety of ways, depending on how the decision is taken, by whom, what are the decision makers' attitudes, and whether these are conflicting.

The implications of the answers to these questions for the planning process will be discussed, by using a meta-analysis of the documentation related to the wind power planning in *Slovenia*, for example the surveys of general public attitudes, and the two concrete examples of the (failed) WPP projects.

3. Governance and public perception issues of WPP planning: review of the case studies' documentation

Similar to elsewhere in the *EU*, the general attitude of the Slovenian public is rather in favour of the wind power. According to the *Eurobarometer poll 2006*, *Slovenia* is the fifth among the compared countries with 81% of respondents in favour of, 16% indifferent and only 2% opposing to the wind energy. Similar results are reported by GOLOBIČ, M. – MARUŠIČ, J. (2001) in their survey in *Primorska region*, which has the highest wind potential in *Slovenia*. After solar, hydro and small hydro, wind power was assessed as the third most suitable for *Slovenia*, with a score 3.7 out of 5. Interestingly, these results differed between lay and professional respondents, the latter scoring wind (3.3) as well as hydro, and especially small hydro power, much lower than lay public. On the other hand, the experts' scores for biomass, gas and nuclear power were higher *(Figure 4)*. A survey on a smaller sample in the part of the same area (VOLK, T. 2016), also positioned wind energy as a rather or very suitable.

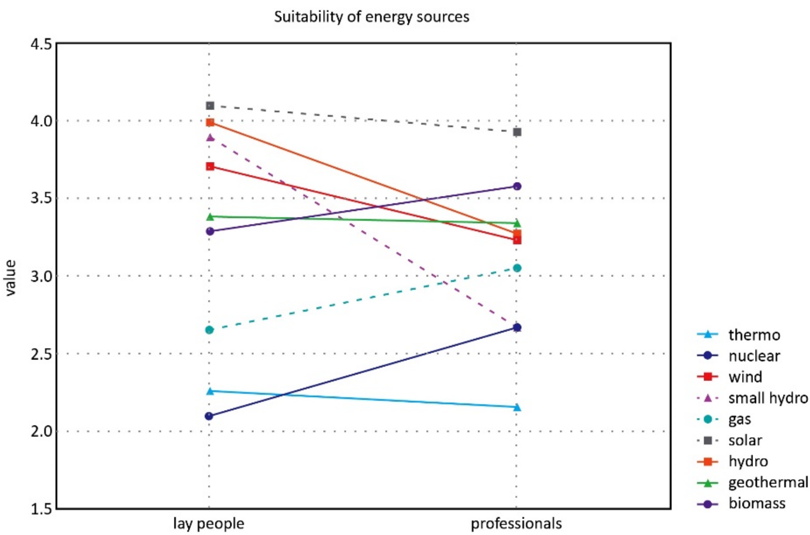

Figure 4 – Suitability of different sources of energy for Slovenia as assessed by the respondents from Primorska region and spatial planning experts

Source: BREČEVIČ, D. et al. (2012)

Nevertheless, this general support changes when particular projects come into question. The following part will discuss, whether the reason behind this is a typical NIMBY (not in my back yard) effect, or there are other, more complex factors to be considered.

3.1. Case I: Volovja reber

The first wind power plant initiative began in 2001, when the distribution company *Elektro Primorska* considered 8 potential sites in *Primorska region*. They commissioned a comprehensive study on evaluating the potentials and restrictions for the wind power development in the area (BREČEVIČ, D. *et al.* 2001). The study involved assessment of the proposed sites from the different aspects: infrastructure availability, energy potential, wind speed, availability of space, nature conservation, natural resources, noise, and visual impacts. The sites which performed best in terms of their potential (*Golič*, *Vremščica* and *Volovja reber*), were at the same time least favoured in terms of the environmental acceptability and consequently, not recommended. Nevertheless, the developer decided to pursue one of these sites, namely *Volovja reber (Figure 5)*.

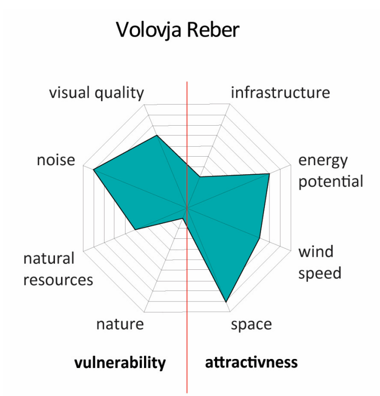

Figure 5 – The assessment of Volovja reber site from the various aspects
Source: BREČEVIČ, D. et al. (2001)

Volovja reber is a high plateau with distinct karst formations in the south of *Slovenia*. The surface is a rather rocky dry grassland and pastures *(Figure 6)*. Rare vegetation is present throughout the area. Due to high density of karst landforms and well preserved nature the area is considered a highly valuable landscape (MARUŠIČ, J. 1998a).

Figure 6 – The area of proposed WPP on Volovja reber
Photographed by ZERDIN, M. (2005)

The landscape guidelines (MARUŠIČ, J. *et al*. 1998a) for the area include: conserving the pristine remote areas, unfragmented forests on slopes, especially on visually exposed locations, and karstic and dynaric geomorphologic features. Because of these features, the site was proposed for *Natura2000*, but was excluded from the designated area due to the demand of the *Ilirska Bistrica Municipality*. However, 60% of the municipalities' total surface was still included in *Natura2000* network.

In the process, the project was downsized from 88 to 29 turbines due to the demands from the forestry and nature conservation administrations, archaeology requirements, and land ownership *(Table 1)*.

Table 1 – The chronology of the process for Volovja reber WPP
Source: VOLK, T. (2016)

2003

- The idea is presented by the developer to the local community;
- Conflicting attitudes form: Municipal council shows support, Birdwatchers asks for the formal protection status of the area

2004

- The coalition of 24 civil organisations for *Volovja reber* collects 2400 signatures under the petition against the WPP
- Municipal council adopts the spatial plan for WPP,
- Decree on *Natura* sites is adopted, *Volovja reber* is excluded from the categorisation on the demand of the municipality
- An agreement between the developer and the mayor on the compensation is made. The money is to be used for the primary school in *Ilirska Bistrica*
- The process for obtaining the permits begins, including the various demands of the institutional and civil stakeholders.

2005–2006

- The *Birdwatchers Society* fights for the right to become a party to legal proceedings
- The National parliament's committee for the environment supports the WPP

2007

- Developer **gets the building** permit for 29 turbines
- The *EU* warns *Slovenia* because of the unjustified exclusion of the proposed WPP area from the *Natura2000* sites

2008

- The building permit is **revoked** because of the procedural mistakes in the environmental impact assessment process (the formal role of the birdwatchers' society is recognised)

2009–2010

- Internal negotiations between the developer and the birdwatchers
- The previous environmental assessment and the **building permit are confirmed**

2011

- The administrative court **revokes the building permit** based on the birdwatchers' society complaint

2012

- The environmental **consent** for 33 turbines **is being granted** and contested immediately by the birdwatchers' society.

2013

- The Environmental **consent is revoked** by the Ministry for the environment. The process is stopped.

In 2010, the public opinion survey among the 268 inhabitants of the municipality (VOLK, T. 2016) showed, that 61% supported and 25% opposed the project. The highest support was in the villages close to the proposed site. Their opinion was not uninformed, as the survey results proved that people were well knowledgeable about the renewable energy and about the *Natura2000* sites. Two thirds also said that they had sufficient information on the proposed project. Their main sources of the information were either friends and neighbours, or public meetings.

As it can be concluded from the project's chronology, the main 'battle' was fought about the stakeholders' roles in the process. As it was clear from the beginning the civil societies, based on the nature conservation (mainly birds) arguments, were strictly against the project, while the local community supported it, mainly due to the benefits agreed with the developer. After the responsible bodies their decisions 4 times, and the further finial rejection of the environmental permit, the developer finally gave up the project.

3.2. Case 2: Wind park Senožeška Brda

The proposed WPP was to be located east and west along the highway between *Ljubljana* and the coast, in the municipality of *Divača*. The WWP should consist of (up to) 40 wind turbines with altogether 120 MW, access roads, connecting and transport electricity lines, and the transformation station *(Figure 7)*. The area is between 400 in 800 m above sea level, consisting mainly of forested hills and ridges. The landscape guidelines (MARUŠIČ, J. *et al.* 1998b) for the area focus on preventing the forest overgrowth and conserving the typical botanic grassland features. The choice of the site was based on the study "Comprehensive evaluation of potential sites for the use of wind power" (MLAKAR, A. *et al.* 2011), which was an input to the National energy program 2010–2030 (URADNI LIST, 2004). This study identifies *Senožeška Brda* as one of the 14 potentially suitable sites in *Slovenia*, as it complies with the conservation (distance from the existing settlements, and the *Natura2000* sites—specifically, the wildlife migration corridors) as well as the development criteria (wind potential, geomorphology, the accessibility of roads and existing electricity power lines). An adequate wind speed was confirmed by the on-site wind monitoring.

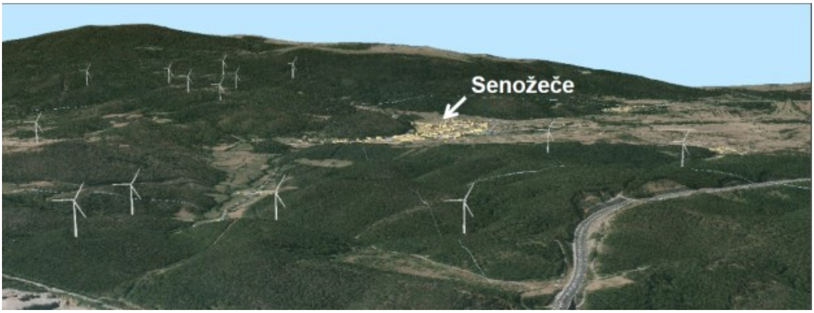

Figure 7 – The proposed WPP in Senožeška Brda
Source: VEPA (2013)

The project was presented in 2013. The developer informed the public about the project by using several ways of the information provision: roundtables, field presentations, info points, meetings with inhabitants. On the other hand, the civil group against the project, *The Protection of Senožeška Brda*, organised the expert presentations on the negative impacts of wind turbines.

In 2014, the initiative for the national land-use plan was submitted and the environmental report for the *Strategic Environmental Assessment* (SEA) was prepared. The number of turbines was downsized from 75 to 40 (120 MW) due to the environmental constraints, and further on to 15–20 (50 MW) due to the economic considerations (for example, reduction of the subsidies). The local community negotiated a minimal 800 m distance from the houses, and a share (3%) of the total income to be paid to the community, including the rents for the landowners, compensations for the affected individuals, and participations into the municipality budget.

That year, a non-binding referendum was organised in the municipality, resulting in the 57% (of around 60% attendance) of votes against the project. Furthermore, an opinion poll, conducted in the local community in the same year, resulted in 50% of the locals supporting the project, and 29% opposing, others were undecided. A survey on a small sample of inhabitants in 2016 (OBLAK, Š. 2016) showed, that despite all the information and surveys, people don't feel well informed about the project. Only 6% said they have a good knowledge, 64% thought they have the basic knowledge, while 30% claimed to have no knowledge about the project at all. Furthermore, 42% did not know which site is being proposed, 33% of those who knew, approved of the site, and the rest disapproved either of the site or the WPP in general.

The project is presently pending due to the financial issues of the developer as well as the uncertainties related to the noise legislation, which needs to be adapted to the technical specifics of the wind turbines.

