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ÚSTAV ELEKTROENERGETIKY

CONVENTIONAL ENERGY SYTEMS IN NUMBERS
KONVENČNÍ A OBNOVITELNÁ ENERGETIKA V ČÍSLECH

BACHELOR'S THESIS
BAKALÁŘSKÁ PRÁCE

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1. Individual energy and electrical sources and their parameters, material and energy demand, definition of monitored parameters.
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3. Energy consumption and use of electricity in numbers.
4. Energy resources in the territory of the Czech Republic.
5. Proposal of power systems concepts for the Czech Republic together with their requirements.

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doporučená literatura podle pokynů vedoucího závěrečné práce

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Abstract

This work evaluates the potential future energy mixes for the Czech Republic. It presents data related to each of the available energy resources, focusing on electricity generation. Greenhouse gas emissions and other relevant parameters are weighted and used to rank a variety of proposals using a Pugh Matrix to quantify the scenarios objectively. A survey is used to capture the opinions of the public and to verify if the data available through research aligns with their views. Criticism is provided for the methodologies used to rank the scenarios, and recommendations are given on which should be discarded, and how to improve a repeat analysis.

Keywords

Energy Mix, Energy Resources, Electricity Generation, Greenhouse Gas Emissions, Renewables, Pugh Matrix, Czech Republic.

Abstrakt

Tato práce hodnotí možné budoucí energetické mixy pro Českou republiku. Uvádí údaje týkající se jednotlivých dostupných energetických zdrojů se zaměřením na výrobu elektřiny. Emise skleníkových plynů a další relevantní parametry jsou váženy a použity k hodnocení různých návrhů pomocí Pughovy matice, která umožňuje objektivně kvantifikovat scénáře. Pro zjištění názorů veřejnosti a ověření, zda se údaje dostupné prostřednictvím výzkumu shodují s jejími názory, je použit průzkum. Metodiky použité k hodnocení scénářů jsou podrobeny kritice a jsou uvedena doporučení, které z nich by měly být vyřazeny a jak zlepšit opakovanou analýzu.

Klíčová slova

Energetický mix, energetické zdroje, výroba elektřiny, emise skleníkových plynů, obnovitelné zdroje, Pughova matice, Česká republika.

Rozšířený abstrakt

Hlavním cílem této práce je poskytnout doporučení pro budoucí energetický mix v České republice. Za tímto účelem byl jako výchozí stav zkoumán stávající stav a příslušné parametry pro jednotlivé technologie, které by mohly tvořit budoucí mix.

Byla předložena analýza životního cyklu, která má čtenáři poskytnout dostatečné základní informace tak, aby byl schopen učinit vlastní závěry o výhodách a nevýhodách klíčových energetických technologií jednotlivých scénářů oproti seznamu kritických parametrů.

Pro stanovení vah všech důležitých parametrů, které by přispěly k úspěšnému rozhodnutí, byla použita Pughova matice poté, co byly vyhledány kvantifikovatelné číselné údaje, které by odůvodnily váhy, jež dostaly. Celkem bylo zváženo 39 parametrů a 12 potenciálních budoucích scénářů.

Mezi hlavní parametry patří environmentální faktory, jako jsou emise skleníkových plynů, využití půdy a materiálů a eutrofizace vody, dopady na člověka, jako je hluk, vizuální dopad a zaměstnanost, a ekonomické aspekty, jako jsou ceny EU ETS a náklady pro konečného uživatele.

Poté, co byly definovány potenciální budoucí scénáře, bylo dalším krokem hodnocení každého z nich podle jednotlivých parametrů. Celkové skóre bylo poté vypočteno pro každý scénář vynásobením vah parametrů skóre scénářů a jejich sečtením pro každý scénář. Tyto scénáře pak byly seřazeny podle preferencí na základě bodového hodnocení.

Dále byl vytvořen veřejný průzkum, který měl dva aspekty. Prvním bylo požádat veřejnost, aby poskytla váhy parametrů, aby tyto váhy mohly být porovnány s váhami vycházejícími z autorova výzkumu. Tím bylo nejprve zachyceno stanovení priorit parametrů veřejností, aniž by jejich bodování bylo zkresleno znalostí potenciálních scénářů - jednoduše vážili na základě toho, co je pro ně důležité, bez konečného cíle. Druhým aspektem bylo přímé požádání respondentů o seřazení potenciálních scénářů od nejvíce preferovaného po nejméně preferovaný.

Výsledky z Pughovy matice následně mohly být vypočteny s využitím vah parametrů veřejnosti i těch, které vycházely z výzkumu. Jejich analýza umožnila nahlédnout do případných rozporů mezi tím, co respondenti považovali za důležité, a tím, co výzkum označil za klíčové parametry. Z toho byly vyvozeny závěry ukazující, u kterých parametrů byl rozdíl největší, a kde tedy byla veřejnost o konkrétních parametrech nejméně poučena.

Váhy parametrů na základě průzkumu byly vypočteny třemi různými způsoby: demokratickým hlasovacím systémem (nejčastěji vybrané skóre vyhrává); průměrným průměrem; rozdělením vah s ohledem na zkreslení celkového počtu odpovědí respondentů.

Bylo zjištěno, že metodika průměrného hodnocení poskytla nejmenší rozsah výsledků, a tedy nejmenší rozlišení mezi jednotlivými pořadími. Metodiky demokratického a zkresleného průměru poskytly nejširší rozsah výsledků, což dokazuje,

že lépe rozlišují pořadí preferencí scénářů. Metodika skew také poskytla nejlepší sladění oproti výzkumu, a proto byla doporučena jako nejlepší varianta pro případné budoucí studie podobného charakteru.

Pořadí z Pughovy matice bylo porovnáno s výsledky veřejného průzkumu scénářů, aby se zjistily případné neshody mezi výsledky. Bylo zjištěno, že návrh Pughovy matice mohl být mírně zaujatý vůči technologiím obnovitelných zdrojů.

Celkové závěry vyplývající z výsledků studie jsou následující:s

1) Současná výchozí situace energetického mixu v České republice není špatná a představuje přijatelný výchozí bod, ze kterého je možné vyjít.
2) O dalším rozšiřování těžby uhlí jako zdroje energie by se nemělo uvažovat a lze ho vyloučit jako budoucí energetický mix, a to jak v případě domácího, tak i dováženého uhlí
3) Úplný přechod od uhlí k plynu lze jako variantu zavrhnout
4) Diverzifikace energetického mixu je žádoucí, aby se předešlo přílišnému riziku s jedním dominantním energetickým zdrojem
5) Obnovitelné zdroje energie i jaderná energie představují pro veřejnost žádoucí možnosti a vynikající volbu pro snížení celkových emisí budoucího energetického mixu.
6) Je třeba dbát na to, aby se obnovitelné zdroje energie nerozšiřovaly nadměrně, protože hrozí negativní dopady na veřejnost, například vizuální a hlukový ruch
7) I když se jaderná fúze jako technologie rozvíjí, neměla by být v budoucnu upřednostňována před jinými možnostmi
8) Při navrhování jakýchkoli nových modelů Pughovy matice pro definování budoucího energetického mixu by měla být věnována pozornost tomu, aby některé technologie nebyly v seznamu parametrů znevýhodněny dvojí penalizací
9) Respondenti průzkumu mají tendenci upřednostňovat parametry, které mohou vnímat v každodenním životě, před abstraktnějšími pojmy, jako je legislativa, s nimiž se přímo nesetkávají

Nakonec byla na základě Pughovy matice a výsledků průzkumu formulována doporučení, která lze shrnout jako postupný odchod od uhlí s trvalým nárůstem rozmanitého portfolia výroby energie, včetně větrné a solární energie jako obnovitelných zdrojů, a další jaderné kapacity.

Studii lze nyní použít jako základ pro budoucí zpřesnění průzkumu, odstranění nepravděpodobných scénářů a přepracování použitých nástrojů tak, aby poskytovaly objektivní výsledky.

Bibliographic citation

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Author's Declaration

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Topic:	*Conventional energy systems in numbers*

I declare that I have written this paper independently, under the guidance of the advisor and using exclusively the technical references and other sources of information cited in the project and listed in the comprehensive bibliography at the end of the project.

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Brno, May 29th, 2023 --

author's signature

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Brno, May 29th, 2023 --

Author’s signature

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INTRODUCTION

The ultimate goal of this thesis is to propose power system concepts for the Czech Republic, together with their requirements. These concepts are delivered in the form of a study which analyses the advantages and inconveniences of a variety of potential future scenarios of the energy mix. The scenarios are judged in a quantified way by scoring them for a list of critical parameters. To differentiate the importance of the parameters, they were also weighted.

Firstly, the parameters are researched in detail, with numerical quantified data to support the claims provided. The intention of this part of the report is to educate the reader in the complexity of the different parameters, allowing them to make informed estimations of their own. It was also critical to ensure correct scoring of the baseline and future scenarios using facts and not assumptions.

Secondly, a public survey was carried out, using the same parameters, and having the respondents rank them such that it was possible to identify if the public's perception aligned with the in-depth research or not. The same was done for the potential future scenarios to see if the public ranked them in the same order as the detailed research concluded or not.

Differences were found between the results of the research-driven scenario scoring, and that of the public, but in overall outcome, in the results were similar. These results are important for the following reasons:

- they allow the future scenarios to be reduced to a small number of feasible outcomes for further investigation;
- they eliminate unlikely scenarios from the discussion, reducing confusion and distraction;
- they identify gaps in public knowledge and perception on the topic, allowing government education and marketing of solutions to effectively target the right points of concern;
- they demonstrate which elements of the discussion the population is already educated about, avoiding unnecessary pushing of plans that are already accepted.

Finally, the results are provided in the context of correct decision making on a national basis for the Czech Republic for future energy mix and puts this into an international setting to provide a point of comparison globally.

All of this is detailed on a fundamental foundation of each energy and electrical source, described by their key parameters, and material and energy demand to implement them. Information and data to support this was taken from a variety of sources listed in the references section. All the referenced material is available publicly and accessible for academic purposes. It should be noted that this is not a commercial report but is also intended for academic use only. Figures which are not the author's work and have been taken from the references are marked as 'Note: reprinted' throughout this report.

1. INTRODUCTION TO ENERGY

Each section of this report introduces the basics concepts of energy systems, their demand, and fundamental principles of economics and definitions. Its intention is to educate the reader enough to understand the weighting of the parameters defined later, and to allow them to make fact-based judgements of the scenarios.

1.1 Basics of energy systems

At a simplistic level, an energy system is made of some fundamental steps. Firstly, it must produce energy. Then, it must convert it to a usable form, and finally, the energy post-conversion, must be used.[1] In any energy system, energy is neither created, nor destroyed – it is only transformed into a different type of energy. During the conversion step, inefficiencies occur, meaning that not all the energy makes its way into the desired usable form.[1]

1.2 Evolution of energy systems and energy usage

We must remember when analysing energy systems that the end use, or service, is the product that is for sale. End-users primary concern is the use of the energy, or the service that they employ it for, either for their own benefit or for profitable gain.[1] This is important when making intelligent decisions on appropriate energy resource selection for given uses.

Different sources of energy have different transmission losses, which may push energy providers to select one energy source over another.[10] Local availability, geo-political situation, environment, and sustainability all play their part in making the right choice of energy resource.

The evolution of the energy landscape has been impacted by technological advancement. In an energy system, there are two important steps, each with their own level of efficiency – conversion from primary energy source to final, and final energy to useful energy.[1] These two steps differ in efficiency, the first being around 70% efficient globally in 1997 [3], and the second being around an estimated 40% in 1995 [3]. The product of these makes 28% - any improvement that can be made here will be important in optimising mankind's energy use.[1]

In the past there have been pluses and minuses of both high and low energy prices. High energy prices result in higher costs of mobility and importing.[12][48][1] On the other hand, higher energy costs increase profits for energy suppliers, which allows them to reinvest into exploring new energy resources.[1]

It is important to differentiate prices from costs. Costs may be higher than prices, but countries' governments may choose to subsidise energy costs to give their population, and therefore end-users, lower prices.[13][17]

2. ENERGY RESOURCES AND SOURCES

This chapter introduces the main categories of energy types, stratifies them, and provides definitions of parameters to quantify them. To make a thorough analysis of the best options available for future scenarios of energy concepts in the Czech Republic, it is important to start by exploring all the different types of energy sources.

The first way to divide energy sources into groups is to define them as renewable or non-renewable. Non-renewable sources come from materials found on our planet that are finite. Renewable resources are those that are infinite.[42]

Non-renewable sources are the ones which have been used for the longest time. Since the invention of power plants and large-scale electrical energy distribution, they have become the primary ones. The first group of non-renewable energy sources to consider are fossil fuels. Their three main forms are solid, liquid and gas, namely coal, oil, and gas.

After fossil fuels, we can consider fissile materials –the fuel for nuclear energy. This comes from two main sources – uranium, and thorium. Nuclear energy requires a high level of technological advancement, access to and refinement of fissile materials, and the correct geo-political status.[1]

2.1 Stratifying energy resources

When trying to compare different energy sources, we need to define quantifiable units of measure for them. The first definition to consider is the one made by the World Energy Council – that is ‘the occurrences of material in recognizable form’.[1] After this, we can start to break down this total amount into more logical buckets. The most relevant group is a reserve. This is a quantity of energy resource which can be recovered with current technologies. There are also indicated, inferred and probable reserves. A useful method by which the above definitions and stratifications of energy resources can be visualised is known as the McKelvey diagram:[14][80]

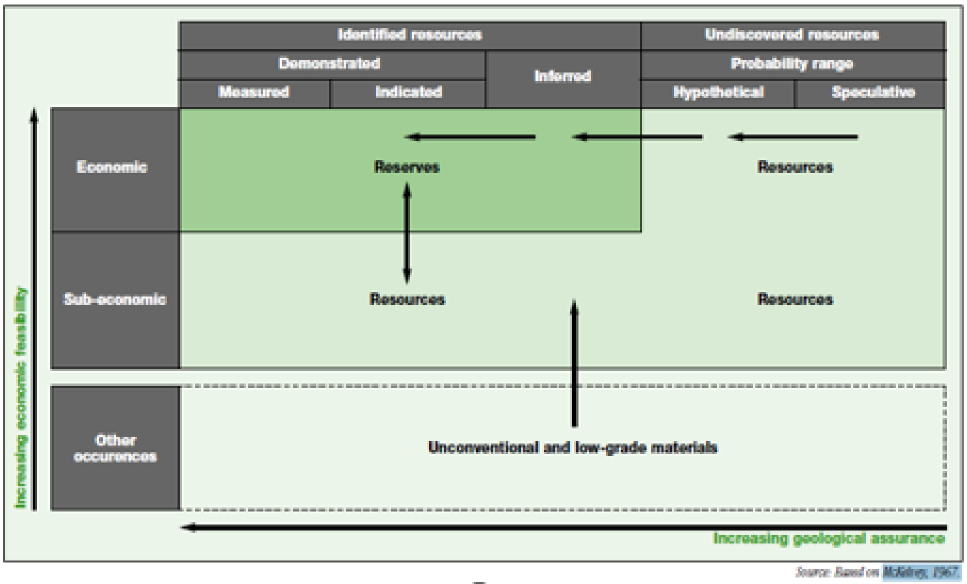

Figure 1 McKelvey diagram (Note: reprinted) [1]

Noticeable from the diagram is the existence of unconventional occurrences of certain energy types.[15] Examples of these are oil shale and uranium dissolved in seawater.

When reading the McKelvey diagram, the increasing vertical axis, from bottom to top, describes the feasibility economically of a resource, and the horizontal axis, from right to left increasing, essentially describes the probability of geological success from the resource.[1] The diagram relates to non-renewable energy sources only. For renewable energy sources, we must slightly adjust the terminology to be able to draw comparative conclusions.

2.2 Renewable versus non-renewable energy indicators

To find equivalent indicators for renewables, as a starting point, an occurrence of a non-renewable can be equated to the annual natural flow of any given renewable.[1] For example, the amount of sunlight falling onto the Earth's surface. What can we use to represent a resource? The answer is the potential maximum that can technically be extracted from the given renewable using today's technology.[1]

2.3 Units defining energy resources

Now that we have defined stratification of energy resource types, it is important to define units to quantify them so that the use of each can be compared.

Starting with oil, which is measured in tonnes for its mass and exajoules for energy content, the energy equivalent is defined as gigajoules per tonne of oil.[1]

Gas on the other hand is measured in cubic metres, and exajoules, so an energy equivalence of gigajoules per 1000 cubic metres needs to be used.[1]

For a solid energy resource like coal, tonnes of coal equivalent are used.

Finally, to complete the list for non-renewable resources, energy equivalence for uranium is noted per tonne.[1]

The following table gives energy equivalence values for comparative purposes, and highlights the comparatively huge energy available in nuclear fuel, which is several orders of magnitude larger than the fossil fuels which have similar energy levels:

Table 1 Energy equivalence comparison of non-renewables

Energy Resource	Energy content	Per unit value
Oil	42 GJ	Tonne
Gas	37 GJ	1000m3
Coal	29 GJ	Tonne
Uranium	589 TJ (589000 GJ)	Tonne

3. NON-RENEWABLE RESOURCES AND TECHNOLOGIES

3.1 Fossil resources, reserves, and technologies

Fossil fuels are non-renewable fuels and as such are not long-term sustainable since they are used faster than they form. Each state of fossil fuel has its advantages and disadvantages. Their extraction and use to generate energy make economic sense, even if their environmental impact is high.[16]

Based on the information presented, volumes of each fossil fuel remaining, and the relative accessibility of each for conventional and unconventional resources, current estimates show that there will be sufficient oil and gas for at least 50-100 years.[21]

3.1.1 Oil

Conventional oil resources are important as these are easily accessible with today's technologies – when calculating existing reserves, only those from conventional sources are counted.[1]

In 2000, 90% of the oil consumed globally came from oilfields that were over 20 years old. Estimates for the amount of conventional oil remaining are around a trillion barrels, which equates to around 123 gigatonnes (5124 exajoules). On the other hand, unconventional oil reserves are estimated to exceed this value quite considerably at around 245 gigatonnes (10206 exajoules).[2][1]

Based on the volume of oil that was available in the world, it can be expected that half of it will have been used up by around 2030. At that point in time, annual production will be around 4.4 gigatonnes, a significant increase from 3.5 gigatonnes in 1998.[2][1] It would be wise to start investment in unconventional oil extraction sooner rather than later.

3.1.2 Gas

The difficulty with gas relates to its form and the associated problems in complete extraction and distribution.[17] Transmitting gas over long distances is possible but the problem is that a large amount of capital investment is required to install the infrastructure needed to transfer it.[18]

Estimates of reserves have increased over the last decades. An estimate for the total amount of gas globally that may be able to be recovered in 2000 was around 502Tm3, equivalent to 18390 exajoules, but due to ongoing use, this has decreased.[1] It should be noted that this value is higher than the total for oil, which makes up a higher fraction of global energy production due to the relative ease of its extraction.

As a last word on natural gas, it is important to state that this is the fossil fuel with the lowest level of carbon intensiveness, making it a great relatively clean fossil fuel for the future.

3.1.3 Coal

Sometimes coal is found near the surface of the Earth, so can be extracted in an open pit, but often it is necessary to mine it. Mining comes with its own issues, such as endangering the lives of miners, and gas explosions, since many coal deposits also contain gas deposits too which can be accidentally ignited.[19]

Although coal is the most polluting in terms of carbon dioxide, coal still provides a significant amount of energy globally. 37% of the electricity produced globally is made in a coal-powered power plant.[98]

Due to the drawbacks of nuclear waste, and the need to install pipelines for gas distribution, it looks unlikely that coal's position as a key energy provider will change in the near future.[20] This can be demonstrated by the increase from 2.4 gigatonnes of oil equivalent (Gtoe) being used in 1995, versus 4.0Gtoe in 2020 [71]. In terms of exajoules, this global consumption can be quantified as around 95 exajoules in 1995, increasing to 160 exajoules in 2021.[99]

Access to coal reserves is easy, but the lead-time to development new mines is usually around 5 years. New technologies are being developed such as carbon reduction and disposal to improve its image as a cleaner fuel. This may help to prolong the lifespan of coal, since it will improve the ecological aspect of coal combustion.

Most coal which is extracted, more than 90% [71], is used inside the country where it came from. However, there are some countries which do not have many reserves of coal, and so there is a market globally to sell coal.

In 1998 (WEC), there was estimated to be more than 7400 billion tonnes of coal globally [1]. This is equivalent to around 4470 gigatonnes of oil. However, the portion believed to be available for extraction was only around 500Gtoe of that total – this is what we could consider as reserves.[1]

3.2 Fissile materials resources, reverses, and technologies

There are two elements in the periodic table that are fissile and occur naturally, uranium and thorium. Just like with fossil fuels, the supply of them on Earth is finite.

Firstly, as with the other types of energy resources, a way to define uranium and thorium deposits is required. To do this, deposits are grouped into ranges of cost for their extraction. This defines what is an assured reserve, and what is an additional supply resource. This grouping was defined in the 1970's because at that time it was expected that demand would quickly outstrip supply.[1]

Due to this expectation, investigations were made into unconventional reserves of uranium like that contained in seawater. Even at less than 3 parts per billion, it still means that there is a huge amount of uranium contained in all the oceans – approximately 700 times as much as there is naturally occurring on the land.[1]

3.2.1 Uranium

At present, uranium is the fissile element of choice. Despite the dangers, the amount of energy contained in fissile materials is huge – one kilogram of uranium contains about 14000 times more energy (573 gigajoules) than a kilogram of oil.[1] The risk may be high, but so too is the reward.

3.2.2 Thorium

Thorium is not used for energy production in the same way as uranium, because when fission takes place with thorium, fewer neutrons are released so it is harder to keep a chain reaction continuing.[25] Since uranium is relatively cheap, there is little desire to source thorium.[24][25] There are many reserves of thorium deposits around the world though. Data for world thorium deposits show around 2.16M tonnes of assured reserves, and 2.35M tonnes of additional resources.

3.2.3 Nuclear energy technologies

Nuclear energy generation grew rapidly from 1965, through to the late 1980's, before steadying in the 1990's. [8] It has since remained stable, up until the Fukushima disaster in 2011, when some countries, especially Germany, decided to reduce their nuclear energy production. [8]

There are many factors that influence predictions on the expansion or contraction of nuclear energy production. Firstly, the cost of nuclear power plants has proven to be higher than estimated at the beginning of the nuclear power expansion.[22][26] Competition in the energy marketplace has also grown with other technologies like renewables providing equally cost-effective solutions.[27]

One particular benefit of nuclear energy is the fact that it does not emit any greenhouse gases. It can be argued that nuclear power plants can help to reduce CO_2 emissions into the Earth's atmosphere, however, some quantification is needed.[29] Two extreme scenarios can be compared – firstly a high-growth scenario, and secondly a low-growth one that reduces nuclear energy contribution to zero by 2050.[1] In the high-growth scenario, an increase to 6500 gigawatts of electricity from nuclear is assumed by 2100.[1] Assuming nuclear replaced coal and natural gas as power sources, then 225GtC and 110GtC of CO_2[1]emissions could be avoided respectively. That would represent only 16% and 8% of CO_2 emissions during that period [1] – a large increase in nuclear energy capacity is required to have any significant impact on climate change.

To reach the desirable situation where nuclear energy becomes more attractive, technological advancement will be needed not only in terms of maximising the energy extracted from the fission process itself, but also in terms of waste management.[23] If nuclear energy can improve its image by demonstrating safe waste management, and total avoidance of nuclear catastrophes, then it has a chance of securing its position on the path to greenhouse gas reduction.[28]

An important aspect to consider for nuclear energy is its costs versus fossil-fuel alternatives. The costs must be considered in two ways, both fuel cost, and operation and maintenance costs. The number of staff required to run a nuclear power station is very large compared to other fossil fuel plants.[103] That is mostly because safety regulations to avoid nuclear disasters require more people.[1]

There is a large amount of capital investment required to install a new nuclear power plant.[22][30] This means that it is only affordable for large and wealthy nations who have the financial resources to invest without the need for loans. There are only two countries in the world where nuclear power plants are cheaper than coal or gas power plants to install – France and China.[1] It is not a coincidence that these two countries have some of the largest nuclear power outputs in the world.

The costs for waste storage are not too high fortunately, as the waste is relatively dense. Going back to the high-growth nuclear scenario mentioned above, a storage of 270 square kilometres [1] would be needed to keep all the nuclear waste from the 21st century – only 0.003% of continental land area on the planet [1].

As a summary, it can be stated that political and public opinions on nuclear waste storage are the biggest issues it faces, rather than technical ones.

4. RENEWABLE RESOURCES AND TECHNOLOGIES

The next category of energy sources, renewables, have been providing energy for many decades, but steps have been made over the last two decades in making such energy more affordable and cost-effective.[31] Here we will briefly visit each energy source in turn to determine its origin and briefly assess the pros and cons of them.

4.1 Solar energy

The first renewable energy source considered is solar because all the other renewable sources are processes that follow in some way from energy from the sun.

Solar energy has an incredibly large potential to satisfy the energy requirements of mankind. The theoretical potential energy received by the planet from the sun is many times larger than the total requirement of energy for the human population of the world.[1] It has aspects that make it difficult to collect though. Firstly, the amount of energy falling on a square metre of the Earth's surface is not equal. The amount of energy received varies over time based on a variety of factors such as climate, time of day, and latitude.[1][32]

Solar energy faces issues in terms of its collection, storage, and distribution.[1] Firstly, if land available for installation of photovoltaic cells is far from the end-user, then the electricity needs to be stored as it is collected for usage later and distributed over potentially significant distances. The cells used to collect solar energy can be expensive, and for the true potential of solar energy to be released, cost-effective conversion technologies are required.[33]

4.1.1 Photovoltaic solar energy

This type of energy production uses photovoltaic cells which generate free electrons from the energy in the light which hits them, making electricity.[43] Insolation is defined as the amount of energy falling on a specific area in a specific amount of time, for example, kilowatt-hours per square metre per year. We can expect 3 times as much insolation in deserts over the course of a year than at the North and South Poles, 800 versus 2500 kilowatts-hours per square metre per year respectively.[1]

Usually an efficiency of around 10-15% can be achieved with a photovoltaic cell. If the sun produces on average about 100-300W per square metre [1], a lot of cells over a large area are required before any useful amount of electricity is produced. This is important to realise because although the theoretical potential of solar energy is very big, the reality of capturing it is low.[1]

In developed countries with strong infrastructure, the situation is improved because they can integrate photovoltaic panels onto buildings and connect them directly to the supply grid.[44]

There is a need for storage of the electrical energy produced by photovoltaics, otherwise it would be wasted. Either a battery is installed to be charged by the system and retain energy for when it is needed, or the system is connected to the main grid of electrical power infrastructure where it can be used elsewhere and helps to reduce the amount of energy needed from other sources.

On the positive side, a photovoltaics does not emit any harmful gases. On the downside, their initial manufacture does create emissions. Newer technologies have extended the life of solar panels and they are now overall net producers of energy. This is an argument for photovoltaic cells helping to reduce carbon emissions globally.[45] Use of harmful elements is worth mentioning for photovoltaic systems – some technologies for the cells contain cadmium, and many of the batteries for storage contain lead.[204][47]

4.1.2 Solar thermal electricity energy

Solar thermal energy is the use of radiation from the sun and subsequent heat to generate electricity. [48][49] Such plants can be made as large stations that are connected to the grid network, or as remote standalone plants. They can offer low-cost solar electricity with a high value and are in that respect the best option for solar power – they can even compete with coal power plants. Currently existing coal power plants and nuclear power plants have a lot of empty land around them for both security reasons and because it is not attractive for other developments – these areas represent opportunities to install solar thermal energy installations and can be connected directly to the grid.[50]

The central receiver/power tower design has a tower with a lot of mirrors around it. These mirrors can rotate so that they always capture the most amount of sunlight as possible and reflect it onto the receiver in the tower. A medium is used to transport the heat to a generator which runs on steam.[52]

The parabolic trough system is laid out like a farm of mirrors with a concave shape, through which a pipe runs. The pipe contains a liquid which can be heated up by the mirrors and then used to heat water which then drives a standard steam turbine. These are probably the most mature of the technologies available.[53]

In terms of a cost-effective and sustainable option, solar thermal energy systems have a great deal of potential, as with the right technological advancement, they can be competitive with oil, gas or coal powered plants whilst using a renewable source and reducing overall CO_2 emissions. Other benefits include a low requirement for land area, and after the initial capital spend, relatively low running costs since less personal are needed to run them compared to a nuclear plant.