4. Results and discussion

4.1. The role of the impact on landscape in approving/disapproving the WPP

The impact of the RE facilities on the appearance of the landscape is most often perceived negatively by the public. This perception depends on the landscapes' characteristics of a particular site as well as the social factors, such as the attachment to, and the identity value of the landscape (GRAHAM, J. B. *et al*. 2009; TORRES-SIBILLE *et al.* 2009; MCPARTLAND, S. 2012; MOLNAROVA, K. *et al.* 2012; VECCHIATO, D. 2014; BETAKOVA, V. *et al*. 2015). The summary of different surveys in the *Primorska region* (BREČEVIČ, D. *et al.* 2001; OBLAK, Š. 2016; VOLK, T. 2016) shows, that the health and well-being concerns (for example noise, EMR) are less important than nature and landscape *(Figure 8)*. The birds are of highest concern, while the visual impacts, in both cases assessed as medium (3 or slightly less on a 1–5 scale), were placed second. While the scenic values have been mentioned a few times in the debates at both sites, they never came to the front of the discussions. Typical quotes from the discourses are shown below, putting wildlife (birds in particular) in front of the discussion in the *Volovja reber* case, and health (noise and EMR) in the *Senožeska Brda*.

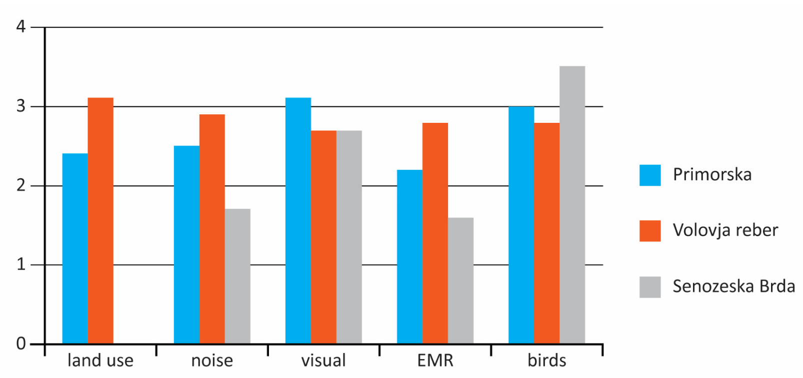

Figure 8 – Importance of different impacts; comparison of the results from three different surveys
Source: Brečević, D. et al. (2001); Oblak, Š. (2016); Volk, T. (2016)

"The proposed areas are a part of a complex of highland karstic ridges of high nature conservation importance and exceptional scenic value. They are the sites of endangered flora, habitats of big carnivores, and migration corridors for vultures and other internationally protected birds. Building the wind turbines in this area would be a rude and permanent disruption, which would degrade the areas' nature conservation value" (from the "petition against the WPP on Volovja reber).

"... on Volovja Reber there is nothing but old grass and a few rocks and bushes here and there, the same on Vremščica, only a few sheep in addition. So, what would the wind turbines disrupt there? The sheep would still graze and the birds would still fly" (the internet forum about the Volovja reber).

"The existing turbine on Griško polje disclosed another reason for opposing the project: The turbine emits sounds, which are detrimental for health and can be heard through closed windows and are especially disturbing during the night time. The forest of wind turbines around our settlements does not only destruct the landscape but also our living environment." (The civil initiative to protect Senožeška Brda)

The relative importance of the landscape's scenic value can also be concluded from the answers to the question where the WPPs *should* be. The responses are mainly very rational. The main criteria involve the wind potential (in terms of the landscape characteristics) and the appropriate distance of the industrial or degraded areas from the settlements (GOLOBIČ, M. 2005; VOLK, T. 2016), which is consistent with the findings in literature (LOTHIAN, A. 2008; BETAKOVA, V. 2015).

In terms of the individual landscape features, the results of public surveys are not consistent. When asked about the suitability of different landscape types for WPP, the respondents choose the *above the timber line* and *agricultural land* as the most appropriate (with scores between 3 and 3.5 on a 1–5 scale), followed by the *visually exposed*, *forested* and *settled areas* (GOLOBIČ, M. 2005). The areas of cultural and natural heritage were evaluated as least suitable (scores less than 2).

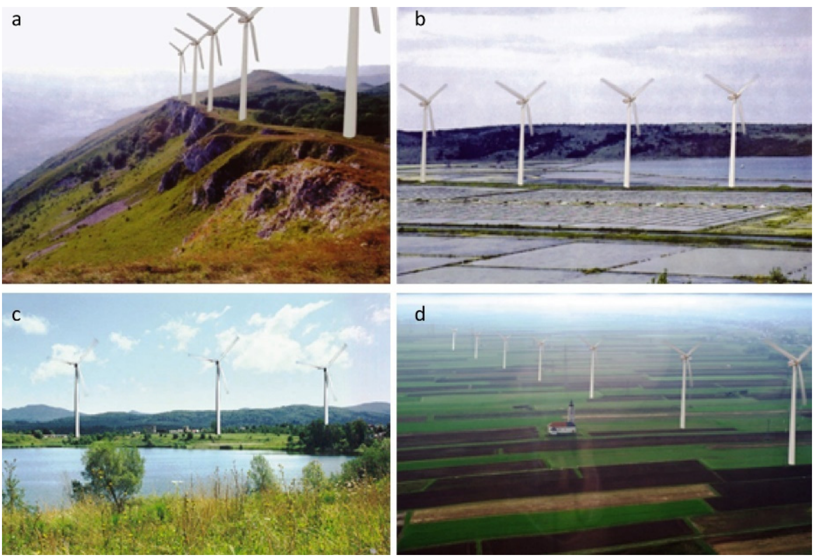

Figure 9 *– a) The landscape assessed as the most visually sensitive to wind turbines. b, c and d) The landscapes assessed as the least visually sensitive to wind turbines*

Source: GOLOBIČ, M. (2005)

However, when using the photo surveys to assess the baseline (without turbines) and modelled (with turbines) sceneries against a set of the landscape quality criteria, the results were just the opposite. The largest degradation was perceived in the natural (above the timber line, visually exposed) landscape (photo *a* in *Figure 9*), and the smallest in the cases of the *Sečovlje* salt fields (cultural and natural heritage site, photo *b* in *Figure 9*), settled countryside (photo *c* in *Figure 9*), and agricultural land with cultural heritage (photo *d* in *Figure 9*).

In general, plains are a preferred setting for wind turbines as opposed to hilly landscapes. This may be related to the natural vs. cultural image of the landscape. The facilities for the use of renewable energy sources (RES), as markedly anthropogenic structures, disrupt 'the natural' which negatively affects the landscape's appearance, a finding which is in line with some other studies (BROWN, G. – BRABYN, L. 2012). On the other hand, the presence of cultural elements (church for example) does not seem to reduce the acceptability (GOLOBIČ, M. 2005).

The most consistent are the findings showing that the wind turbines are less attractive from up close than from a distance, regardless of the surrounding landscape. Additionally, partial hiding by other elements (for example shrubs and trees) increases the visual acceptance (*Figure 10*—photo *a* preferred over photo *b*).

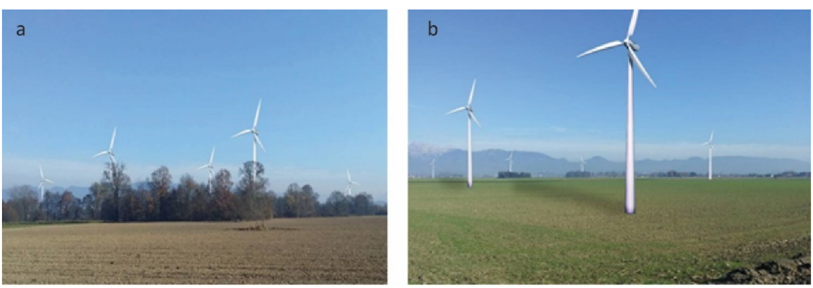

Figure 10 – Impact of landscape feature on visual acceptability of wind turbines, 'a' preferred over 'b'
Source: OBLAK, Š. (2016)

4.2. NIMBY or a lack of process governance?

The difference between the general acceptability of the WPP and the opposition to the projects in a local neighbourhood is often explained by the NIMBY effect. The surveys in both case studies are also ambiguous in confirming this hypothesis. In the case of *Volovja reber*, 38% of the inhabitants would accept the turbines closer than 1000 m from home *(Table 2)*, a distance, which was, for example, required as a minimum in the case of *Senožeska Brda*.

Table 2 – Acceptable distances of wind turbines from home

Source: VOLK, T. (2016)

m	< 100	100–500	500–1,000	1,000–5,000	5,000–10,000	> 10,000	other	sum
%	20	11	7	20	9	13	20	100

On the other hand, the distances obtained in the survey among the three different local communities (one of them was to host the proposed *Senožeška Brda* WPP) were much larger—the WPP should be 7 km (!) away from home (*Figure 11* top).

These distances hardly seem rational, in particular when taking into account the dispersed settlement pattern in *Slovenia*. It is interesting, however, that the required distance for the WPP was significantly higher in the hosting community—more than 20 km (*Figure 11* bottom), then in the other two (the accaptable distances were higher for the objects proposed inthese communities, for example an electric power line and a waste disposal facility).

Trying to summarise the success or failure factors of the wind energy projects, the following main groups were identified *(Table 3)*: characteristics of the object (for example scale, environmental compliance, innovation potential), characteristics of the site (for example peripheral, degraded, industrial), compliance and synergy with other uses, and (perceived) local economic benefits and governance of the process (trust, transparency, etc.).

From the perspective of the factors which are often considered as the most important, for example the process governance and perceived economic benefits for the local community (BREUKERS, S. – WOLSINK, M. 2007; JOBERT, A. *et al.* 2007; WUSTENHAGEN, R. *et al.* 2007) both projects did fairly well. Nevertheless, other reasons caused their hindrance and possibly failure.

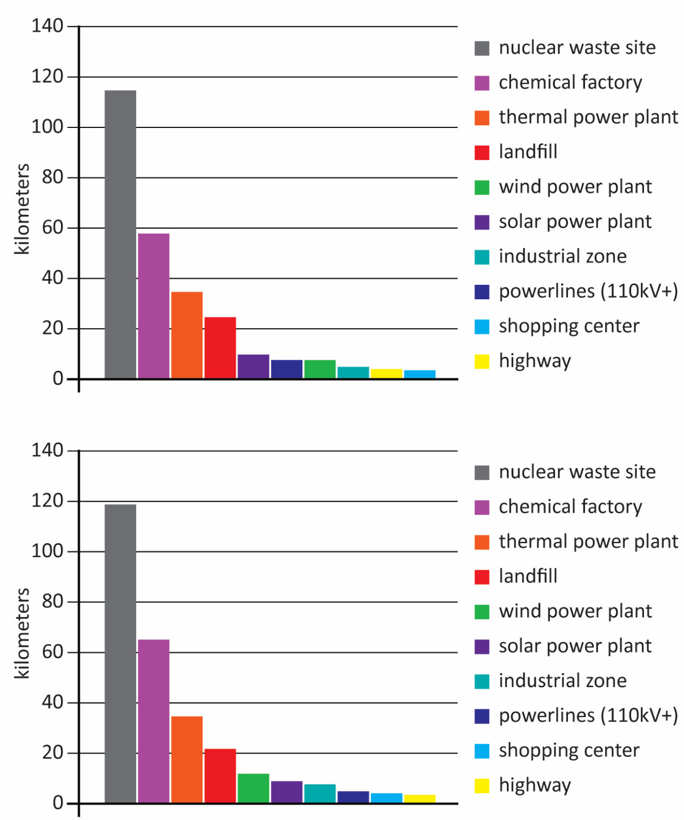

Figure 11 *– Required distance for different facilities by respondents in the three different communities (top) and the community hosting the proposed WPP Senožeška Brda (bottom)*
Edited by VOLK, T. (2016)

Table 3 – Success factors of wind energy projects

Edited by GOLOBIČ, M. (2005)

	Volovja reber	**Senožeška Brda**
Characteristics of the object		
Small scale (deconcentrated energy, small visual and other impacts, pilot or experimental projects) –	–	–
Unambiguous compliance with environmental standards	–	**(+)**
Characteristics of the area		
Peripheral area (rural, less populated, no land use conflict)	**+**	**+**
Reuse, multipurpose (infrastructure, industry)	–	–
Compatibility & synergy		
Use for tourism, recreation and education	–	–
Local economic benefits		
Energy independence, shareholding, economic profits	**(+)**	**(+)**
Process governance		
Embeddedness in higher level document (strategy, programme	–	**+**
Trust in manager of the process/developer, perception of fair distribution of burdens and benefits	**+**	**(+)**

5. Conclusions

Maybe more than other contemporary processes, the RE development has the potential to create the vital modern landscape, and thus contribute to the palimpsest of heritage landscapes, created by past land use practices and technologies. However, present discussions raise a question whether the current management and spatial planning approaches are capable of simultaneously achieving the RES objectives and ensure the quality of the landscape.