4.1.3 Low-temperature thermal solar energy

Active and passive low and medium temperature thermal solar energy solutions are an excellent solution to needs up to 200°C. Storage of the energy in a battery is needed so that it can be collected when the sun is present and used when it is not. Applications of such technology range from domestic hot water systems, which are the most popular use, to heat pumps for interior heating of homes.[104]

Electric heat pumps have been implemented in the tens of millions. They work by using an electric pump to extract heat from a heat source and distribute it around a system, such as is the case for domestic space heating. They can also be used in reverse, and act as air-conditioning to cool instead.

Hot water systems using this kind of technology are made up of a collector panel to absorb the solar energy, a tank for storing the water to be heated as a conversion medium, and a system capable of circulating the heat from the collector to the point of storage.

Large scale systems are also possible and are used for a wide variety of applications. They require capital expenditure upfront, but after this can easily compete with fossil fuel alternatives – therefore, they are a good option for long-term installations. Examples include hospitals, and industrial applications.

4.2 Hydro energy

Hydroelectric power generation relies on a volume of water running downwards due to gravity to convert its potential energy through mechanical conversion into electrical energy. To do this, the water needs to reach higher ground, and it does this via the natural evaporation of water which is only possible through energy that comes from the sun.[1] There is a constant cycle of water evaporating from the oceans, falling as rain on the land, and flowing through rivers back into the oceans again. This makes hydroelectric power very sustainable.

Hydroelectric power plants have a large impact on water quality downstream, in particular high amounts of sediment due to the stirring up of material into the water. This can be seen through the changes of biodiversity after hydroelectric plants as local mammals, fish, and birds have their habitats disturbed.[34]

Often the location of available water, with enough pressure head, or altitude, and sufficient flow, is far from end-users. Hydroelectric plants are quite expensive to set up in the beginning and take a long time to develop.[35]

It is expected that global warming will increase the amount of rainfall as a warmer planet means that more evaporation will take place.[36] Real-world potential of hydroelectric energy production will be much less than the theoretical maximum. Developed countries will not invest in such power sources unless it is able to show a huge economic benefit and so the Czech Republic is unlikely to prioritise this option.

4.3 Wind energy

Wind shares many of the same elements to consider as solar energy. Many of the factors that limit it from reaching its absolute potential are the same. Geography plays a part, as windy areas are the best to target.[57] Storage and efficient transmission of such energy is vital to making it a viable large-scale solution.

The origin of wind is, again, the sun. This is because solar radiation hits the Earth's surface, heats it up, and causes differences in air pressure, and density. The temperature rises on average closer to the equator, and reduces closer to the Poles, so there is a natural cycling effect of the wind. We must also consider the rotation of the planet which can influence the wind on a large scale.

As a general guide, if 400-500W per square metre can be recovered at 30-50m above the ground, then it will be worthwhile considering wind energy recovery. It has been estimated that only around 10% of the theoretical potential of wind energy can be captured because most locations don't allow correct siting of a turbine.[58]

4.4 Biomass energy

Biomass can be sourced from wood, such as trees and shrubs, or non-woody, such as grass or straw. It can also be processed, for example municipal waste, or by-products of food processing.[37]

To improve fuel quality, biomass fuels can be processed into briquettes, which can help to make them denser to save on transportation costs and reduce water content. Some processed fuels have been consumed for a long time, such as charcoal and plant oils.

Biomass is not without limitations. It has low efficiency and is highly polluting.[1] It can also cause health problems, especially amongst the young. Nonetheless, it is still a large contributor globally to energy needs, providing 6% of all the energy produced globally in 2022.[100]

Increasing biomass fuel consumption will require appropriate areas to produce it. In some countries, priority must be given to the production of food, and so biomass fuel production will be secondary.[38] However, there are still areas where biomass exploitation can exist where it is unsuitable for food production.[39] The other aspects to bear in mind when thinking about increasing biomass production, is the supply of fresh water and impacts on soil.[40]

Biomass has a huge potential to satisfy human energy needs but since only a fraction (<1%) of solar energy converts into biomass during the production of plants or crops, this means that extremely large areas of land would be needed to support it.[41]

4.5 Geothermal energy

Geothermal energy is thermal energy which is stored inside the Earth. There are several types of it, but hydrothermal is the only one which is currently used commercially to produce energy. Between depths of approximately 0.1 to 4.5km under the crust of the Earth, hot water or steam is present which can be used to generate useful energy. The amount of energy available is estimated at 140,000,000 exajoules [1], but the problem here is accessibility.[1] This total amount would easily satisfy man’s need for energy, but the distribution of such hydrothermal resources is spread around the Earth, not always in convenient locations. As a result, only a fraction of the available energy is used as for the most part it is not economically viable.

4.6 Ocean energy

There are various types of energy that can be extracted from the sea or oceans. The most developed one is tidal energy. This involves using the energy which is transferred to the oceans by forces induced by gravity from the sun and moon. There are commercial operations existing for tidal energy, but the other types have not progressed to the same level.[59]

Apart from tidal energy, there is wave energy, ocean thermal energy, and salt gradient energy.[1] None of these have been developed commercially and so will not be investigated here. Since the Czech Republic is a land-locked country, no ocean energy options are available.

5. TECHNOLOGIES AND ENVIRONMENTAL IMPACT ASSESSMENT

5.1 Introduction

A lifecycle assessment is an attempt to capture all the consumption or impact of a particular parameter throughout the life of a technology. This includes the front end, such as mining or capture of any required fuel, processing, and transportation, the process of generating energy for end use itself, and the back end which includes any recycling of waste, and ultimate decommissioning of the power plant at the end of its useful life.

Resources and technologies considered in this part of the study will be briefly reviewed in terms of their lifecycle impact to the environment.

To start with, coal will be considered. Around 34% of the world's energy was produced using coal in 2020, and it will remain as a significant contributor to the population's energy needs for many years to come.[60] The following pyramid chart shows the existing coal power plants in the world on the right side of the vertical axis, and those proposed to be built, in ranges of age. The coloured bands also show the geographic regions where they are used:

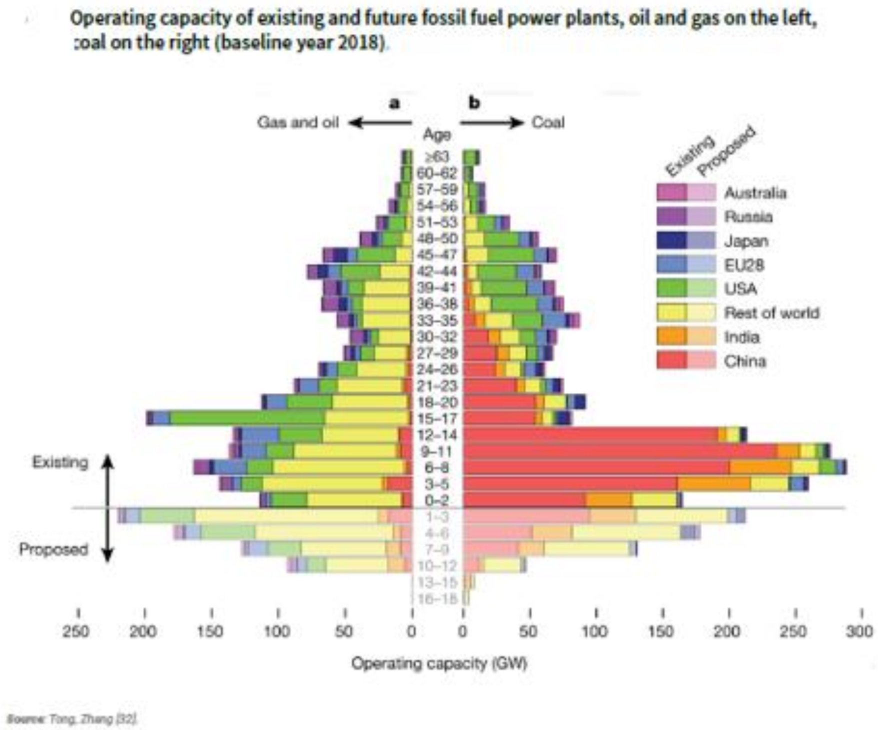

Figure 2 Existing and future fossil fuel power plants (Note: reprinted) [60]

China had a huge surge in coal-powered plant construction 15 years ago[60], and now they dominate the world in this respect. India is the second largest consumer of coal, and so these two huge nations in terms of population will need to diversify their energy portfolios significantly if the world will reduce its reliance on coal overall and cut CO2 emissions – 20% of carbon emissions globally in 2020 came from coal burning.[60]

Also interesting from the chart above is the left side of the vertical axis, where gas and oil and shown together combined, on the same scale as coal. Here it becomes apparent that around 20-25 years ago, the USA started to focus its energy production on oil and gas rather than coal.[60] A similar trend is observed in other territories except for China and India, who use this source of energy comparatively very little.

A large part of the problem in shifting from coal power is the fact that so much money has already been invested in existing infrastructure, and the governments of countries will not waste the money they have already spent.[71]

A compromise would be to make part of the transition include the adoption of carbon capture technology for existing plants, whilst focusing new plants on other energy sources. However, even this is not an attractive solution economically due to the relative abundance and low cost of coal.

5.2 Coal Environmental Impact

Coal power has the largest environmental impact, especially without carbon capture in terms of emissions. The extraction process, in other words mining, contributes the most in many respects but especially two – water dissipation and climate change total.[60] This is because these two are dominated by the actual combustion process where water is used for cooling and carbon dioxide is produced when burning the fuel.[60]

Comparing the same case but with carbon capture clearly demonstrates the differences and the penalties to pay for reduced emissions. There is a significant increase in water dissipation, up over 2 litres per kilowatt-hour from without carbon capture (3 litres per kilowatt-hour)[60]. This has a direct impact on additional water eutrophication, but emissions reduce to around a third of the value without CCS.[60]

5.3 Natural Gas Environmental Impact

In 2020, natural gas accounted for 23% of all the electricity produced in the world, making it the second largest energy resource globally.[60] Natural gas has the benefit versus coal of producing less particulate matter during its combustion, and therefore being a cleaner energy source. Interestingly, as coal's dominance as the primary energy source in the world has reduced over the last 10 years, gas has remained stable in the range of 20-23%.[60]

Most of the newer gas power plants in the world today run on the natural gas combined cycle (NGCC), which uses the exhaust of the gas turbine to run a steam turbine, rather than wasting the energy.[65] As a result, they reach excellent levels of efficiency compared to their coal counterparts, anywhere between 50 and 60%.

Comparing overall values for gas in terms of emissions, they are markedly lower than coal. It is clear why the USA and Europe have focused on gas power instead of coal power over the last few decades. However, we must be careful before jumping to conclusions and making over-generalisations about the benefits of gas versus coal. What is also important to consider is the amount of leakage of natural gas, or methane, into the atmosphere during extraction and distribution.[66]

This can have a significant contribution to greenhouse gas emissions per unit of electricity produced. Depending on the amount of leakage, coal can become better in terms of emissions, although it has also been shown that there is leakage of natural gas from coal mines after they have had the coal extracted and been abandoned too.

The following graph shows the boundaries of the scenarios when coal or gas is a better option depending on methane leakage and methane to carbon dioxide conversion[60]:

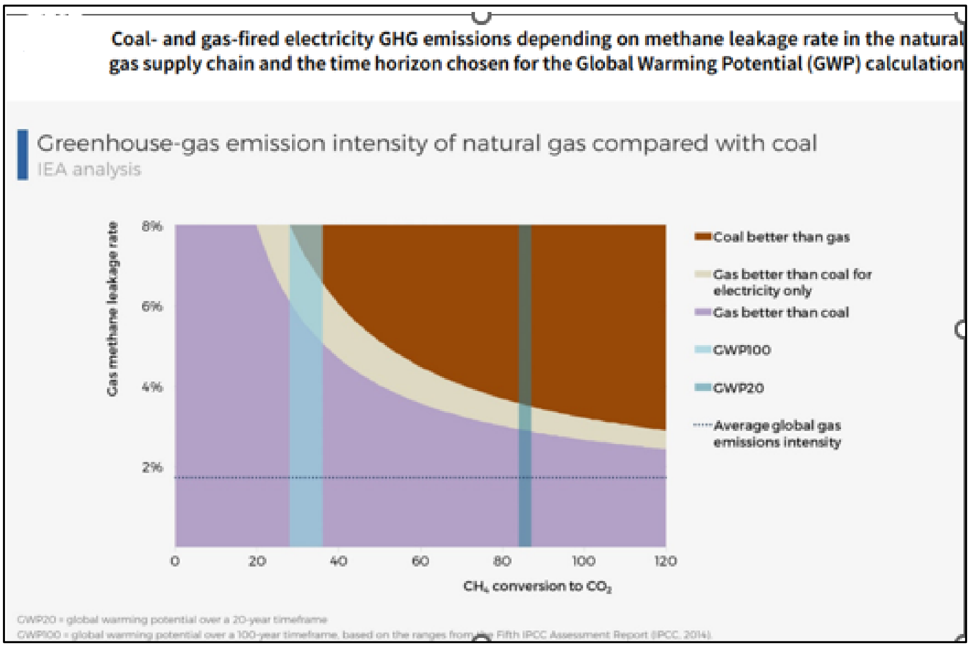

Figure 3 Greenhouse gas emission intensity of natural gas compared with coal (Note: reprinted) [60]

It can be seen from the above chart that only a few percent of leakage from gas results in coal being the better option. The middle band in the chart where gas is better for electricity production only is because gas power plants are simply more efficient than coal ones.

5.4 Nuclear power Environmental Impact

There are a lot of different types of nuclear reactor, and generally they are grouped into generations 1 to 4. The earliest Generation 1 reactors are no longer running, as they were from the original designs of the 1950's and 60's. [60] Today, most reactors are of Generation 2 and are mostly light water reactors, both of pressurised water reactor and boiling water reactor type. Generation 3 reactors include those of heavy water, fast neutron, light water graphite, and advanced gas-cooled reactors. The following chart shows the split of reactors by type in service in December 2019, by absolute number on the left side, and by capacity in gigawatts on the right side. It also shows for each split the number in construction [60]:

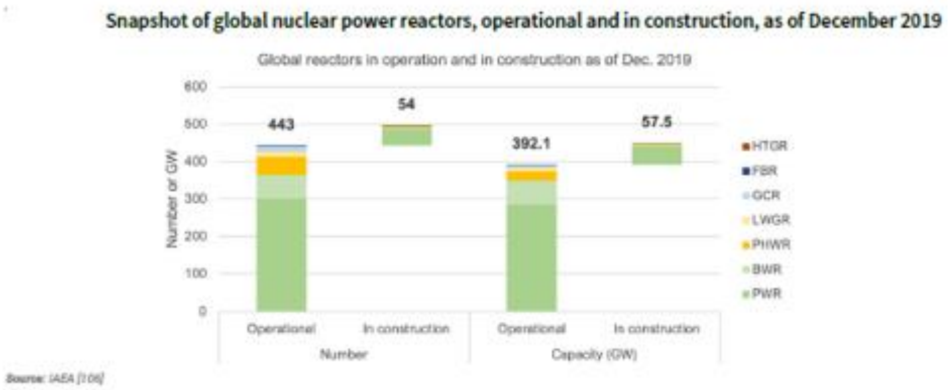

Figure 4 Global nuclear power reactors (Note: reprinted) [60]

It is clear from the size of the bars in dark and light green that pressurised and boiling water reactors make up most of the market share. Generation 4 type reactors are not widely in use yet, but one of the main benefits targeted for them is to be able to reuse spent nuclear fuel. The types of technology being developed and pushed for roll out in Generation 4 are Very High Temperature, Molten Salt, Lead-Cooled Fast, Supercritical-Water-Cooled, Sodium-Cooled Fast, and Gas-Cooled Fast reactors.[60]

To make a fair comparison with the other technologies in study, pressurised water reactors will be considered, since those are the ones most in use today. For nuclear, like all thermal plants, water dissipation comes from electricity production, as water is used for cooling. There are major contributions to mineral and metal use from spent fuel and its subsequent management – this is because used nuclear fuel needs to be stored in safe containers that use copper and other materials to keep them safe at the backend of the process.[60]

The frontend of the process, which includes mining of uranium, enrichment of it, and making of fuel pellets for the nuclear plant to use contributes to the rest of the parameters considered later in this report.[60] This activity is carried out by only a few suppliers of fuel worldwide.

Overall, nuclear energy emits relative low amounts of carbon dioxide compared to other technologies, especially the other ones using steam turbines driven by fossil fuels. The greenhouse gases released are for a large part not from the technology itself, but from the energy supply used at the plant which are usually made up of Diesel generators.[60]

Land use is low, but radiation is relatively high, which is driven by higher values across the whole of the nuclear fuel supply chain, right from the very beginning of the mining or extraction process.[60] As a summary, nuclear power represents an excellent option in terms of the parameters studied, in the absence of catastrophes – the very problem that weakens the attractiveness of nuclear power in the public eye.

5.5 Solar energy – Photovoltaics Environmental Impact

Photovoltaic panel installation has grown significantly this century, especially since 2010. There are several different types of cells available for this technology, offering different costs and efficiencies. The two main technologies currently are both crystalline silicon based, either single-crystal or multi-crystalline.[270] Initially, multi-crystalline dominated the market, due to their low cost, but since they are also relatively inefficient, more recently, single-crystal types have started to take over as their costs come down and their higher efficiency becomes more affordable. Finally, there are thin-film cells, but these currently represent a much smaller share of the market. The graph below shows the progression of each technology over the years since the turn of the century:

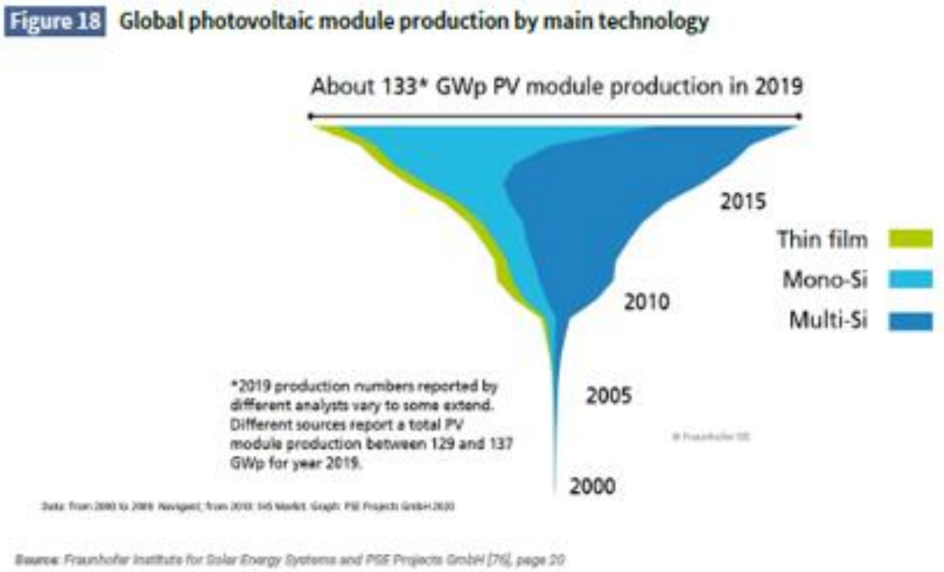

Figure 5 Global photovoltaic module production by main technology (Note: reprinted) [60]

Most of the carbon dioxide emissions for photovoltaics come from the production of silicon to make the modules.[60] Maintenance costs for cleaning can be high, for example where sandstorms are common. Land use is also high for ground-mounted panels, but for roof-mounted cases the land use is indirect for the most part.[60] Silver is used in relatively small amounts in photovoltaic cells, and of course copper in various electrical parts of the system, including inverters.[60]

5.6 Solar energy – Concentrated solar Environmental Impact

There are many different designs of concentrated solar power, but trough and tower designs are the two most common ones. Trough systems use mirrors to heat a tube of fluid running through the middle of a portion of tube-shaped reflectors to run a steam turbine. Tower systems use a central tower to reflect light from many mirrors onto a single point where a collector fluid is located.[48][51][54][55]

Their carbon emissions impact is mostly made up of the construction phase and assembly of the field of troughs – this is because it is assumed to be done using electricity from other sources which do have significant carbon emissions.[60]

Significant non-emissions related factors are mostly made up of the assembly or preparation of the field for the solar troughs, the subsequent energy storage system, and maintenance of the site during its life.

Tower designs approximately halve the CO_2 emissions versus troughs – this is mostly coming from the increased efficiency of the system overall.[60] Land use is similar to trough design and is a direct result of the land occupied by the reflectors in the solar field. Beyond this, the operation costs and maintenance are relatively high, since whilst the tower and solar fields are not supplying power, they are supported by electricity that comes from the rest of the grid.

5.7 Hydro energy Environmental Impact

Hydroelectric plants take two main forms – either they use water from a reservoir, usually formed by building a dam, or they are what is referred to as 'run of the river' type, which diverts a portion of the river water along another route into a tank where it can then be used to power a water mill or powerhouse.[67]

Most of the impact from hydropower is from transportation during the construction phase, the construction itself, and the dam.[60] The overall impacts of CO_2 are relatively low compared to other technologies since the life of a hydroelectric plant is usually designed to be 50-100 years long, so the payback of the initial investment carries on for a long period of time.[60]

5.8 Wind energy Environmental Impact

Wind turbines have improved their efficiency over the years, simply by becoming larger, which helps them to capture more wind energy with higher wind sheers at greater altitudes – this has had a knock-on positive effect on reducing their environmental impact too.

Wind turbines use a lot of materials – in particular offshore ones, where the amount of concrete and steel for their structure and foundations increases significantly.[60] Nonetheless, when comparing this technology to the fossil-fuel options of coal and gas, it is clear that its impact in terms of climate change, water use, and other harmful factors is much reduced.[60] It should be noted when comparing the land use to other technologies, most studies consider the direct use of land and not the indirect one which would consider the whole land of a wind farm, even if it is used for agriculture too – as a result, the land use values in study are taken as being relatively small.[60]

Along with the material use for the structure, there is a significant contribution from the generator of the turbine – this is because of the high amount of copper used in them.[62] Manufacture of the blades of the turbines contribute to water and land use, radiation, eutrophication, and climate change but are passive contributions as the manufacture of the blades themselves requires electrical energy which is assumed to come from other sources.

We have to take into consideration that data relating to wind farms does not usually take into account at all the indirect land use, any perceived destruction of the natural beauty of the surroundings, noise, or secondary effects like death of birds in the area.[63] Such issues can be improved, but this is not visible in any quantifiable data, and is therefore considered in specific parameters to capture it in the later Pugh Analysis in this report.

It is important to think about the usage of rare earth elements, and other materials in general. For wind turbines, there are different designs – they can be split into those that use a gearbox, and direct drive ones.[60] Direct drive wind turbines use more materials than those with a gearbox. Given the relatively large amounts of metal used to make wind turbines, for example the copper used in their cabling, which can run into many tonnes, it is important to plan ahead and think about mining and supply chain issues in case such a technology enjoys a rapid acceleration of implementation globally. The chart below shows the number in kilograms for each element used in onshore wind turbines (the values for offshore would be much higher due to the longer cabling requirements) per megawatt of electricity produced [60]:

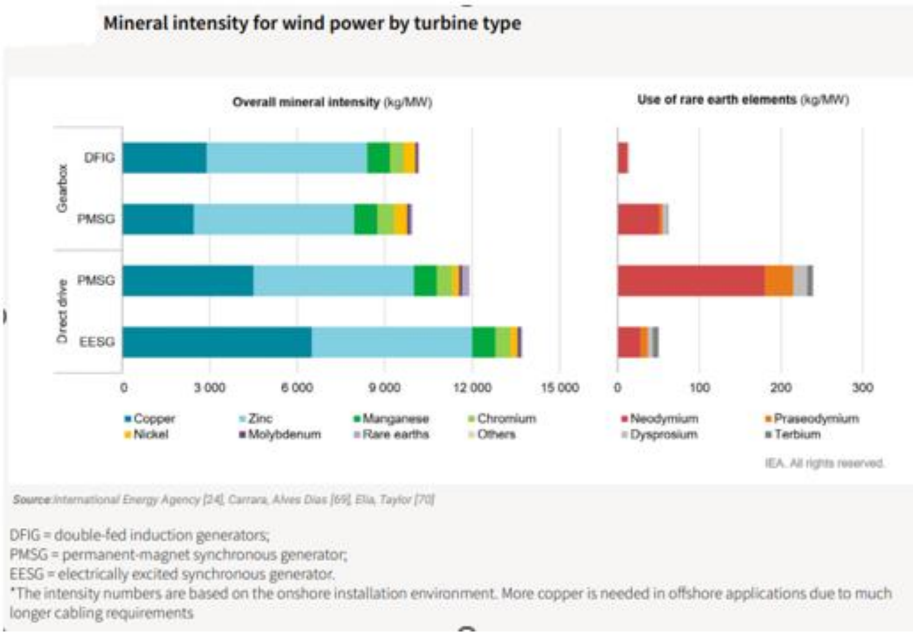

Figure 6 Mineral intensity for wind power (Note: reprinted) [60]

5.1 Electricity Storage Environmental Impact

Energy storage is a vital addition needed for renewable energy sources to capture energy and store it for when it is required.

A large variety of energy storage options exist, and they can be categorised by the time-period over which they are capable to store energy effectively without excessive losses. Within electrical systems, capacitors can be used for periods ranging from seconds to up to around a minute.

Beyond this, flywheels begin to be a viable option for periods up to a little under an hour – the right size and design of flywheel can store kinetic energy effectively if it has an appropriate inertia and low-friction bearings. Spanning a similar range of time for energy storage are small compressed-air energy storage systems, whereas the larger systems of this type can store energy for several days.

Sitting in the middle of this range are batteries, both lead-acid type and lithium-ion type.[64] Cobalt is also used for batteries – both elements (cobalt and lithium) are relatively rare in the sense that they have quite specific geographic locations where they are found.[60] As a result, it is important to develop cost-effective alternative technologies to using these elements to protect against stress on the supply chain of them, and to avoid shortages in case of political issues, or even war. The chart below shows all the above-mentioned energy storage options plotted in terms of their power rating on the y-axis, energy capacity on the x-axis, and then with isochrones of constant time-period plotted diagonally for a second, minute, hour, day, and month respectively[60]:

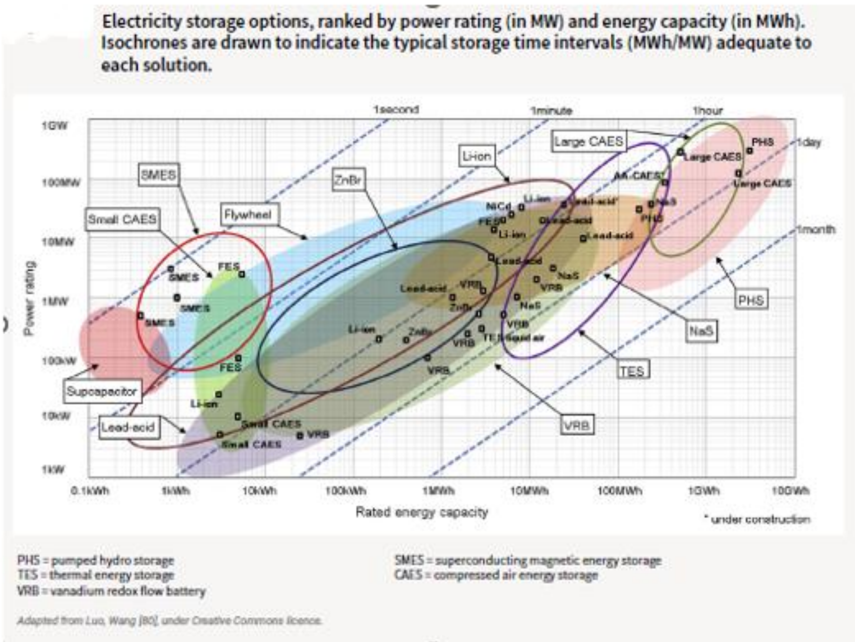

Figure 7 Electric storage options (Note: reprinted) [60]

At the right-hand side of the chart, we can see pumped hydro storage which can store energy for the longest out of all the options.[267] During off-peak hours, water is pumped up into a reservoir using excess energy in the network and can then be allowed to flow down by the force of gravity to turn a turbine when it is needed later.