So, what is the role of experts (and our knowledge) in planning WPP? Traditionally, we would be asked to provide independent scientific studies about the environment and impacts. However, as the examples above show, the roles became more diversified. Providing knowledge support for the developer (optimisation of project) became an important one, especially with the formalisation of the (strategic) environmental impact assessments. Additionally, with the recognition of public participation, providing knowledge support for civil groups (empowerment) came up front. Therefore, not surprisingly, the participants of the LeNotre RELY e-lecture from all across *Europe* quite equally recognised as important all of the three roles.

The Slovenian national documents in preparation, partly acknowledge the attitude of people as important for achieving the objectives of the RE. The national action plan for RE resources (AN OVE, 2010) highlights the 'information and awareness' as important for achieving the goals, and provides the measures for informing the actors (consumers, builders, architects, etc.) about the benefits, cost and energy efficiency of devices, systems, and electrical energy from the renewable sources, and for stimulating the activities of the non-governmental organisations operating in the public interest in the energy sector. However, these measures aim to increase the general public support for RE, which is already high, and will not help in solving the problems that the current projects are facing. The new energy concept for *Slovenia* (MINISTRSTVO ZA INFRASTRUKTURO, 2015), goes a little closer to the point by aiming to achieve 'the social agreement on the siting of infrastructure'; however, it does not provide any instruments for that.

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Decentralised Electricity Storage Possibilities – From a Geographical Viewpoint

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Abstract

The development of energy systems has a quite conspicuous direction which can be described as renewable energy based decentralisation. This way of the energy evolution demands an extensive presence of storage applications, in regional and local level, as well. The battery storage is the simplest solution but the financial part of these applications (pumped hydro, power-to-gas, liquid air, and compressed air energy storage) can be demanding. This is why this research is focused on some alternative technologies and their spatial dimension. This latter is considered as a limitation in some of the researches. In our approach, the spatial aspect is considered as possibility for the less-developed rural regions, as the research area of this paper, the operation area of the 'Bükk LEADER rural development region' in North East Hungary. According to the GIS analysis, all the four storage technologies seem to be applicable: 78–160 pumped storages; 29 power-to-gas storages; 7 liquid air storages; and a significant number of small-scale compressed air energy storage would be applicable in the research area. However, it is important to underline, that the above mentioned values are not comparable from the quantity of the stored energy point of view, because it is mostly affected by the technology.

Key words

Decentralised energy system; electricity storage; seasonal storage; GIS; environmental burden; rural development

1. Introduction

The current increase in the deployment of new renewable electricity generation systems is making the energy storage and other methods (demand side management; energy mix optimisation; energy system optimisation with involvement of heat and transportation solutions; import and export) more and more important in order to secure the supply of electricity. The decentralisation in the field of the energy production especially highlights the importance of small scale storage solutions, as batteries. On the other hand, the popular and simple battery storage seems an expensive technology so far. This paper focuses on its main alternatives.

According to ANTONELLI, M. *et al.* (2016) "an ideal energy storage technology would have a high power rating, a large storage capacity, high efficiency, low costs and no geographic constraints". This paper argues this statement, that in some regions geographical abilities cannot be seen as constraints, but much more as possibilities.

Figure 1 – Research area
Edited by HARMAT, Á (2016)

This paper considers that energy storage technologies offer advantages of balancing the demand and supply of the electricity grid throughout the day or even through seasons of the year, moreover they can help to solve some electricity system management tasks, as frequency regulation.

As for the research methods, the main ways are desktop research, field research (plant visits in existing energy storage facilities) and GIS analysis. The latter focuses on special geographical areas in *Hungary*, namely the *Bükk LEADER rural development region (Figure 1)*—as a part of a more general research on sustainable energy solutions in these regions.

2. Current state of the energy storage technologies

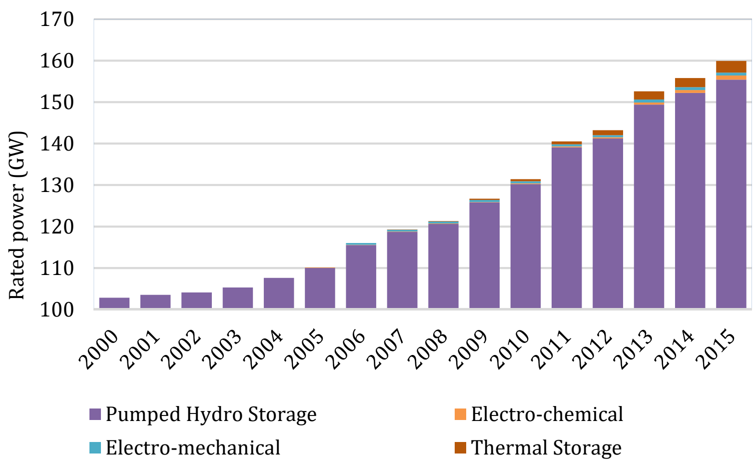

Figure 2 – Global energy storage capacities by technologies

Source: DOE (2016); Edited by HARMAT, Á. (2016)

2.1. Power-to-Gas

Power-to-Gas (P2G) is one of the most promising methods in which the surplus electricity can be transformed into gases, in order to store energy *(Figure 3)*. The stored gas can be:

a) *hydrogen* via water electrolysis;
b) *synthetic methane* or 'synthetic natural gas' (SNG) or 'renewable methane' via subsequent methanation;
c) a *mixture* of hydrogen and methane.

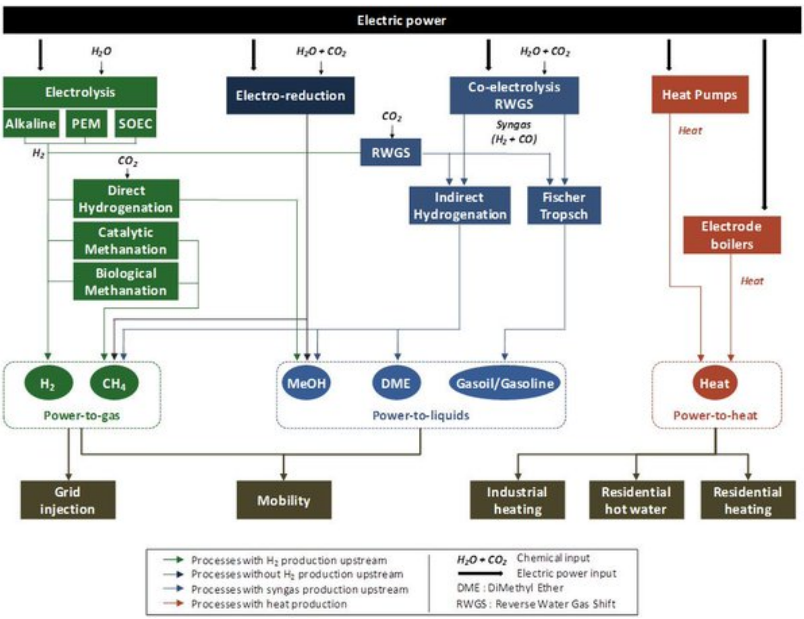

Figure 3 – Power-to-gas, power-to-liquids and power-to-heat routes and their energy markets
Source: ENEA (2016)

There is a similar method *(Figure 3)*, in which the energy storage happens in the form of liquid methanol (Power-to-Liquid) (RÄUCHLE, K. *et al.* 2016).

The main advantage of the method is the huge storage capacity of the *existing gas grid*, including the caverns and other storage facilities. According to HAFENBRADL, D. (2016), it means 300 TWh storage possibility only in *Germany* against the 0.04 TWh existing pumped hydro and battery storage capacities.

The Power-to-Gas procedure has two or three steps:
1) the *electrolysis* in order to create hydrogen;
2) chemical conversion, like *methanation*—an optional step;
3) the *storage*.

The first step is the water electrolysis which is a mature and well understood technology (PAIDAR, M. *et al.* 2016). The main goal is to create hydrogen in such periods when the electricity demand is low and the wind or/and photovoltaics (PV) solar power production is high.

The second, optional step is the conversion. Its main goal is to create more stable chemical forms in order to find simpler storage solutions. The most relevant stable forms are the liquid organic hydrogen carriers (LOHC) and the synthesised hydrocarbons. One of the simplest methodology is the methanation which can be done both in catalytic and biological methanation reactors. In a *catalytic methanation* reactor the methane is synthesised under high pressure and temperature (Sabatier process) and in the *biological method* special microbes (for instance *Archaea*) create the methane *(Table 1)*.

Table 1 – Comparison of methanation processes

Source: HAFENBRADL, D. (2016)

	Sabatier process	**Biomethanation using Archaea**
Operation temperature	300–400°C	60–65°C
Ramp up time (0–90%)	~1 hr	Sec/Min
Tolerance against contamination (H_2S, O_2, KOH)	low	high
Product gas	CH_4 + side products	CH_4
Product purity (%CH_4)	~92%	98–99%
Energy efficiency	~50%	58%
System complexity	high	low
Scalability	low	high

In the last decades, several reactor concepts were developed for large scale coal-to-gas plants, mainly in Japan. However, the smart grid system requires smaller and more flexible methods (GÖTZ, M. *et al.* 2016). The biological method, using *Archaea* seems proper for the future applications as its scalability and overall efficiency are higher.

In a sustainable energy system, in these conversion processes CO_2 emissions of biogas plants or industrial facilities must be used (SCHNEIDER, L. – KÖTTER, E. 2015). Another requirement due to the excess heat produced during methanation is to have heat demand—preferably a district heating system—nearby. Both of these factors make the P2G facility more efficient; thus, less costly to run (VARONE A. – FERRARI M. 2015).

In the *third step* the hydrogen or the methane (or their mixture) or another product of the chemical conversion need to be stored. It can be both a short time and a seasonal period of time. The storage unit for the *hydrogen* can be

- surface or subsurface tanks
  - compressed gas tank;
  - cryogenic compressed liquid hydrogen tank;
  - metal hydride storage;
- geological underground storage *(Figure 4)*.

As for the *methane*, the most important type of gas storage is in underground reservoirs (depleted gas reservoirs, aquifer reservoirs and salt cavern reservoirs).

The large scale geological storage can be one of the cheapest ways, however in the case of hydrogen there is no direct option to store it in high amount for long period (SCHIEBAHN, S. *et al.* 2015). In the case of methane, the long-term storage from weekly to seasonal time periods may require huge underground gas reservoirs, however their availability is regionally limited.

Another feasible option can be the injection into the existing natural gas grid. In general, 4–5% of biogas (synthetic natural gas [SNG] or hydrogen is allowed to be injected into the system (QADRDAN, M. *et al.* 2015; SCHNEIDER, L. – KÖTTER, E. 2015).

Figure 4 – A geological underground storage site for methane (90%) and hydrogen (10%) mixture at a depleted natural gas reservoir near Pilsbach, Austria
Photographed by MUNKÁCSY, B. (2016)

2.1.1. Projects

There are many different parameters (location, intersectoral co-operation) which influence the efficiency of Power-to-Gas systems. According to the *European Power to Gas Platform*, 41 projects are existing today, most of them are in pilot phase. The biggest project is in *Wertle* (*Lower Saxony, Germany*—launched in 2013) which produces 1300 Nm^3/h of methane and hydrogen while its installed capacity is 6.3 MW.