Compressed air storage works in a similar way to pumped hydro, except that instead of water being pumped, it is air. Storage volumes of compressed air are built up, and then released later to turn a turbine and deliver power. This is an excellent option in terms of maximising the energy consumption from variable generation technologies like wind and solar, as the load on the network does not need the power generated, it can be stored for later.[268]

Another option for long-term storage of energy is to produce hydrogen. In this way, the excess energy produced by renewable energy sources which is not needed immediately can be used to make hydrogen which can then be converted back to useful energy via a fuel cell.[269] Water electrolysis as a production method of hydrogen is not highly efficient, with losses of around 30-40%, but this is still much better than losing the energy altogether. The only point to consider when using hydrogen as an energy store is that due to the overall efficiency of the processes involved in making the hydrogen and then converting it back to electricity later being around 30%, it means that the carbon dioxide production of the original source of energy gets multiplied by around 3.[250] As a result, it does not make much sense to use this for fossil fuel sources.

6. TRANSMISSION AND DISTRIBUTION OF ELECTRIC POWER GRID

6.1 Modernisation, Challenges, and Opportunities

Traditional electrical power grids grew for many decades with approximately the same structure. That is that they had a relatively centralised format, using fossil fuel and sometimes hydroelectric power plants to generate electricity through turbines, which was then transmitted and distributed around networks to end users. Over the years, as the power grids over regions overlapped and intertwined with each other, these networks became interconnected ones that required greater levels of control and management. For a long time, the growth of energy grids grew steadily and in an easily foreseeable manner where peak demand and consumer use of electricity grew proportionally with the population.[68][69][70]

Significant changes in the growth and format of electricity power grids are driven by advancements in technology that change possibilities for creating electricity. Recently the rapid acceleration of photovoltaics is a good example of this. [362]

Installations of photovoltaic panels by homeowners has resulted in the need to create a power grid that not only provides electricity to end users, but also readily accepts their excess production during sunny periods. In effect, the modern power grid has become a two-way street, and is becoming more and more so as time progresses – the term prosumer is becoming more appropriate than consumer for a growing portion of users. People want to be able to create electricity locally, store it, use it when required, provide their excess to the grid, and be paid for doing so, and rely on the grid in times of their own low production – all these demands on the network drive it to become more complex and adaptable.[101][69]

Overall, it is necessary to know that ever-changing energy demands and production of both energy providers and end-users necessitates architectural changes to the energy grid.

Changes to the energy grid mentioned include making sure that sufficient capacity of backup energy is available for times when renewable energy sources are either offline completely (solar panels at night) or providing little output (wind farms on calm days).[101][362][283]

Nonetheless, the transmission and distribution grid will need to be capable of carrying the peaks of supply when the need arises, and to distribute the electricity in a smart and intelligent way between the homes or end-users with and without their own local power production capabilities. The installation of smart meters and switches is an upgrade to the distribution network that facilitates this.[97]

6.2 Energy storage

Energy storage, primarily as batteries, is another area that needs improvement in terms of its capability. Increasing the capacity and longevity of storage will allow the grid to become more reliant on energy that is stored for moments of peak demand, and to store energy generated by both large and small-scale variable generation technologies like wind and solar.[68]

The ability to store energy not only at a local level, but also on a scale that can serve the distribution network over a large range will become more important as energy resource diversification grows.[68]

6.3 The grid of the future

A summary of the future of the energy grid is that demand for electricity will increase, and innovation will bring improvements in efficiency, transmission, and distribution. Increasing population will drive a requirement for more energy output, and more complex and intelligent ways of controlling it.

Electric vehicles will impact the grid through charging needs, and possibly by acting as energy storage as well. Modernisation of the existing grid will be mandatory in order to deliver all of these needs and developments.

Legislation adjustments will be needed to allow rapid integration of variable generation technologies at a local level into the larger network. Transmission and distribution networks will need to act together to regulate output versus demand. Physical hardware updates to the infrastructure, alongside software and computing technology will support bringing electricity to new levels of reliability.

7. CURRENT ELECTRICAL AND ENERGY CONCEPT IN CZECH REPUBLIC

7.1 Current energy mix at national level in the Czech Republic

Historically, the Czech Republic has relied heavily on coal – today it gives a third of the total energy supply. For electricity, it provides 46% of the total, and for residential heating plants, it makes up 25%.[71] It has reduced significantly in the decade between 2009 and 2019, down 19% due to wider implementation of alternatives such as gas, solar photovoltaics, bioenergy, and increased nuclear production.[71]

In 2021, the Energy consumption by source in Czechia was 450 Terawatt-hours, made up of 151TWh coal, 113TWh of oil (mostly for transport), 77TWh nuclear, 91TWh natural gas, 6TWh of hydropower, bioenergy, and waste (the highest with renewable contribution), and then minor contributions from solar (6TWh), and wind (2TWh) and other renewables (5TWh). Of these figures, more than half was produced in the Czech Republic itself. The following graph shows Energy consumption by source in the Czech Republic by year from 2000 to 2021[105]:

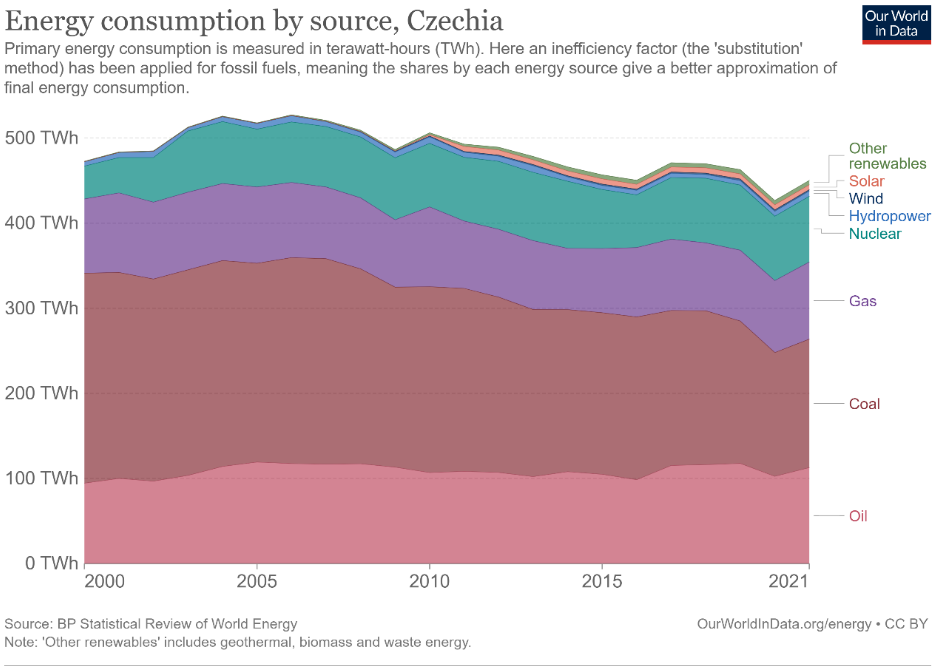

Figure 8 Energy consumption by source in the Czech Republic by source, 2000-21 (Note: reprinted) [105]

It is clear from the graph above that energy dependency on coal has been reducing steadily over the last two decades, however, the Czech Republic is still above average for CO_2 output and needs to focus on reduction of coal use and introduction of more renewables. This can be seen in the chart below showing Czechia versus Europe and the World [107]:

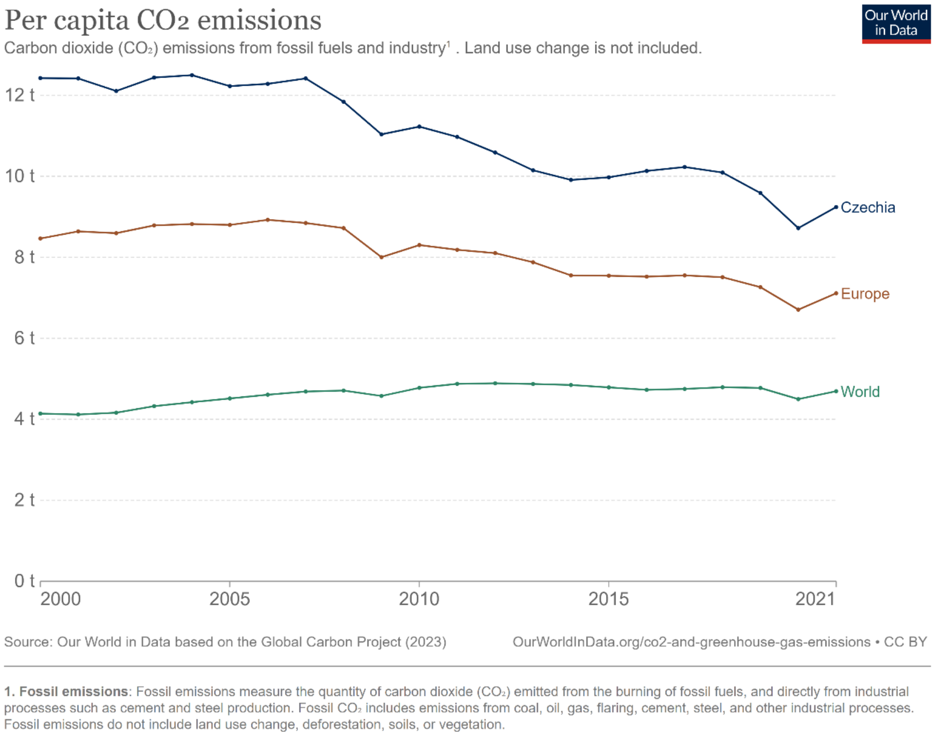

Figure 9 Per capita CO2 emission, Czechia, Europe, World (Note: reprinted) [107]

Only 3% of oil and 1% of gas used in the Czech Republic is internal, all the rest is imported.[71] Due to nuclear plants and heavy coal use, currently the Czech Republic is a net exporter of energy.[71]

Prior to 2015, the country was also exporting coal itself to Austria, but this has since stopped because the rate of production of coal reduced faster than the rate at which it was used for electricity generation.[71] Since 2016, the country became a net importer of coal, with most of it coming across the eastern border with Poland at 68%, and most of the remainder coming from Russia at 12%.[71]

The COVID pandemic did have a positive influence in terms of reducing coal power production in the Czech Republic – from 2019 to 2020, it dropped by 24%.[71] Although renewable energy sources are not common yet, they are growing quite rapidly, increasing by 71% between 2009 and 2019[71], where they have reached contributions of 22% towards heating, 14% of electricity[71], but only a small amount towards transport at 8%.[71] A subsequent positive from this was the 15% reduction of carbon intensity of the Czech economy.[71]

7.2 Energy resources in the Czech Republic

Energy security – the capability of a country to continue running as normal when there is a disruption to supply – is an important factor to keep in mind when considering the energy resources available in any country.

Energy security was stress-tested during the COVID pandemic, and the country did not experience any significant supply problems. In terms of post-COVID demand and supply to satisfy it, levels have now reached approximately the same as before the pandemic for both oil for transportation, and energy resources to support electricity production.[71]

7.2.1 Oil

Starting with oil, of which 97% is imported, the Czech Republic follows the IEA's guidance to hold oil stocks and has done so since 2004.[71] Currently there are around 125 days' worth of oil stocks.[71] However, these stocks are controlled by the government, and they have been called into use during minor disruptions, which suggests that Czech industries are holding little to no stock of their own and relying on the government in case of need. This should be considered if during the transition phase of the coal phase out additional pressure would be put on oil reserves. Most oil in the country is imported from Russia at 49%, then Azerbaijan and Kazakhstan at 28% and 13% respectively.[71]

7.2.2 Gas

In terms of gas reserves, the country is in a very positive position. Geographically, the Czech Republic is an important crossroads for gas transmission, and therefore has excellent storage facilities, which have reversible capabilities.[83] The storage system has overall capacity much greater than that required by current IEA guidelines and could easily withstand the failure of the largest storage facility whilst continuing without problems.[71] Gas storage projects have been continuing and at present, the storage capability is roughly equal to 6 months' worth of nationwide use.[71]

7.2.3 Coal

At current rates of use, there are around 3.8 billion tonnes of coal remaining in Czechia. There is some debate about how much is economically extractable, but estimates predict that the accessible reserves will only last for another 18 years.[107]

7.2.4 Nuclear

Currently there are 60 000 tonnes of Uranium in the Czech Republic which could be extracted. All mines are closed at the moment due to imported Uranium being cheaper.[108]

7.2.5 Renewables

There have been issues with government policies regarding renewables in the past which has held back growth. For example, in 2009 to 2010, many new solar plants were installed. This created a lot of new payments from the government for promises of support to fund them.

To slow this down, from 2011 to 2013, the government decided to make an additional charge to solar plant owners, the logic being that it compensated for the large support they had received.[95]. This had a very negative effect on confidence levels for companies to introduce more solar energy plants, and growth stagnated for some time as a result. Policies that have been put in place to correct this mistake have not proven effective to date, and so renewable growth is still limited.[71]

Heating and cooling represent the largest contribution to renewable use today in the Czech Republic, with a target to increase that by 1% per year until 2030.[71] As mentioned previously, biomass is the main source of fuel. However, the use of heat pumps has increased over the last decade. Once again, the country does not have very well-defined policy for this type of renewable energy, and therefore needs to formulate appropriate legislation to promote the further increase of such technologies. The chart below shows the split of renewable energy in the heating and cooling sector over the last 10 years [71]:

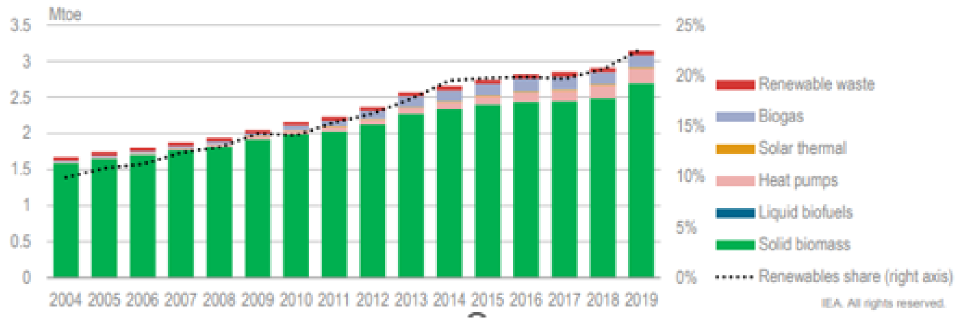

Figure 10 Renewable energy in heating and cooling in the Czech Republic, 2004-19 (Note: reprinted) [71]

Renewable energy sources in the Czech Republic for transport use are limited and are mostly made up of biofuel blending into oil-based fuels (95%) [71], with the rest being renewable electricity used to power trains.