In the field of biological methanation (based on *Archaea microbes*) have been some significant steps ahead: a demonstration plant in a biogas plant of *Allendorf (Hesse, Germany)*, a pre-commercial scale facility in a biogas research centre in *Foulum, Denmark* and a 1 MW commercial-scale field trial at a wastewater treatment plant outside *Copenhagen, Denmark* have been launched lately.

Table 2 – Operational and planned P2G projects in Europe
Source: EPGP (European Power to Gas Platform)

	Operational projects (number of units)	Planned (number of units)	Installed power (kW)	Planned power (kW)
United Kingdom	4	0	1,436	1,436
France	3	1	0	1,150
Spain	2	0	4,270	4,270
Germany	20	8	15,996	26,661
Norway	1	0	48	480
Denmark	4	1	1,270	2,470
Netherland	2	1	15	12,327
Belgium	1	0	150	150
Switzerland	1	1	315	1,015
Italy	1	0	1,000	1,000
Austria	2	0	700	700
Total:	**41**	**12**	**25,200**	**51,659**

2.1.2. Geographical aspects

As it was mentioned above, in these conversion processes CO_2 emissions of biogas plants or industrial facilities must be utilised. In order to identify the suitable areas of P2G storages in the *Bükk LEADER rural development region*, GIS analysis were used. In case of the study area, block industrial and chemicals production facilities were identified as significant CO_2 sources. Also, livestock facilities and existing or planned wastewater treatment plants—where biogas utilisation is viable—were selected according to the amount of livestock units. In terms of the storage, the location of the existing gas grid was in the scope of the study. According to SCHNEIDER, L. – KÖTTER, E. (2015), it was assumed that the maximum distance to the gas grid is 5 km. This buffer distance was used in this research, as well.

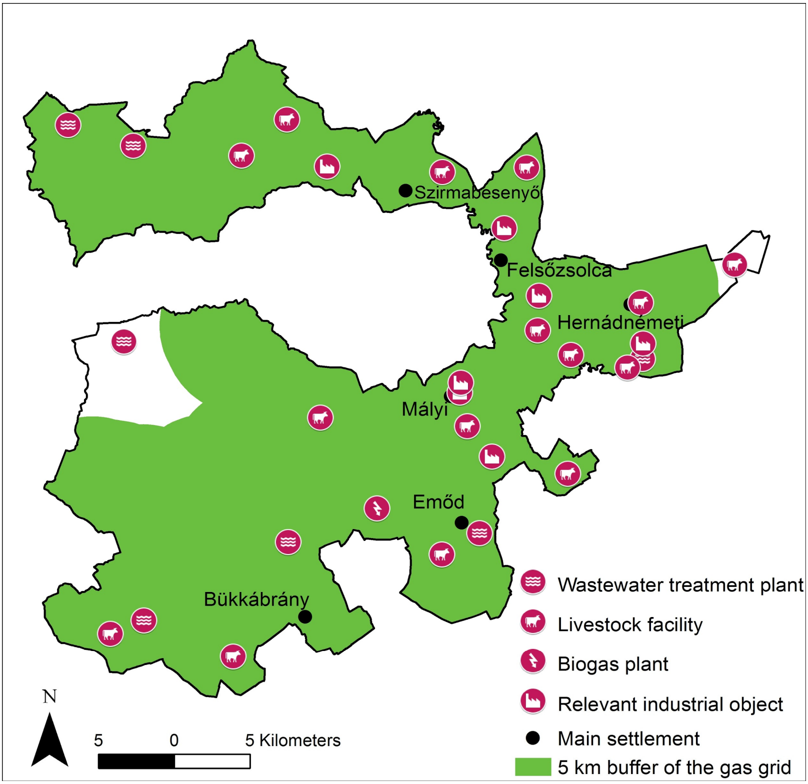

Figure 5 – Potential CO_2 sources for P2G facilities in the Bükk LEADER rural development region

Edited by HARMAT, Á. (2016)

As for the results, in the research area there are *26 potential sites (Figure 5)* within the 5 km buffer of the natural gas grid system (namely 1 biogas plant and 7 industrial objects where surplus CO_2 could be captured; 3 wastewater treatment plants and 15 significant livestock facilities where surplus CO_2 capture is possible) and *3 planned units* (wastewater treatment plants) seem appropriate as possible sites for P2G storage facilities, most of them is situated in the eastern part of the area.

2.2. Compressed Air Energy Storage

Compressed Air Energy Storage (CAES) is a promising technology for future electric grids that may help to compensate the unbalanced generation of renewables and consumption of power. A CAES facility can be effective with a coal and nuclear energy based electricity system, however the most impressive is cooperated with wind or solar farms which production depends on the weather circumstances (LUND, H. – SALGI, G. 2009). The importance of this is meaningful considering the energy and climate strategy of *European Union* for 2020 where renewable energy sources have higher (20%) participation in final energy consumption, while renewable electricity already contributed to 27.5% of total electricity consumption in 2014 (DA GRAÇA CARVALHO, M. 2012). Among all forms of energy storage some are still under development or are on pilot project level. When considering each technology, there is no absolute best one, implementation depends on location, purpose and costs. In consequence, there will be a chance to find the most appropriate technology after analysing each location or business case individually.

On the one hand, a CAES plant fits well in a more sustainable electricity system that minimises losses and fuel usage. Current pilot projects of CAES plants on some occasions suggests more than 80% round trip efficiency (JOHNSON, P. M. 2014). On the other hand, a CAES system should be suitable in international electric grids and make advantage of price arbitrage (LUND, H. – SALGI, G. 2009). The latter authors made an analysis about some energy storage systems like CAES, EB (electric boiler), HP (heat pumps), ELC (electrolysers), an H_2 electrolysers for comparison. They determined that CAES plants may can be parts of the future electric grids. CAES is not the only solution, however because other options—like batteries or P2G—might be more attractive in the long run.

2.2.1. Brief History

Currently there are two working CAES plants worldwide with an installed capacity of 431 MW. The timeline on *Figure 6* shows the evolution of CAES technology.

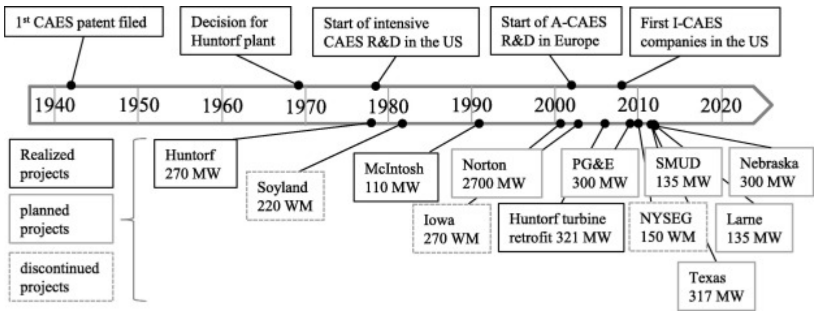

Figure 6 – Timeline of CAES R&D and industrial efforts; projects are not exhaustive and limited to the largest installations

Source: Budt, M. et al. (2016)

The first finished plan and patent appeared in the *USA* in the 1940s but the first CAES plant had been planned and constructed in *Huntorf*, *North Germany* only in 1978. The idea of energy storage occurred partly due to the first oil crisis in 1973 and was even more attractive after the second crisis in 1979. Reliable operation of the German facility spread interests in the *USA* and the CAES got into the sight of R&D. New technologies were developed to reduce the fossil fuel dependency. There were plans to construct a CAES facility in the *USA* and in 1991 the first one came into operation in *McIntosh*, *Alabama*, which draw attention to the technology again. For example, in the states of Tennessee and Hawaii the technology got in sight, but it remained only on the level of plans. In *Norton*, *Ohio* state, another one was planned through delays and proprietor changes so far it was not constructed. *Seneca project* had a similar way until its cancellation in 2012. There are plants which are under planning process both in the *USA* and *Europe*, the details of these running and planned CAES constructions are summarised later in this paper. So, besides some very small (1–2 MW range) plants, no utility sized CAES facility was built since 1991 (BUDT, M. *et al*. 2016).

2.2.2. Technologies

Figure 7 shows a simple, fundamental diabatic CAES (D-CAES) process.

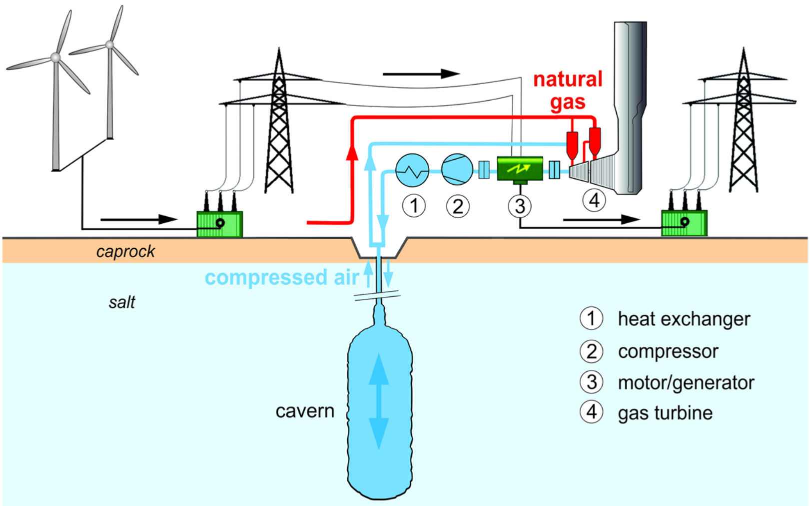

Figure 7 – Schematic illustration of a D-CAES plant
Source: KBB UNDERGROUND TECHNOLOGIES (2014)

Diabatic in this situation means that excess heat during air pressurisation (energy storage mode) is released without thermal storage and during expanding process, the air has to be heated up by external energy (for example natural gas). The basic idea is similar to most of the other energy storage alternatives. The process starts in the off-peak periods (typically at nights) or when generation is high, but consumption is low. The latter often occurs as a consequence of high solar and wind energy penetration connected to the grid. In this situation, a compressor pumps air into a reservoir/air storage where the gas is pressurised, thus stored in the form mechanical energy. In peak demand periods the stored air is released, and while expanding it goes through a turbine that is connected to an electric generator. According to the laws of thermodynamics, as air loses pressure and expands (its volume grows), its temperature decreases rapidly and to avoid freezing in the case of D-CAES air is usually heated up using combustion of fossil fuels, thus making it inefficient and environmentally damaging. *In spite of using natural gas as a means of heating air up, a typical CAES facility releases 80% less CO_2/MWh than a coal fired* and about 45% less than a natural gas fired *power plant* (AzRISE, 2010)**.** The next step of the exhausted air (natural gas mixture) is to spin up a turbine and finally to leave to the environment. The turbine drives a generator that produces electricity for the national or local grid. This is a simple description of a diabatic-CAES plant. However, in the last approximately 70 years of development and research of compressed-air energy-storage more and more developments were created, variances for higher efficiency, lower emissions and cost effectiveness.

When developing higher efficiency CAES systems the main direction is to create a plant that is more sustainable in both environmental and economic terms. The most crucial problem is reheating expanding air that would otherwise cool down. Solutions had been found by R&D programs which may be able to solve this issue.

Adiabatic-CAES (A-CAES) focuses on storing thermal energy that accumulates during the compression phase *(Figure 8)*. Correspondingly to D-CAES the process start with usage of the off-peak (or intermittent renewable) electricity that drives the motor of compressors. Air pressurisation happens in two steps by low and high pressure compressors. The arising heat energy can be captured in two ways: with or without thermal energy storage (TES). Firstly, without TES process the heat is stored in the air itself with a combined thermal energy and compressed air storage system. In consequence, the air becomes hot and it narrows the storage possibilities and steepen the prices. Understandably, there are no plans to construct one like this.