7.3 Supply

Since the country currently exports electrical energy to Austria and Germany, they have many international connections in their energy grid.[84] This is a good support structure for the interim first stage of coal phase out, but it is anticipated that in the worst-case, extra connections between neighbouring countries would be required to sustain the country's energy requirements until new renewable and nuclear sources are online.

7.4 Current electricity generation at national level in the Czech Republic

Coal and nuclear are currently the largest contributors to electricity generation in Czechia. The following graph shows the major contributors [109]:

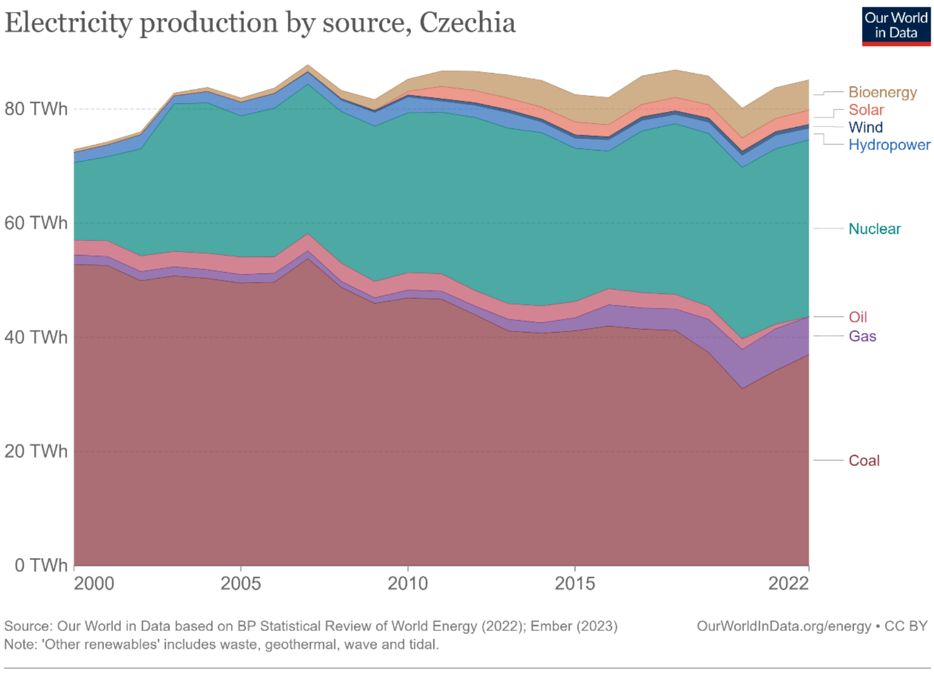

Figure 11 Electricity production by source, Czechia (Note: reprinted) [109]

Renewables currently make up a small fraction, which since its initial growth in the period of 2005-2010, has subsequently stagnated somewhat between 2010 and 2022. Total installed capacity for electricity generation is 18 326 MWe, of which 3,830 MWe is nuclear, 11 655 MWe thermal plants, 2 183 MWe hydro plants, 193 MWe wind, and 465 MWe solar [109].

In 2017, this meant that steam power plants covered 50% of the installed capacity, followed by nuclear (19%), solar (9%), steam-gas (6%), hydro (5%), pumped storage (5%), gas and combustion (4%) and wind (2%) power plants.[111]

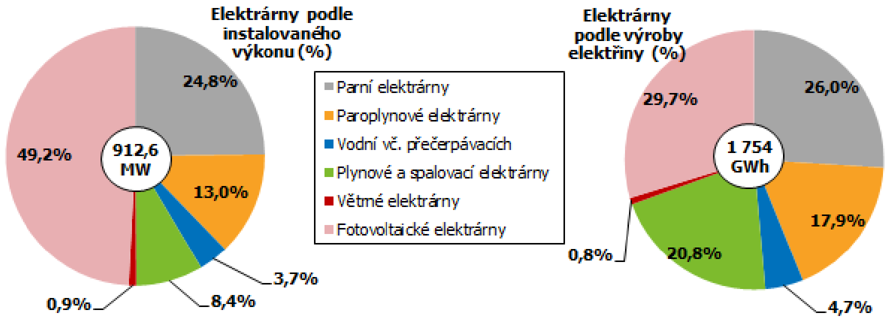

Figure 12 Installed capacity versus electricity production for the Czech Republic, 2020 (reprinted) [110]

7.5 Energy consumption, and use of electricity in the Czech Republic

Identification of areas for deployment of efficiency improvements starts with understanding where energy is used the most in the country to begin with. The following chart shows Total Final Consumption (TFC) from 2000 to 2019 for each of the key groups of Industry, Buildings, and Transportation:

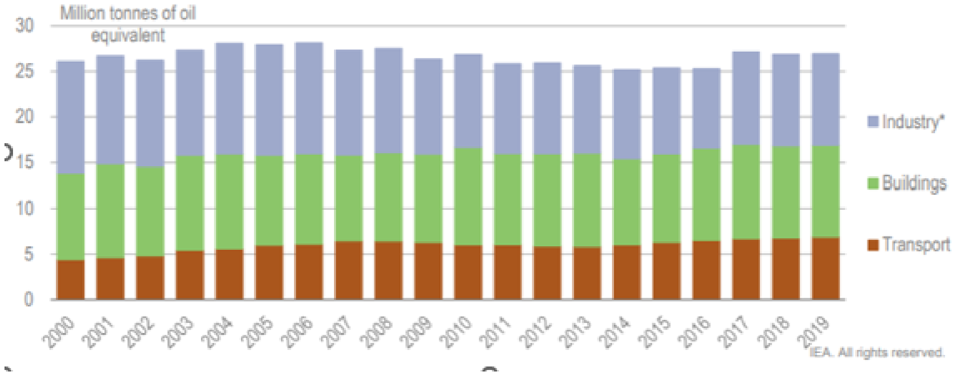

Figure 13 Total final consumption in the Czech Republic by sector, 2000-2019 (Note: reprinted) [71]

TFC is approximately a third each for each group, but with transportation being the slightly smaller one of the three at 26%.[71] Industry has been slightly decreasing over time, and buildings slightly increasing in its place. Although transportation makes the smallest contribution of the three groups, it means that oil is the primary resource used in the Czech Republic due to it dominating the fuel market for road traffic.

Observations from the chart above are that if the approximate 7 million tonnes of oil equivalent used in transportation are to shift to Electric Vehicles for the majority, then additional electricity supply will be required.

To target these groups for a better understanding of any future energy mix, it is important to understand the contribution of each energy resource type to each group. The following chart shows how each resource makes up the total for each group[71]:

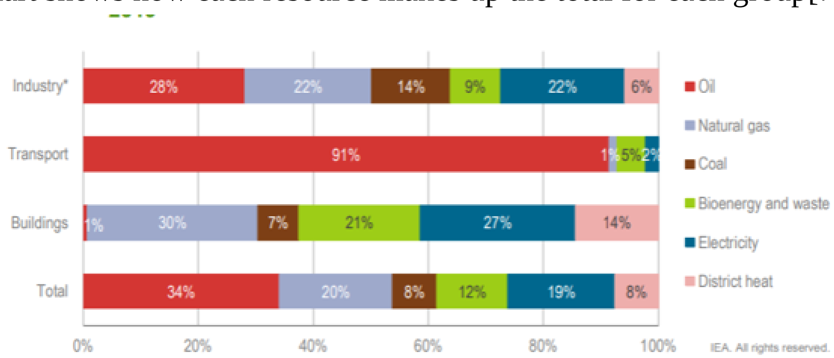

Figure 14 Total final consumption per sector per fuel in the Czech Republic, 2019 (Note: reprinted) [71]

The amount of energy that a country consumes can be made up from the following input: its activity level; the activities structure within the country; the efficiency level of those activities.[71]

Increasing activity increases the economic output of a country, but it is possible to achieve this by structuring that activity in a reduced energy-intensive manner, and by making notable efficiency savings.

The following chart shows these factors over the last 20 years, and demonstrates that actual energy consumption has remained approximately equal over time, despite activity rising, due to structural and efficiency improvements [71]:

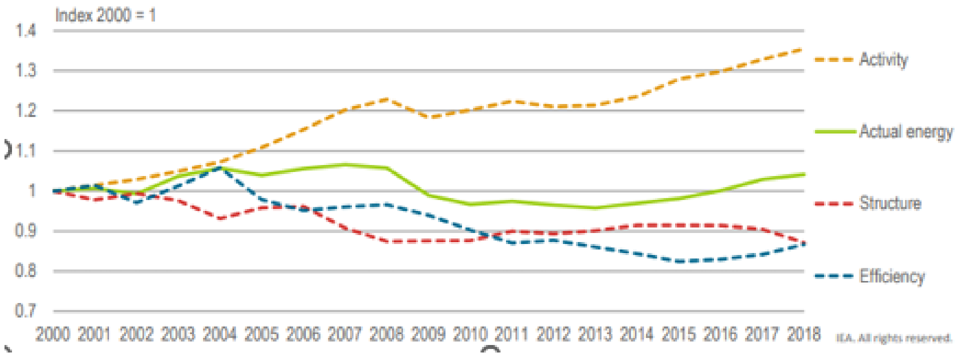

Figure 15 Drivers of final energy consumption in the Czech Republic, 2018 (Note: reprinted) [71]

The truth is in fact that overall savings in the residential and industrial sectors have been sadly offset by increases in the amount of energy used in both passenger and freight transportation.[71] The following chart shows this – we can imagine that if savings can be made through more efficient vehicles:

Figure 16 Cumulative savings (Note: reprinted) [71]

7.5.1 Industrial energy consumption

Although energy use in the industrial sector decreased over the last 20 years, we know that it is still the largest contributor to energy usage in the Czech Republic, and therefore offers the area for the most significant continued reductions. It is important to understand the types of energy used, and the types of industries that are using them. Starting with the types of energies used, the following chart breaks down the Total Final Consumption in industry in the country by source [71]:

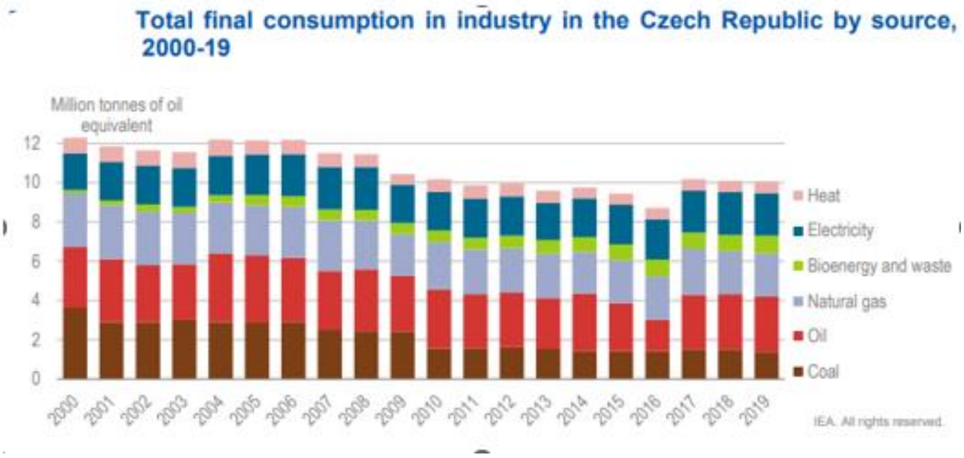

Figure 17 Total final consumption in industry in the Czech Republic by source, 2000-19 (Note: reprinted) [71]

It should be noted in the chart above that the anomaly of 2016 was not a reduction in energy usage, but in fact a reduction in oil due to a failure at a refinery in Kralupy which reduced oil production significantly.[71] Observations from the chart include the reduction in coal use, and the overall reduction in energy use too. Bioenergy has increased, and the total has stayed even over the last few years.

Looking next at the types of industries present in the Czech Republic, chemical and petrochemicals dominate the production output. The contributions from other industries can be seen in the pie-chart below:

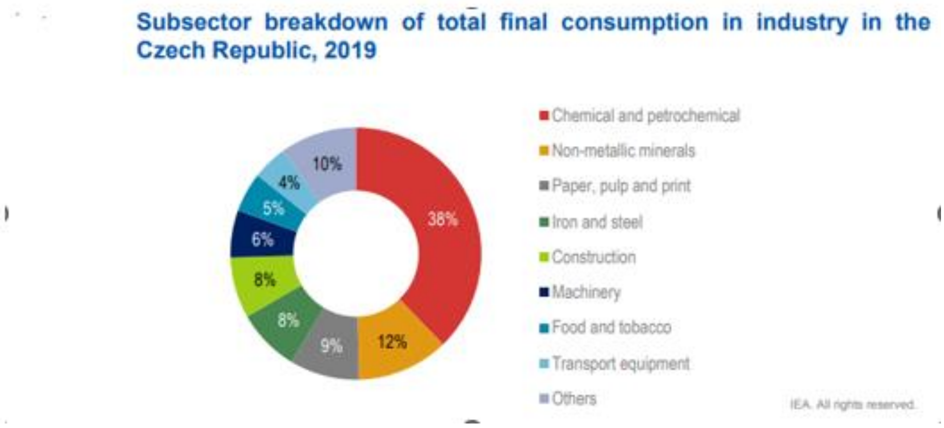

Figure 18 Subsector breakdown of total final consumption in industry in the Czech Republic, 2019 (Note: reprinted) [71]

Any future energy strategy would need to consider the needs of these industries, and their potential growth. This could have a very significant effect on the country's future energy needs, just in the same way that a switch to Electric Vehicles instead of oil-based fuel ones would have.