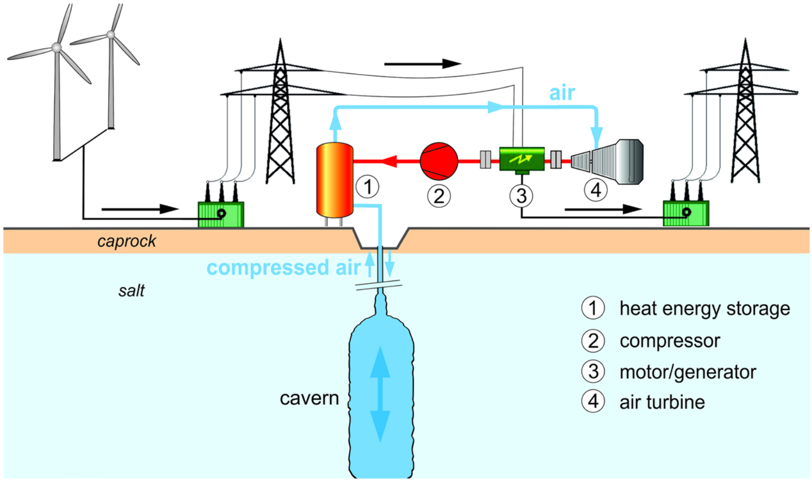

Figure 8 – Schematic illustration of the main elements of an A-CAES plant
Source: KBB UNDERGROUND TECHNOLOGIES (2014)

The other option (with TES) is to keep the heat in a separated tank. It is possible in three levels of pressure:

- High-temperature processes (above 400°C)
- Medium-temperature processes (between 400°C and 200°C)
- Low-temperature processes (below 200°C)

The heat storage media and the system can be different depending on the temperature. Solid storage media can contain more heat energy but liquid media is more mobile that gives the possibility of pumping it. Consequently, when it is on-peak period, the expanding air is heated up by the stored thermal energy. The advantage of the whole A-CAES process, therefore, is that it does not need external intake energy, this leads to higher efficiency and lower CO_2 emissions. At the end of this process the air escapes through a turbine and the generator generates electricity (BUDT, M. *et al.* 2016).

Isothermal compressed air energy storage, however, (I-CAES) pays attention to reduce heat energy by a specific compression process. It is supported by additional water which absorb and store heat energy.

During the expansion, the warm, heat container water is injected in cooling down air. The electricity production is like above mentioned ones (BUDT, M. *et al.* 2016).

2.2.3. Storage

Storage reservoir is a crucial part of a CAES plants, because the construction opportunity usually depends on the spot. There are three types of CAES plant by storage reservoir, the one which is least depending on the location is the one using an *aboveground tank*. This is a favourable technology on the view of mobility because it is almost always possible to settle close to a solar or wind farm to shorten the electricity transport distances. The disadvantages of this storage are mainly the size and volume limits comparing to a natural geological reservoir. In short, it gives opportunity to create a mobile, but expensive and relatively small CAES plant. The most spread out technology is underground air storage. It has two types depending on underground storage formations. The two working plants are implemented into *salt caverns,* that is the most known type of underground air storage. However, salt caverns are very infrequent geological formations (salt domes especially), so there is not so much spot where it coincides with (intermittent) renewable generation. Another type could be *porous rock aquifers*. There are no working plants implemented into this, but research shows possibility of further development (HAVAS, M. – HRENKÓ, I. 2015). In short, the underground storage largely depends on location, but it usually has a nature created, large store capacity that can be used with relatively low costs. Some of these geological formations are used as natural gas storages, which might be transformable to a CAES plant. Finally, there is a yet relatively unknown storage idea: underwater compressed air energy storage. This "emphasizes a solution for storing the compressed air that employs bags under waterbodies using the hydrostatic pressure to keep the air stored" (GALLO, A. *et al.* 2016). The technology still requires to be researched, but it may become a relevant future possibility (GALLO, A. *et al.* 2016).

2.2.4. Operating plants

There are two working CAES plants worldwide as mentioned earlier. *Huntorf plant*—with its 321 MW installed capacity—was the first constructed compressed air energy storage plant in the world. It works by the process of the diabatic CAES technology. Due to this there is energy loss at the compressing phase which demands additional heat source at the expansion phase. However, the two-staged compression used in *Huntorf* technology reduces this deficit. The compressed air is stored in two solution mined salt caverns with 310,000 m^3 total capacity. These two caverns allow the plant to be maintained and run at the same time. In 2006, the expansion turbine was retrofitted for a more efficient one, so installed capacity reached 321 MW from the previous 290 MW.

13 years after the first CAES plant, another D-CAES facility with 110 MW of installed capacity was implemented in *McIntosh*, *Alabama*, *USA*. Storage capacity is higher than in the *Huntorf* one (26 hours of nameplate capacity with ~2,800 MWh storage capacity, while only 3 hours of nameplate capacity in *Huntorf* with ~1,000 MWh of storage capacity), but it has only one large cavern in an abandoned salt mine. It works with diabatic process, so there is no heat storage device. Like previously mentioned, the energy loss is reduced by a multiple stage compression system. In this system, the usage of an exhaust-heat recuperator poses the main difference and advancement compared to *Huntorf*. The recuperator is applied as a simple form of exhaust heat recovery to limit the exergy losses which would come from the hot exhaust gas (GALLO, A. *et al.* 2016).

In recent years, no utility sized CAES facilities were built, however, there are good examples of decentralised CAES plants like the one in *Gaines*, *Texas*, *USA* that uses no external energy source and has a rated power of 2 MW. The *Huntorf plant* went into reserve as there is no business case for it in *Germany*, because renewable generation and imports tend to be a cheaper option (GALLO, A. *et al.* 2016).

2.2.5. Opportunities in Hungary

The installed intermittent renewable energy capacity is still in a low level in *Hungary*. However, some energy storage plants can be effective with the current energy mix, too. Especially if we check the European trends and the aims of *EU* then the research of energy storage possibilities will be indispensable in the following decades. In the case of underground CAES the main restrictive point is the underground geological formation itself. In *Hungary*, there is no countrywide research about rock formations focusing especially on compressed air storage. The salt dome storage is not possible, because that is not exists in *Hungary* (SUCCAR, S. – WILLIAMS, R. H. 2008). On the one hand, the porous rock formations usually occur. On the other hand, most of them also not measured for compressed air storage. For northwest *Hungary* however, there is a research about the underground storage conditions and possibilities of creating a CAES plant. This survey was created by HAVAS, M. – HRENKÓ, I. (2015) They worked with water drillings, and they appointed 7 eligible rock strata were suitable out of the 16 examined ones. These are in *Győr–Moson–Sopron County* (2), *Vas County* (3) and *Zala County* (2). They mentioned that a more comprehensive location based research would be a necessity. This survey also compared the available locations of CAES plants and wind turbines and the 7 suitable locations are close to the competent wind energy production spots. This article can be a base to plan CAES plants in *Hungary*, but the examination cover only a part of the country. There is no another survey, but underground gas reservoirs may be able to store compressed air, too. This is confirmed by ZSCHOCKE, A. (E.ON Innovation Center Energy Storage), who saw CAES as a possible energy storage system, and he also mentioned their four gas storage in *Hungary* (ZSCHOCKE, A. 2012). The problem can be the size of the previous and other reservoirs in the country, because these are much larger than the ever constructed or planned compressed air storages.

With decentralised CAES facilities—like the one in *Texas*—implementation in the *Bükk LEADER rural development region* could be possible. Such a small (~2 MW) facility would not need an underground reservoir or a large area, so taking it into consideration is essential.

2.3. Liquid air energy storage

The use of liquid air as energy carrier has been studied since 1900 with the first liquid air car application in the *USA*. *Liquid air energy storage* (LAES) is a much younger methodology which dates to 1995, as “liquid air storage energy system” (KISHIMOTO, K. *et al.* 1998). It uses the air as an energy storage medium and applies the natural law that air can be turned into a liquid by cooling it to a very low temperature, around –196°C. Therefore, it sometimes is referred to as *Cryogenic Energy Storage* (CES). The liquid air can then be stored in a relatively small unpressurised insulated vessel—as 700 litres of ambient air becomes about 1 litre liquid. When heat is reintroduced to liquid air, it boils and turns back into gas, expanding 700 times in volume. This expansion can be converted into electricity or mechanical energy by a reciprocating engine or a turbine (STRAHAN, D. [Ed.] 2013) or *Organic Rankine Cycle technology* (MORGAN, R. *et al.* 2015). The expansion process can be boosted by the addition of low grade waste heat (cooling water of power stations, factory process heat up to 100–150°C), which significantly improves the energy return (KANTHARAJ, B. *et al.* 2015). It is also possible to use waste cold (mainly from regasification of *Liquid Natural Gas*) during the cooling process.

In practice, there are two main ways of LAES research, the first one deals with *ambient air*, the other focuses only on *nitrogen*, the main component (78%) of the Earth-normal air. The industry has a significant surplus of gaseous nitrogen that could be made available for liquefaction.

LAES can be a competitive storage alternative in applications above 50 MW and for storage durations from 2–20 hours. According to the calculations of an industrial player *(Linde)*, a 1600 m^3 liquid air tank can store about 220 MWh of electricity.

There is also an interesting future development possibility to create a hybrid thermodynamic system of CAES and LAES in order to convert compressed air to liquid air and back with heat pump and heat engine with a relatively high efficiency (KANTHARAJ, B. *et al.* 2015).

2.3.1. Existing projects

The LAES technology is in a pre-commercial, demonstration phase *(Figure 9)*. A first significant *pilot project*, called *Highview Power Storage*, was located in *Greater London*. This small unit could provide to the electricity grid 350 kW power with 2.5 MWh storage capacity between 2011 and 2014. In order to increase the system efficiency, waste heat was used from the neighbouring biomass power station. The plant was relocated to the *University of Birmingham (Centre for Cryogenic Energy Storage)* in 2015.

A much bigger *pre-commercial project* is under construction in *Greater Manchester*. Its capacity will be 5 MW/15 MWh. The waste heat supply will be provided by the gas engines of the nearby landfill site.

Figure 9 – Pre-commercial demonstration plant
Source: HIGHVIEW POWER STORAGE

In a next phase, a *full commercial* design could be built up to 200 MW capacity, presumably within 3 years.

The benefits of the LAES are:

- theoretically it can be located almost anywhere *without geological constraints* and risk—*Figure 10* (STRAHAN, D. [Ed.] 2013a; KANTHARAJ, B. *et al*. 2015);
- it uses existing mature components;
- it does not need a special pressurised storage vessel;
- it has a relatively large volumetric exergy density at ambient pressure.

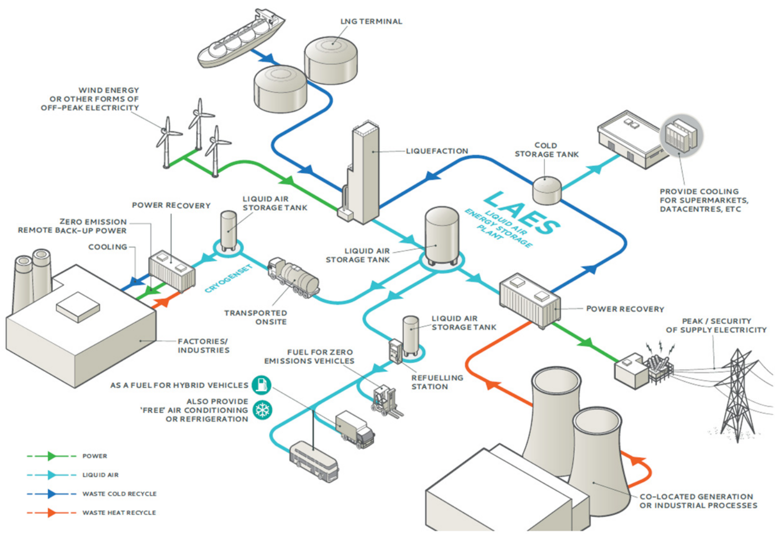

Figure 10 – Optimal location of a LAES facility showing the significant geographical constraints of a system
Source: STRAHAN, D. (2013b)

Its drawbacks are:

- it works in very low temperature, which requires insulated storage tank;
- cryogenic liquids present significant hazards because of their intense cold and substantial gas production when warmed;

- in a simple design, the system has lower roundtrip efficiency (~50–60%) than other energy storage technologies;
- to improve the efficiency with waste heat or/and waste cold utilisation, it is important to locate to nearby proper industrial sites (STRAHAN, D. 2013a)—which means a strict *geographical constraint (Figure 10)*.