7.5.2 Transportation

The following chart shows how transportation energy needs are covered up to 2019:

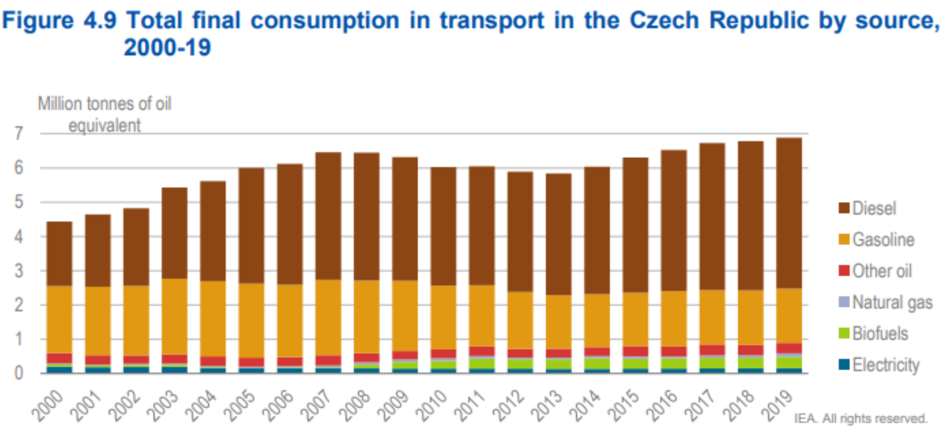

Figure 19 Total final consumption in transport in the Czech Republic by source, 2000-19 (Note: reprinted) [71]

It is very clear from the above that oil, specifically Diesel and Gasoline, covers almost all the energy needs currently. There are very few Electric Vehicles in the Czech Republic today, and equally there are not many vehicles running on natural gas or biofuels – indeed, most that do are for public transport.

7.5.3 Buildings

Total Final Consumption of energy in the Czech Republic used for buildings has remained even for the last 20 years. Since most of the energy is used for space heating (69%) [71], the amount used each year is for the majority a function of winter low temperatures. The following charts show residential energy use by application, and by energy type for 2019.[71] Although coal use has declined over the last 20 years, the data for 2019 can be taken as representative, and certainly sufficient for making future decisions on which areas are the best to focus on in terms of efficiency improvements[71]:

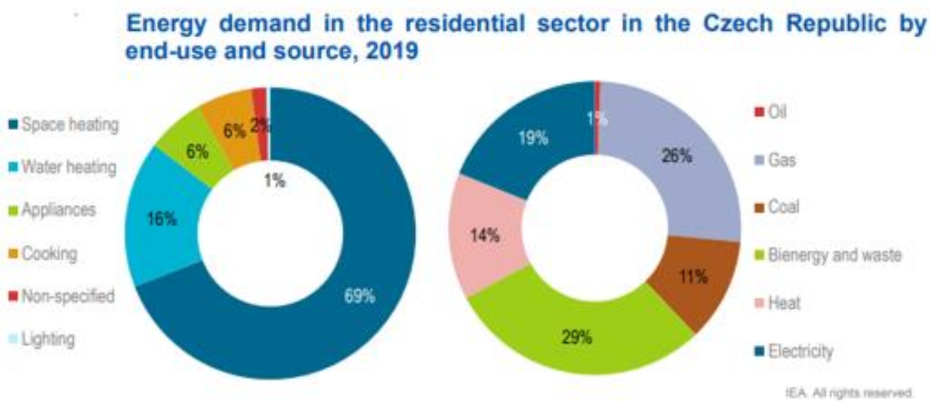

Figure 20 Energy demand in the residential sector in the Czech Republic by end-use and source, 2019 (Note: reprinted) [71]

7.5.4 District Heating (DH)

The Czech Republic has a slightly more complex structure in this respect than some of its other European Union member countries in that it uses DH systems for a large part of its population, around 40%.[71] Currently the taxation on these large DH systems is higher than compared to smaller or individual heating options. Coal is used to provide heat for 58% [71] of the DH systems across the country. The following chart shows the complete breakdown of fuel sources used for DH in the country [71]:

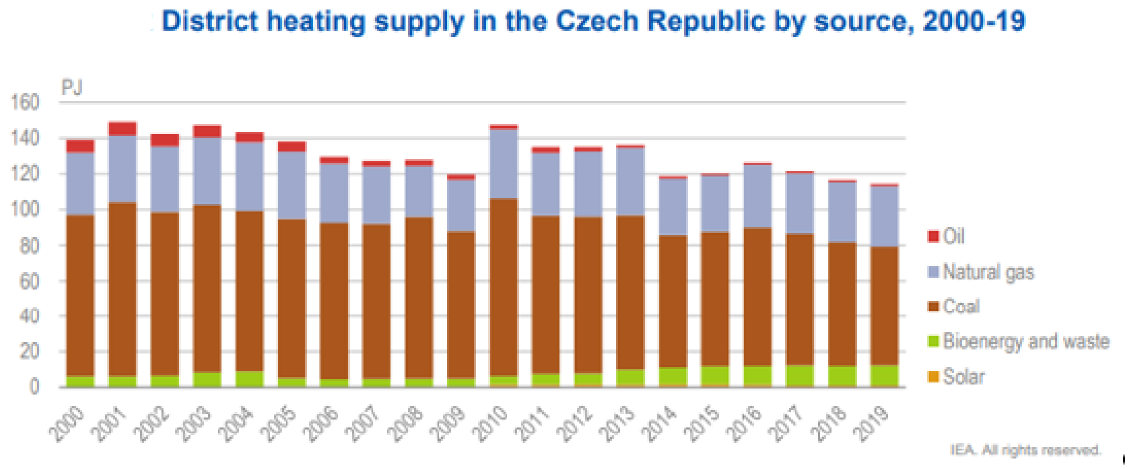

Figure 21 District heating supply in the Czech Republic by source, 2000-19 (Note: reprinted) [71]

7.6 Influencing factors on future energy concepts for the Czech Republic

The current plan of the Czech government is to phase out coal by 2038 at the latest.[73] The coal industry provides many jobs in the Czech Republic. Closing it down will require time to put in place renewable alternatives, and to allow the population employed in the industry to find new work.[71][72] Coal miners and plant workers will need to be retrained – government initiatives will be required to get the population on board with the change as without them, it will not be successful.[72]

Gas power would initially cover the energy needs as coal was phased out, and eventually, from 2036 onwards, nuclear would take over most energy production in Czechia as by then new facilities could be online and commissioned.[71]

However, as coal is phased out, it could become a net importer if no new infrastructure is put in place to replace coal. Interconnections in the electricity power grid with neighbouring countries are strong, but even more may be required to cover the coal phase out period before new resources are online.

Identified possible routes to accelerated coal phase out are energy efficiency policies and the introduction of carbon taxation.[71] The government is currently working on updating energy policies, regulations, and legal requirements.

7.7 Phasing out coal

The country has targets and commitments to phase out coal as laid out by the European Union, so sooner or later, the phase out of coal will need to happen.[77]

The timing of this has not been agreed yet, because in the Czech Republic, the situation is quite complex because the country has a lot of coal, and has used it to power its economy, industry, and to provide electricity to its population. Time, planning, and appropriate policy will be required for success.[74]

Part of the time dependency is due to the time it takes to construct, and fully commission, new alternative sources of energy, particularly nuclear.The other important factor is the existence of infrastructure for coal energy production, which will not be wasted and should serve its useful life, even if that means reducing its efficiency by upgrading it to run with carbon capture technology.

Gas represents an excellent interim step in the coal phase out. Due to the desire to exploit existing infrastructure before de-commissioning it, and the time to install new nuclear reactors, a two-phase approach is likely to happen.[76]

The first phase would take place until new resources, such as nuclear, were online. A continued increase in renewable energy infrastructure will carry on, slowly improving its contribution to the overall energy output. At the same time, in the short to medium term, gas power could be used to further reduce coal output.[76] In this way, coal could be brought down to a level estimated to be in the high 30's in terms of percentage contribution to energy demand.

In the second phase, likely to be around 2036, when new nuclear plants are online, the coal contribution could be significantly reduced, allowing a phase out of coal by 2038.[74]

This means that existing coal plants need to be maintained and kept running until their de-commissioning in approximately 15 years from now.[71]

Such a strategy does raise specific questions in terms of feasibility, and still relies upon aggressive targets being met.

For example, the targeted contribution from renewables is an area where the Czechs are lacking in progress. Government incentives, and a new definition of a framework for consumers versus prosumers needs to be made, to push homeowners towards integration of renewables into their homes.[77] In 2019, 3.6% of total energy generation came from renewables, but in 2030, solar and wind should contribute 15%.[71] Ensuring this will then reduce the need for so many new gas-fired plants to make up the deficit as coal power generation reduces over time.

The European Union does provide a fund called the 'Just Transition Fund' [78] which is intended to provide a fair transition for workers whose industry is phased out, allowing them access to training in other domains to ensure that they do not become unemployed.[78] This would be important for the tens of thousands of people employed in the coal industry.

7.7.1 Coal phase out acceleration strategies

Over the last 5 to 10 years, the Czech Republic has been deploying energy efficiency strategies at a government level. This must continue and be intensified. The driving reason for this is that simply by making improvements in efficiency in all areas of industry and domestic living, the amount of energy required will be reduced, and this will reduce the pressure on coal to provide most of the energy in the country. Policy focused on the 'Energy Efficiency First' [79] principle would reduce the need for excess energy in heating and stress the energy network less and allow reduction in coal burning.[79]

Industry's use of coal at 14% is double that of buildings at 7%.[71] Identification of industrial areas and intelligent positioning of alternative renewable energy sources near them is an obvious step in coal usage reduction. However, the 7% from buildings [71] could be reduced by applying the 'energy efficiency first' approach – if a government body existed that promoted and subsidised the costs of installation of increased efficiency lighting and other uses of electricity, then the figure could be reduced simply by using less energy to do the same tasks.[79]

Another strategy that will drive industry and society towards a more rapid coal phase out is introducing an appropriate taxation on carbon dioxide emissions [80]. Currently the Czech Republic has a very low rate of tax on CO_2 when compared to other OECD countries.[81] As a result, there is certainly a margin to increase the level of taxation and drive industries and consumers towards lower carbon technologies which will become more attractive and cost-effective as the taxation increases.

This means that two steps need to be taken – firstly, the decarbonisation of the DH systems needs to happen.[82] This could be achieved via heat pumps. The second step is to ensure that those leaving from the DH systems and using individual systems are also incentivised to use low carbon sources of energy for their heating, since the taxation on them is lower.

The country is also considering research into geothermal heat sources for DH, which could be a decarbonisation option.

Individual metering would also be a good strategy as it is already proven that people are more conscious of the heating they use, and try to reduce it, if they pay on a per person basis rather than as a group.[97]

A major positive of DH is that the plants tend to be located outside of cities which helps to reduce overall air pollution in larger towns and cities. If moves to renewable fuels can be made for all DH plants in the future, then it would maintain this situation that homes inside towns and cities would continue to not emit greenhouse gases when benefitting from hot water and heating.[115]

7.8 Future policy and potential scenarios

Government policy for energy will be critical in determining the future framework for the Czech Republic. The existing State Energy Policy (SEP)[85] was written in 2015 and gave information until 2040. In 2021, it was decided that the policy should be updated, and the next revision is due to be released at the end of 2023.[85]

Before hypothesising about the potential scenarios that could, or should, be described in any new policy, it is important to understand what the main targets of such a policy are. The current document defines security of the energy supply, competitiveness of price, and sustainability as its main objectives.[85]

To support these targets, five priorities are defined which are: a balanced mix of energy; improved efficiency and savings of energy; infrastructure development; investment in energy research; guarantee of energy security.[85]

In addition to the SEP, there also exists a Climate Protection Policy [112], which was released in 2017. It gives targets for emissions in 2030, and desired future paths of emissions reduction until 2040 and 2050.[112] The SEP needs to be defined in such a way to consider these targets, especially as it comes to the use of fossil fuels and greenhouse gas emissions. The combination of these two policies provides an approximate range of what is and is not feasible in terms of energy mixes in order to stay within emissions targets.

The following table provides us with a baseline to work from based on the energy mix as it was in 2016, and the current target for 2040, before the 2023 update of the SEP [71]:

Total primary energy supply in the Czech Republic by source

Fuel source	2016 level	2040 target level
Coal and other solid non-renewable fuels	40%	11-17%
Oil and petroleum products	20%	14-17%
Gaseous fuels	16%	18-25%
Nuclear energy	15%	25-33%
Renewable and secondary energy sources	10%	17-22%

Source: MIT (2015).

Figure 22 Total primary energy supply in the Czech Republic by source (Note: reprinted) [71]

Several observations can be made from the table. Firstly, a significant reduction in coal is obvious, down to around a third of its current value. To replace it, an approximate doubling of nuclear is foreseen, assisted by a similar increase in renewables. Gas also increases, but by a small amount – however, as previously mentioned, gas may have a significant role to play in the interim period before new nuclear infrastructure gets online, as it can take 10-15 years to commission a new nuclear reactor.

Since coal is the only resource for which the Czech Republic is self-sufficient (excluding uranium, where mining has ceased due to lack of commercial viability versus imports), there is a race against the clock to accelerate renewables, start construction of new nuclear plants, and to get gas electricity generation plants ready to cover the interim period.[71]

Such targets also need to take into account how the future energy demand may look, and indeed for what purposes it will be used.[87] Switching from coal to nuclear for electricity generation is a relatively like for like replacement, whereas moving the automotive industry away from oil-based fuels towards Electric Vehicles will put a greater demand on the electricity infrastructure and mean that new investment needs to be made into things like charging stations and so on.

Looking at the renewables target, given the potential for expansion of such technologies in the Czech Republic, the target range looks relatively low and should be easily achievable. An alternative scenario would be to put a greater emphasis onto renewables, to assist bringing coal use down to the lower range of the targeted levels.[71] Since costs of installation of wind power and photovoltaic cell farms is continually decreasing, the potential to increase the share of renewables to electricity should improve over time.

7.8.1 District Heating potential future scenarios

DH provides hot water to almost half of the Czech population (around 4 million people), and coal currently contributes to 58% of that.[71] Installation of heat pumps at the domestic and large-scale level could be a significant help towards reducing coal reliance.

Currently, there are plans in progress to extend the DH systems from the Temelin nuclear plant to Ceske Budejovice, and similarly from the Dukovany plant to Brno.[88] Completing these initiatives would make a large contribution to removing a portion of coal from the fuel mix of DH systems.