On the whole, a geographical site optimisation needs to consider several factors. Most importantly the LAES plants need to be located near to *weather-dependent renewable* (wind and solar) energy applications, in order to provide storage possibility for them without significant energy loss. The distance from the *electricity grid* is also substantial factor in order to limit the electricity loss. To improve the storage system efficiency the most relevant need to build LAES projects in the vicinity of significant *waste heat* producers.

2.3.2. Geographic Aspects

To assume the geographic potential sites of LAES facilities in the study area, industrial objects with surplus heat production were identified. With the lack of such a database, the scale of the industrial production in the municipalities were concluded from the amount of paid business tax. Municipalities where the annual income from business tax was higher than 65,000 Euro were examined, and the potential industrial objects were identified according to their profiles. In the next step, the location of relevant facilities was registered in the GIS software. It was assumed, that the surplus heat can be transformed within 3 km. From the 3-km-radius buffer area restricted areas were extracted, such as forests, conservation areas and landscape protection areas.

As for the results, in the research area 7 potential sites (such as a brewery; a pharmaceutical company; chemical and brick factories) and a geothermal pipeline (with two geothermal wells) were identified as significant heat sources, therefore potential sites for LAES applications in the future *(Figure 11)*.

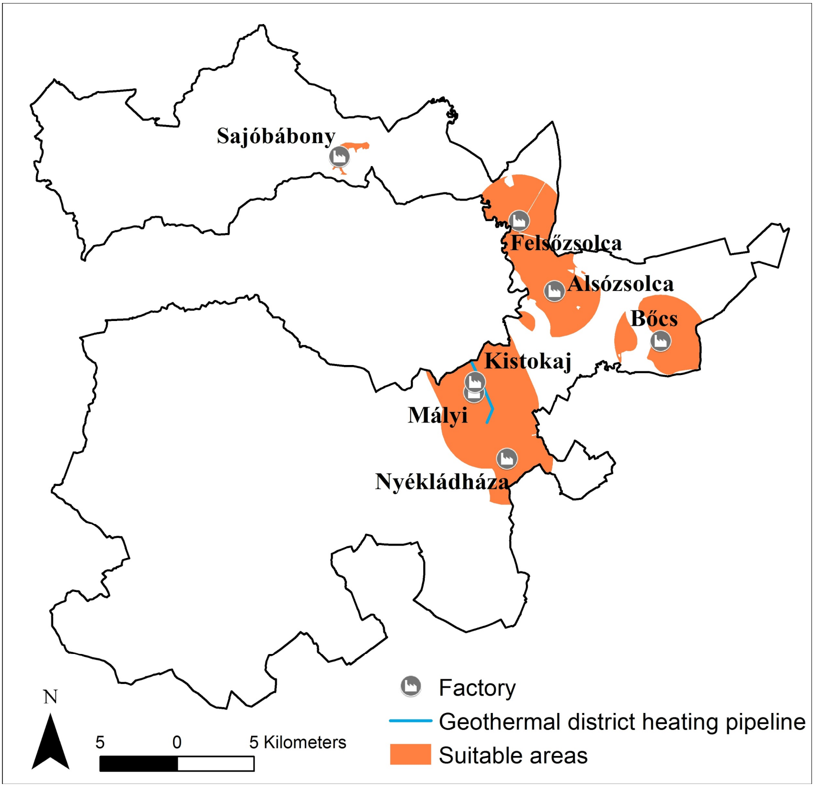

Figure 11 – Suitable area for LAES facilities in the Bükk LEADER rural development region
Edited by HARMAT, Á. (2016)

2.4. Pumped-hydro Energy Storage

Pumped Hydro Energy Storage (PHES) is currently the most widely used large scale energy storage technology, providing *99% of the world's ES capacity* (SAUHATS, A. *et al.* 2016), with 164,630 MW of total installed capacity and around 320 projects worldwide (energystorageexchange.org). The advantages of this system are:

- mature technology (over 120 years of experience);
- long lifetime (40–80 years);

- limited quantity of pollutant emissions (methane—from biodegradation; CO_2—considering the whole lifecycle);
- provide ancillary grid services.

As for the disadvantages, large capacity usually demands large flooded areas which can be a major environmental problem. Solutions with small size applications can reduce the environmental impacts and it also can provide the possibility of decentralised utilisations in microgrids.

PHES requires two water reservoirs in different elevations, connected with a pressure tunnel *(Figure 12)*. Operational projects have 100–500 m water level difference in average, with maximum 2–3 km horizontal distance. Ratio of these two parameters cannot exceed 1:10 to keep up the optimal water flowing speed to run the turbines. Reservoirs can be natural (lakes or rivers) or artificial water bodies, even existing ones. Just like other storage technologies, PHES uses electricity to pump water to the upper reservoir in off-peak periods, or when the renewable energy sources generate more electricity than the consumption of the demand side. This can be converted back (so-called 'discharging') when it is needed, for example peak-periods or when grid regulation is required (CAVAZZINI, G. – PÉREZ-DÍAZ, J. I. 2014). Their efficiency is from 65% up to 85% at recent projects (AENKE, M. – WANG, M. 2016). The newest pumped storage stations use reversible pump-turbine/motor-generator assemblies, in which case water can flow in both directions according to charging or recharging phases. In general, the running projects have a generating capacity between 100 MW and 1,000 MW, however it could be 3,000 MW (KÁDÁR, P. – VAJDA, I. 2010). The amount of stored energy is mainly based on the volume of the water reservoirs. Other factors are

- the head difference of the reservoirs;
- turbine efficiency;
- the ratio of total length of the pressure tunnel and the height difference between the water levels of the reservoirs (LEVINE, J. 2011; ARÁNTEGUI, R. L. *et al*. 2012a).

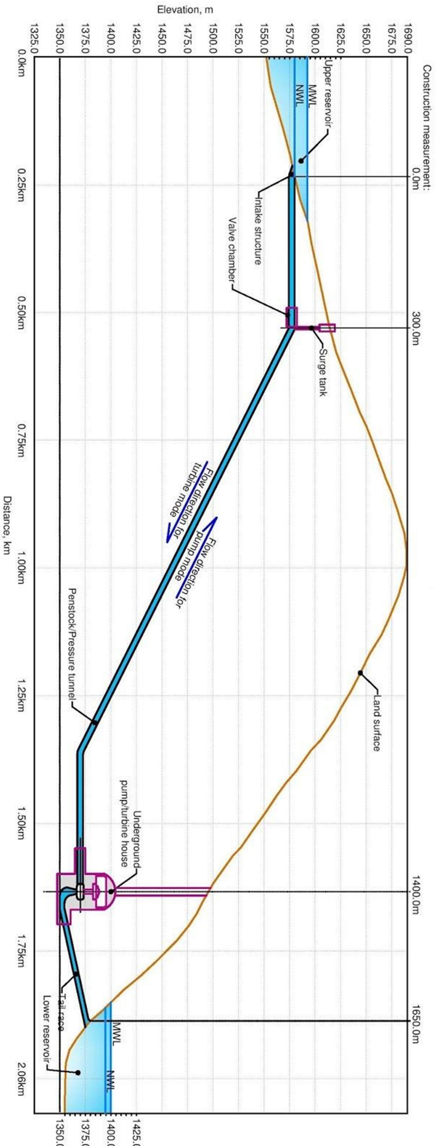

Figure 12 – Basic scheme of a PHES plant

Source: BADARCH, A. (2015)

2.4.1. Recent situation in Hungary

Despite many PHES construction plans from the 1970s to recent days, *Hungary* still does not have any operating plant. In the background, there are mainly financial shortages and the negative environmental effects of the planned projects. The suitable construction sites are situated mainly in the mountainous regions of *Hungary*, among others in the *Danube-band* and in the *Zemplén Mountains (Table 3)* (SZEREDI, I. 2011). Due to the significant planned capacity, the water reservoirs would take large flooded areas as well (38–169 hectares), which also means *higher environmental impact* on natural areas, some of them are protected.

Table 3 – Some of the potential construction sites for large scale PHES in Hungary. *The area data means only the upper reservoir, considering only technical aspects*

Source: SZEREDI, I. (2011)

Region	Site	Area	Planned capacity
Danube-band	Keserűs Hill (Prédikálószék)	38 ha	600+600 MW
Danube-band	Urak asztala (Dunabogdány)	137 ha	600+600 MW
Danube-band	Naszály quarry (Vác)	108 ha	600 MW
Zemplén Mts.	Aranyos Valley (Sima)	85 ha	600+600 MW
Zemplén Mts.	Nagykopasz Hill (Tokaj)	129 ha	500 MW
Zempléni Mts.	Hideg Valley (Szerencs)	92 ha	600+600 MW

2.4.2. Geographical aspects in site location

Using GIS applications, it is possible to effectively investigate ideal sites, due to raster-based remote sensing and other vectorised data. Using the above mentioned information, GIS methods can be used to specify the suitable sites for the water reservoirs.

In European level calculations have already been made for *Croatia* and *Turkey* by the *European Commission*'s *Joint Research Centre* (JRC). The JRC has developed a GIS tool to find the *existing water reservoirs* which can be transformed as potential parts of PHES (ARÁNTEGUI, R. L. 2012b). In this research, the GIS model used to investigate pumped storage potentials was similar to the methodology of the JRC. However, it was not limited to the existing water bodies, but more focused on *smaller storage reservoir sites* in order to redound the integration into the future microgrids, preferring the decentralised aspect. The data used were:

- Digital terrain model;
- Land use–Corine Land Cover (CLC 50) database;
- Settlements;
- Infrastructure components (roads, railway lines, transmission lines);
- Surface hydrography;
- protected natural areas at regional, national, and *EU* level.

The study was made by using *ArcGIS software*, contains 32 major steps. The main steps, in a shortened way, were the following:

- creation of the digital terrain model and slope maps of the study area;
- erasing the area of settlements, infrastructure, and other land use categories, except agriculture and natural habitats;
- selecting of the polygons close enough to water and transmission lines access (2 km and 10 km respectively), and creating pairs by filtering their head/length ratio (min. 1:10) and energy capacity (min. 60 MWh, calculating by 6 hours of operation with a 10 MW turbine capacity);
- reconsidering the results with all the protected natural areas (national parks, NATURA 2000, etc.) in order to promote the energy related developments without the loss of ecological values, moreover, creating higher ecological diversity within the existing ecosystems with new water bodies (PATOCKA, F. 2014).

According to the results, the study area contains significant number of suitable sites as a potential to construct *small scale* PHES water reservoirs. The exact quantity correlates with the slope category, therefore two different calculations were made considering *0–5° and 0–7.5°*

slope categories, respectively. It was also important to consider an *appropriate elevation* (at least 100 metres) as well as a maximum *distance* (2,500 metres) between the potential reservoirs *(Table 4)*.

Table 4 – Small scale PHES reservoir potentials at the study areas (with 10 km buffer zone of the study area), and different assumptions on slope

	Bükk <5°	Bükk <7.5°
Total (number of sites)	78	160
Total area (hectares)	5,852	7,584
Protected (number of sites)	53	109
Not protected (number of sites)	**25**	**51**

The '<5° sites' represent 1.6%, the '<7.5° sites' represent 2.5% of the whole study area (92,563 hectares). Despite the high amount of protected natural areas, there are enough sites remaining for construct in both cases. Based on the <5° model version, suitable sites mainly occur near valleys and ridges, such as vicinity of *Sajókápolna*, *Tardona* and *Tibolddaróc*. Average capacities are 10–15 MW with 100–180 m head between the PHES reservoir pairs. To the south of *Tibolddaróc*, the large suitable area presented by the model means that it is possible to choose the best site for construction within *(Figure 13)*.

The presented model can be developed in many ways:

- more versions can be made by modifying the calculation criteria;
- with the data of the existing water reservoirs (location, volume) the model can more focus on existing water storage basins (JRC method) in order to reduce the construction costs;
- using *ArcMap Model Builder* function, the methodology could be applied to any areas to investigate PHES water reservoir potentials.

2.4.3. Conclusion of the GIS research

In comparison to large-scale solutions, the methodology provides much more results in case of small size reservoirs. It also means that the site selection proved to be much easier in case of smaller projects. The small scale PHES seems to be a proper solution for the integration of intermittent renewable energy sources, such as wind and PV. Furthermore, thanks to the limited area demand, negative environmental effects can be minimised.

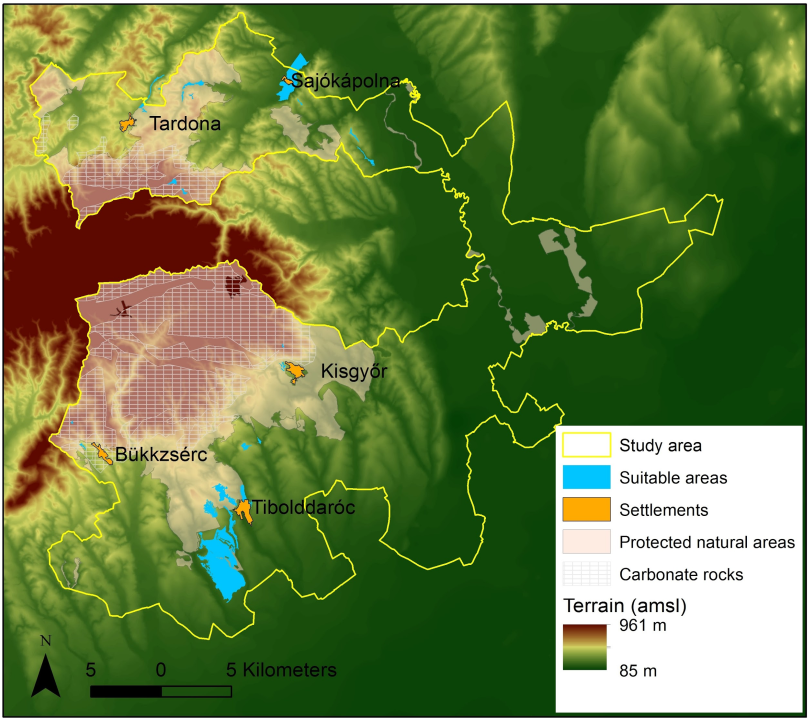

Figure 13 – Map of potential reservoir sites (<5°) for PHES in the Bükk LEADER rural development region
Edited by S*OHA*, *T. (2016)*

3. Summary & conclusion

The whole energy system needs to be rethought and rebuilt at national, regional and local levels. In a *sustainable energy transition*, the different kind of decentralised energy production and storage applications seem to be significant parts of this profound development. According to this research, in the *Bükk LEADER rural development region* all the four of the examined technologies would be applicable; thus, contributing to the rural development, as well as energy autonomy of the area *(Figure 14)*.

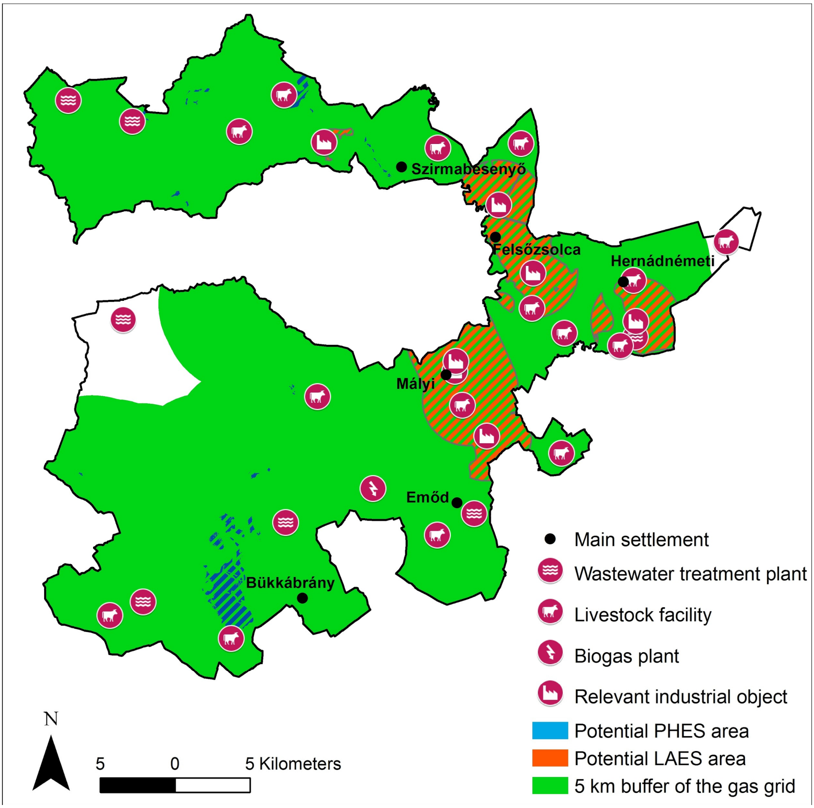

Figure 14 – Potential PHES, LAES and P2G facilities in the Bükk LEADER rural development region

Edited by H*ARMAT*, *Á. (2016)*

As far as *underground geological formations* concerned P2G and CAES facilities have very similar technical parameters regarding strata, as storage media. However, implementing a P2G facility into a given geological formation could be more beneficial, due to higher energy density when storing hydrogen or methane comparing to storing compressed air. In such a situation, another reason to prefer P2G is the multifunctionality of its stored product (hydrogen, or synthetic natural gas), that can be used as fuel for turbines generating electricity, as fuel for transportation or it could straight be injected into the national gas grid.

Another possibility could be the conversion of *existing natural gas storage facilities* into CAES or P2G technology. As the composition of the stored gas is basically the same in the case of P2G (methane), this kind of conversion would be technically feasible. In the case of CAES systems, however, the storage media cannot contain any hydrocarbons so implementation of a CAES system into an existing natural gas storage system is both technically and financially challenging.

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INFORSE-Europe is organising a European NGO Seminar at the Nordic Folkecenter for Renewable Energy in Denmark between the 21st and the 24th August 2017.

The Seminar is focusing on transition to sustainable energy, community power and development of ideas for how we can push the transition forward with new initiatives and projects. After the Seminar, INFORSE-Europe has General Meeting on 25 August 2017.

INFORSE-Europe meeting in Samsø, Denmark in 2010
Photo by INFORSE-EUROPE (2010)

From the Program:

- Transitions to Renewable Energy in European Countries, both in 'West and East'. Examples from *Armenia*, *Belarus*, *Denmark*, *France*, *Macedonia*, *UK* and *Ukraine*;
- Local sustainable energy/community power projects (for example wind and solar energy, community heating) Examples from *Denmark* and *Serbia*;
- How EU regulations and support give a common framework to the transition;
- Fundraising;
- Developing 'Our Own Ideas' for projects and activities;
- Guided Tour at *The Nordic Folkecenter*;
- INFORSE-Europe's General Meeting (25 August);
- Celebration of 25 years networking.

Participation Fee includes accomodation and all meals. (200 EUR in double rooms, 110 EUR in dorm or own tent, 300 EUR in single rooms)

Signing Up: Please send the *Application Form* via email to ove@inforse.org

More information, updated full programme, and the application form are available at http://www.inforse.org/europe/seminar_17_DK.htm

Information for New Authors

Geographical Locality Studies (GLS) is the official journal of *Frugeo Geography Research Initiative* registered in the *United Kingdom* as print serial (ISSN 2052-0018) and online (ISSN 2053-3667) materials. It is a scientific journal that sets its specialist area in locality, sustainability and environmental topics. It is currently issued and published annually, and each number is planned and developed by a specially selected, international editorial board that consists of expert researchers, lecturers, and peer-reviewers.

GLS aims to erect a bridge between academic research and general educational knowledge development; that is why its target audience involves a wide range of students from secondary to doctoral schools, young researchers and anybody from any background who wants to know more about locality and sustainability-related environmental and geographical topics.

Supporting this aim, *Frugeo GRI* invites ambitious researchers to join the success of our projects and to be an original and significant contribution to the human knowledge of *Earth* and *Environmental Sciences*. We provide publication possibilities to academics who have already earned a PhD degree; and we would like to highlight the importance of education and give the chance and opportunity to PhD Students, and also MSc/BSc Students, to help them gain recognition, points and credits, and assist in their scientific life getting an easier start on the, often difficult, path of publishing and academic writing.

We provide opportunity for publications to researchers, although we do accept only outstanding papers; therefore, a published work in one of our upcoming issues has to be of a high standard, must be well-researched, well-illustrated and well-written in an engaging style that can call the attention of anyone who reads it. It must be something interesting, topical, and must contribute to the development of any scientific disciplines. It also has to be educative and build a good balance between academic and public understanding.

Our journal covers many different types of—mainly geographical—subjects; therefore, we encourage and approach anyone who acts outside the fields of *Earth* or *Environmental Sciences*, too. For the upcoming titles and publishing possibilities, please keep an eye on our regularly updated websites (www.frugeo.science / www.frugeo.eu) or contact us (global@frugeo.science).

In order for an article to be published, the author(s) has/have to follow our instructions and must achieve the expected standards of *Geographical Locality*

Studies. In special cases, the requirement is defined according to the project expectations, but mostly we want an article to be:

a.) prepared by

- one individual author, or by
- up to ten co-operating authors;

b.) written in

- British English, and
- the majority of the paper in Passive mode;

c.) be one of the following types:

- Original articles in basic and applied research,
- Critical reviews, surveys, opinions, commentaries and essays;

d.) and follow this structure:

- Abstract (1000–1200 characters with spaces) + 5 key words;
- Introduction;
- Aims of the study;
- Research methods;
- Results;
- Discussion;
- Conclusions;
- Acknowledgements;
- Reference list or/and bibliography (This has to be prepared by using Harvard referencing. See examples on *Frugeo*'s website.).

Anybody wishing to contribute in one of the upcoming GLS projects, please send a fully prepared manuscript via e-mail with the following information provided to global@frugeo.science:

- Title;
- Full name;
- Highest academic degree;
- Workplace / Institution;
- Position;
- E-mail address;
- Contact telephone number;
- Paper's working title;
- Along with your registration, please prepare an abstract no longer than 1,000 characters with spaces and include at least 5 key words.

In 2015, we decided to make the journal participation available for everyone free of charge; although, we would welcome any amount of donation from every participant. Donations can be made voluntarily through the Frugeo websites.

We guarantee that every paper will be

- read by professional and fully independent reviewers (peer reviewers);
- they will be proof-read;
- the authors will be given as much extra help as possible;
- the book will be published;
- the book will be available in a print copy as well as online;
- the online edition will remain free of charge;
- it will be distributed and
- every participant will receive a copy at no extra fee.

If you would like to be considered for our offer or if you have questions regarding the publication possibilities or the GLS project, please contact us instantly.

We look forward to hearing from you!

Frugeo Geography Research Initiative
Shrewsbury, United Kingdom
www.frugeo.science
global@frugeo.science

Upcoming and proposed projects:

- (2017) Water Challenges of the 21st Century
- (2017–2018) Sustainable Tourism Practices
- (2018) Holistic Approach to Environment in the Himalayan Region

More details and project updates are available at www.frugeo.science/gls.html

Notes

A Short Introduction to Frugeo GRI

Frugeo Geography Research Initiative is a friendly and down-to-earth educational, researching, editorial, designing and publishing enterprise that specialises in Earth Sciences (Geography, Geology), Environmental Sciences, Mathematics and Fine Arts. This academic venture was established in *Wolverhampton (England)* on the 20th November 2011 by *László Bokor*. In 2012, the business moved to *Shrewsbury*. *Frugeo GRI* operates internationally and have academic connections in several European and Asian countries including *Germany*, *Hungary*, *Romania*, *Slovenia*, and *Sweden*, and *Bhutan* and *India* respectively.

Frugeo GRI currently offers a wide range of expedient services focusing mainly on home tuition, personal education, research and survey, technical editing and design, and publishing.

Frugeo GRI encompasses qualified and experienced teachers who have met a diverse range of people with variable needs. They can help pupils and students in all key stages and levels. The diverse subject specialism makes *Frugeo GRI* able to teach more than just Earth Sciences. They have got experience in teaching Mathematics, Environmental Sciences, and special Arts subjects.

Frugeo GRI is expert in *World Regional Geography* representing a wide range of geographical fields that includes subjects from both Physical and Human disciplines. They can help clients understand the principal connections between *Physical* and *Human Geography*, and can teach methods to combine different fields. They can help improve geographical thinking and find the right path to a competitive, comprehensive and practicable knowledge about the *World*. *Frugeo GRI* also offer comprehensive book publishing services.

They are also professional researchers who can help their clients to understand the concepts of academic writing and scientific research. They can help with researches, can proofread and edit manuscripts, perform technical editing that is required for works to become a properly designed home assessment, dissertation or a published book.

László (left) and Angus of Treetec (right) on the rooftop of HMP Shrewsbury surveying bats
Photographed by Frugeo GRI (2016)

Katie (left) and László (right) in front of the Frugeo headquarter
Photographed by Frugeo GRI (2016)

More information can be obtained from www.frugeo.science

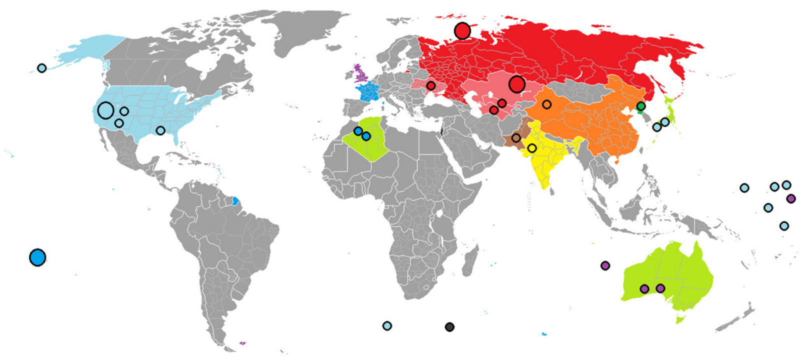
Nuclear Weapons and Power Stations – In the Shadow of Atomic Energy

GLS 4 Timeline Photo Credits and Copyrights
Collected by Tihamér Kovács & László Bokor

(1) 1945 / New Mexico, USA, 'Trinity' test site

First detonation of a nuclear weapon carried out by the United States of America, as part of the Manhattan Project, on the 16th July 1945.

File is available at: Wikipedia (public domain)
<https://commons.wikimedia.org/wiki/file:trinitycolorlargerestored.jpg>



Red: Russia/Soviet Union; blue: France; light blue: United States; purple: United Kingdom. Over 2,000 nuclear explosions have been conducted, in over a dozen different sites around the world. Black: Israel; orange: China; yellow: India; brown: Pakistan; green: North Korea; and light green: territories exposed to nuclear bombs.
Source of text and image:
https://commons.wikimedia.org/wiki/File:Rael_Nuclear_use_locations_world_map.png

(2) 1945 / Hiroshima, Japan

During the final stage of World War II, on the 6th August 1945, the USA dropped a nuclear weapon on Hiroshima which was the first use of this kind of bomb for warfare. 'Little Boy' killed at least 70,000 people, mainly civilians.

File is available at: Wikipedia (public domain)
<https://commons.wikimedia.org/wiki/file:atomic_cloud_over_hiroshima.jpg>

(3) 1945 / Nagasaki, Japan

On the 9th August 1945, the USA dropped a second nuclear weapon, this time on Nagasaki, which was the last use of this kind of bomb for warfare. 'Fat Man' killed at least 40,000 people.

File is available at: Wikipedia (public domain)
<https://commons.wikimedia.org/wiki/file:nagasakibomb.jpg>

(4) 1949 / 'Semipalatinsk' test site, Kazakhstan (former Soviet Union)

Located in northeast Kazakhstan, the site was the testing venue of the Soviet nuclear weapons. The first explosion was carried on the 29th August 1949 called Operation First Lightning (known also as Joe-1). The Soviet Union conducted 456 nuclear tests here until its closure in 1989 with little regard on the local people or the environment.

File is available at: Wikipedia (public domain)
<https://en.wikipedia.org/wiki/file:joe_one.jpg>

(5) 1946 / Operation Crossroads, Bikini Atoll, Marshall Islands, USA

The first nuclear weapon testing operation that was carried out on the Marshall Islands, and the first to be publicly observed. The project involved two explosions: the first was Able on the 30th June 1946, the second one (as seen on the photograph) Baker denoted on the 24 July 1946.

File is available at: Wikipedia (public domain)
<https://commons.wikimedia.org/wiki/File:Operation_Crossroads_Baker_Edit.jpg>

(6) 1954 / Castle Bravo, Bikini Atoll, Marshall Islands, USA

The 1st March 1954 marks the date when the largest weapon the USA has ever tested. The Castle Bravo was at 15 megatons, the blast vaporised 3 islands and was 1,000 times the magnitude of the Hiroshima and Nagasaki nuclear weapons dropped on Japan in World War II. The fallout from this weapon has forever devastated the lives and the lands of the people of the Northern Marshall Islands.

File is available at: Wikipedia (public domain)
<https://commons.wikimedia.org/wiki/file:castle_bravo_blast.jpg>

(7) 1957 / Windscale (Sellafield), UK

The Windscale power station originally was built to support the plutonium and tritium production of the British atomic bomb project whilst generating electricity. The extensive use of the power station led to a fire on the 10 October 1957 which was the worst nuclear accident in Great Britain's history. The fire burned for three days and there was a significant release of radioactive contamination.

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<https://stock.adobe.com/uk/stock-photo/industrial-pollution-and-toxic-waste/65413579>

(8) 1979 / Three Mile Island, Pennsylvania, USA

The Three Mile Island meltdown was the USA's most significant commercial nuclear power station accident occurred on the 28th March 1979. The event brought forward an increased opposition to nuclear power.

File is available at: Wikipedia (public domain)
<https://commons.wikimedia.org/wiki/file:3mileisland.jpg>

(9) 1986 / Chernobyl, Ukraine (former Soviet Union)

It is believed that the Chernobyl nuclear power station disaster is one of the two nuclear energy accidents with the maximum classification on the International Nuclear and Radiological Event Scale. Due to decay heat, several days after the initial explosion on the 26th April 1986, radioactive steam was still released into the atmosphere. 30 years later (2016), the 'temporary' sarcophagus was replaced with a more secure one (as seen on the photograph) for the next 100 years.

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<https://stock.adobe.com/uk/stock-photo/chernobyl-nuclear-reactor-new-sarcophagus/86533357>

(10) 2016 / 'Child against nuclear energy'

"There is growing demand for renewable energy." (Lynn Good, Duke Energy)

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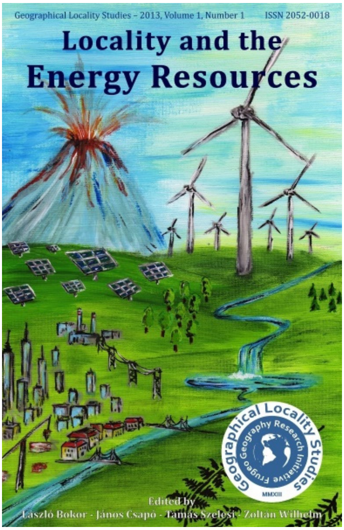
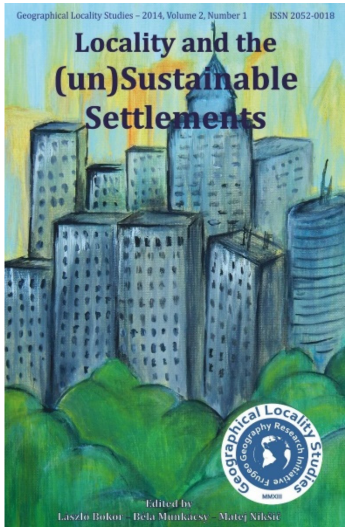
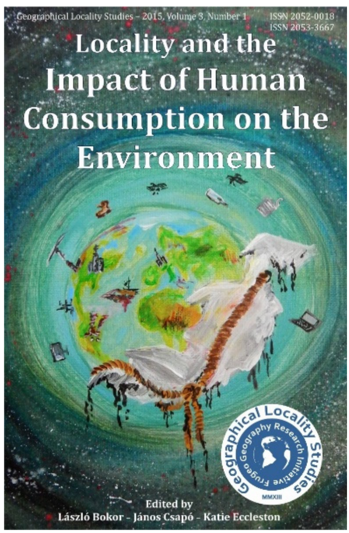
<https://stock.adobe.com/uk/stock-photo/child-against-nuclear-energy/35881169>



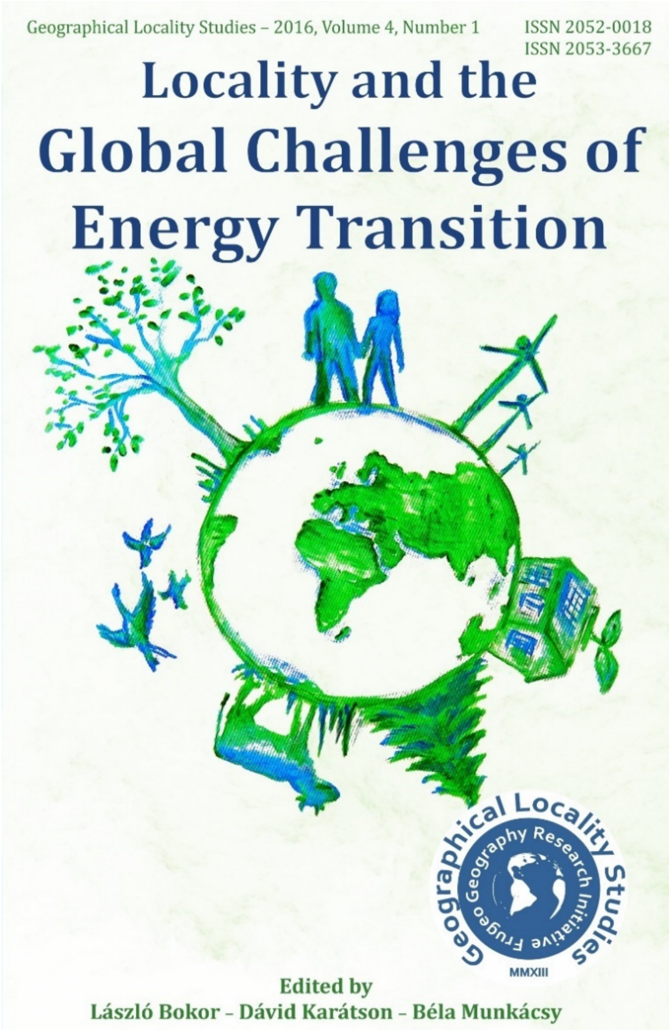




The online version of the previous *GLS* issues are available to download free of charge from the official website of *Frugeo GRI*.

Please donate!

Please visit: http://www.frugeo.science/gls.html



The online version of *GLS 4: Locality and the Global Challenges of Energy Transition* is available to download free of charge from the official website of *Frugeo GRI*.

Please donate!

Please visit: http://www.frugeo.science/gls4.html