Such initiatives as benefitting from nuclear energy for domestic heating are significant in the Czech Republic, not only because of the reduction of coal use, but also because it removes the need to pay for the cost of emissions at co-generation plants which don't use coal.[71] Currently, such costs need to be paid by the supplier if they use coal, and they in turn pass this cost on to their customers. People can avoid this currently by installing their own local heating, which is problematic as it creates a less cost-effective solution for DH for the end-user, even though its overall efficiency is better.[89] Carbon tax could be a solution to this. It could be possible to introduce staggered carbon taxation on fuels over a period of time, so that end-users are not hit with a huge price increase in a short time frame, but rather have longer to react to policy changes over time.[71]

Fortunately, as it comes to the increase planned for nuclear energy in the Czech Republic, the public opinion on this type of energy generation is positive.[90] As a result, plans are underway to install a new reactor with an output of 1200 megawatts in Dukovany by 2036.[71]

7.8.2 Electromobility and Transport

Though transportation currently is not a significant contributor to electricity generation needs, this will change in the future.[93] As we have seen, oil-based fuels will need to be phased out, particularly for passenger vehicles, due to their significant emissions output.

However, the Czech Republic's National Energy and Climate Plan [114] already targets CO_2 emissions reduction via a shift to electric vehicles which will move the transport fleet away from oil-based fuel consumption. [114] This is only worthwhile in terms of CO_2 though if the electricity generation portfolio is lower in terms of emissions than the equivalent oil-based solution.

Efforts are nonetheless being made to improve the emissions of oil-fuelled vehicles, which will help overall CO_2 emissions even if Electric Vehicles are delayed.[71] Increasing the percentage of biofuel which must be included in oil-based fuels from 2% in 2014 to 6%[71] in 2020 has helped somewhat but will still not match the CO_2 reduction achievable from an Electric Vehicle if it is charged using renewable source electrical energy.

Just as targets were laid out above for the contribution of each energy type to the total energy mix, the country also has targets for alternative fuels and associated infrastructure, namely charging and refuelling stations. The following table provide the targets for 2025 and 2030, using 2020 as a baseline [71]:

Status and targets for alternative fuel vehicles and charging infrastructure in the Czech Republic

Type of vehicle	2020	2025	2030
Electric vehicles	17 000	101 000	250 000-500 000
Public charging stations	1 300		19 000-35 000
CNG vehicles	49 820	130 000	250 000
Refuelling stations	200	300	340-400
LNG vehicles	180	500	1 300
Refuelling stations	0	5	14/30
Hydrogen vehicles		95	40 000-50 000
Refuelling stations		15	80

Sources: MIT (2015); MIT (2019).

Figure 23 Status and targets for alternative fuel vehicles and charging infrastructure in the Czech Republic (Note: reprinted) [71]

The information above analysed more. There are around 200,000 new vehicles sold in the Czech Republic each year. Over a 10-year period, this means estimated sales of 2 million vehicles. If the upper target for 2030 is to be met, then it means that a quarter of all cars sold must be electric in that time-period. Unless there is a dramatic increase, then this target seems highly optimistic, as does the EU target to end Internal Combustion Engine vehicle sales in 2035.[94]

Upgrading the country's infrastructure to install the required number of charging points will be required. These activities will take time and should be done in a progressive step-by-step way to make sure that EV's are being charged in a way that reduces CO_2, not simply adding to the volume of applications requiring coal power [71].

Relating to renewables and transportation, a final word should be kept for hydrogen vehicles, as there is a target to have 118200 such vehicles by 2030 in the country.[71] This would achieve a reduction of carbon dioxide emissions of 308000 tonnes.[71]

7.8.3 Buildings

Any efficiency measures to combat heat loss will be effective in reducing energy demand. Block residential housing in the country tends to be insulated with polystyrene blocks to reduce heat loss. There are many older buildings too that the government could focus its subsidies on public non-residential buildings. The benefits for well-used buildings such as older hospitals, schools, retirement homes, and sports complexes would add up to significant savings.

The country has offered subsidies for the replacement of old and coal-burning boilers in the past, ranking them by their age in terms of emissions class, and so there has been a staggered release of eligible owners. By 2023, there will have been 100,000 boilers needing to be replaced under the scheme – another 80,000 will need to be replaced by 2030.[71] The benefit of this activity will be significant – not only will it reduce coal burning, but it will also improve efficiency, and reduce CO_2 emissions.

7.9 Renewables

There is significant scope in the Czech Republic to expand the renewable energy sector. The predominant renewable energy source in the country in 2019 was bioenergy, which made up 3.5 of the 3.8 total million tonnes of oil equivalent energy from renewables.[71] This total made up only 15.8% of the Total Final Energy Consumption of the country.[71] Growth in solar, wind and possibly further hydroelectric power would help. Although the numbers seem low, it is not to say that there has not been growth in renewables over the preceding 10 years, just that more needs to come – the following chart shows the growth by resource:

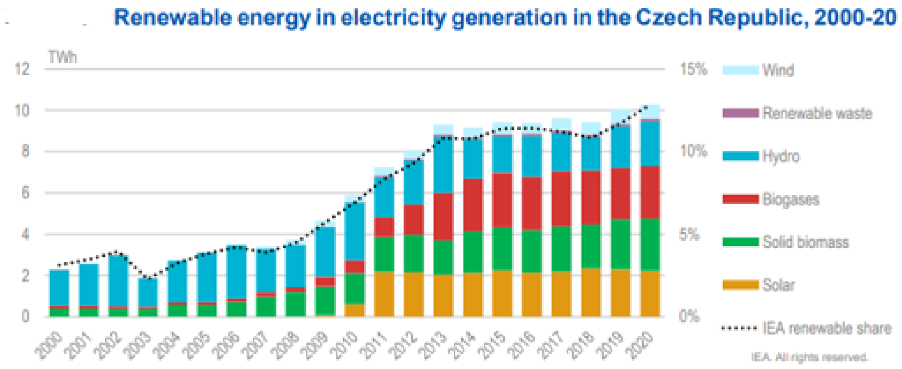

Figure 24 Renewable energy in electricity generation in the Czech Republic, 2000-20 (Note: reprinted) [71]

It is important to understand where this energy produced by renewables is being used to be able to identify where growth could be achieved in the future. Almost all the renewable energy from bioenergy goes into heating and cooling. Contributions to electricity generation and transportation are almost insignificant, and therefore they are the biggest areas for potential growth.

There are a lot of possible options for photovoltaic cell installations, not just in standard solar farm structures, but also in terms of available rooftop space on both government and residential buildings. An attempt to maximise this must be made to accelerate growth and make the 2030 targets become a reality, especially given that rooftop solar power in the country could have a value of around 11.8 gigawatts.[71]

Modernisation and diversification of energy resources contributing to electricity generation requires upgrades to the existing grid. It has been calculated that by 2030, the maximum amount of solar power that could be accepted would be around 8 or 9 gigawatts [71], without threatening the safety of the grid overall.

7.10 Emissions

A significant influence on the future scenarios of energy in the Czech Republic relate to greenhouse gas emissions. Targets are set by the EU, and currently the country is not on track to meet them by 2030.[91] That said, emissions have been reducing with time, as can be seen in the following chart:

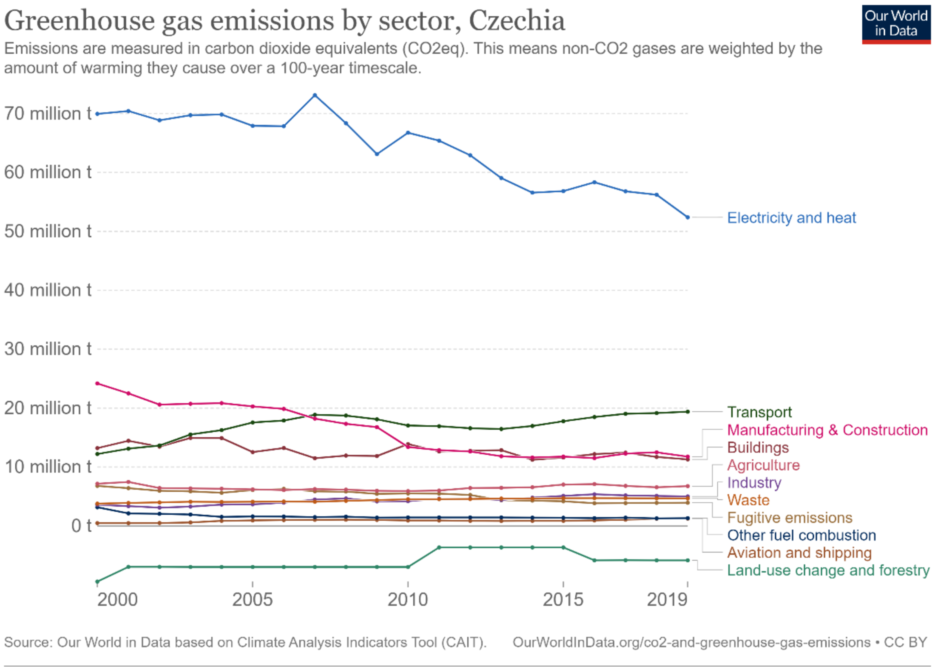

Figure 25 Greenhouse gas emissions by sector, Czechia, 2000-2019 (Note: reprinted) [113]

When observing the chart and interpreting its meaning, it is worth relating back to the previous graph showing energy production by fuel type for the Czech Republic over a similar time-period. There is a clear correlation between the reduction in coal and other fossil fuel use and the number of emissions.

The chart allows us to recognise that electricity and heat production are the main drivers of greenhouse gas emissions, with all other sectors being minor contributors.[113]

It is reasonable to deduce that shifting the electricity generation sector towards renewables and less-polluting types of fossil fuels will bring the country back on track towards the 2030 target. Coal accounted for 58% of carbon dioxide emissions in 2019, despite its output reducing by a quarter in the last 10 years.[71]

Translating the targeted emissions reductions into real numbers in terms of millions of tonnes of carbon dioxide equivalent is useful to help in defining the amount of reduction in fossil fuel use, in particular coal. The following table shows bands of 10 years with their absolute and relative CO_2 reductions with 2005 as a baseline, and noting that in 2019, the absolute reduction level was 25.1 Mt CO_2-eq [71], or relatively speaking, 17%[71]:

Overview of greenhouse gas reduction targets and ambitions (compared to 2005)

Year	Absolute reduction	Relative reduction
2020	32 Mt CO_2-eq	20%
2030	44 Mt CO_2-eq	30%
2040	78 Mt CO_2-eq	53%
2050	109 Mt CO_2-eq	80%

Source: MoE (2017).

Figure 26 Overview of greenhouse gas reduction targets and ambitions (compared to 2005) (Note: reprinted) [71]

There are, of course, other factors to consider when targeting these kinds of reductions in emissions, especially when nuclear power is considered as a major contributor to the reduction, as it still requires a significant amount of water for cooling purposes.[92] The Czech Republic has identified availability of water for cooling as a major risk for energy production, citing recent hot summers which have resulted in low water levels. Possible solutions are circular cooling technologies rather than single-pass cooling.[71] Added to this is the desire to reduce the use of hydro-electric power plants due to their negative effect on the environment and local ecosystems, and the fact that rising global temperatures may mean that there is less water to flow through them anyway – this will create an energy deficit which needs to be filled by nuclear power, resulting in more water being required for cooling.

8. SCENARIOS OF THE CONCEPT OF ENERGY IN THE CZECH REPUBLIC

8.1 Future scenarios outlook

As we have seen over the previous sections, the outlook for electricity generation in the Czech Republic is going to be influenced by some key factors, namely: the targeted phasing out of coal by 2035; making sure that the supply is secure; accommodating new drivers for electricity demand such as EV's.

There are, of course, factors which will stand in the way of the coal phase out – firstly, the existing infrastructure, whose life is to be maximised so as not to waste previous investment.

Secondly, the Czech government aims to sustain its position of being 90% self-sufficient, which will mean that renewables must be invested in heavily, since currently that self-sufficiency is delivered by the naturally abundant coal reserves in the country.

Thirdly, the time delay required to bring online new nuclear power plants will mean that interim solutions like gas-power, or continued coal use will be needed.

Alongside the 90% self-sufficiency target, the government has also imposed another target which is logically not to import more than 10% of the electricity consumed each year. This target, though understandable from an independence perspective, is directly in conflict with the target date of phasing out coal, unless a significant increase in domestic renewable energy supplies is seen.

As a result, the country's Coal Commission made a recommendation in 2020 to phase out coal by 2038[115], or in other words 3 years after the EU target date.

We have already seen the proposed ratios of each type of energy in the total energy mix, and when asked if it would be possible to bring the coal phase out date earlier than 2038, the response of the Coal Commission was that this would then impose the need for more gas-powered plants in the interim.

The obvious question this raises is if it is worth investing in gas-powered plants, meaning further fossil fuel use for a longer period, since the gas-powered plants would need to reach their intended target life, rather than just be a short-term fix.

Perhaps it would in fact be better to just wait the extra 3 years, or whatever time is required, to phase out coal and replace it with something which is not fossil-fuel based, such as nuclear power which would represent a much longer-term solution.

Perhaps another solution is to start much sooner and try to phase out coal even earlier than originally planned, bringing in gas-powered plants which would then spend more of their useful life before 2035. This could achieve a coal phase-out by 2033, and then mean that the gas-powered plants could be phased out later for nuclear plants when they were ready. In either scenario, nuclear becomes the main contributor of electricity generation, reaching around 5 gigawatts of output, meaning a need for approximately 1.2 gigawatts more than is available today. This is currently what is planned long-term by the government – it leaves only the choice between starting gas power introduction as an interim solution sooner, or later.[71]

Another one of the factors impacting the future scenarios worthy of mention, is the EU's Emissions Trading System (ETS). This sets a price for carbon dioxide emissions per tonne, and this price is expected to increase over time, driving the move away from fossil fuels.[96] Although the impact of this is higher on coal plants, it still has an influence on gas plants too, so they will also become less economically viable over time. This will need to be considered when making the decision on how to organise the energy mix to avoid investment in infrastructure that does not make economic sense in the long term.

Many studies have been made into the best route forward for a decision on the Czech energy mix in the future, and each one has had to make a set of assumptions for parameters which are not yet fixed – like, for example, how the EU ETS price will be controlled over the next decade or two.

As a result, all the studies come with slightly different outcomes depending on their bias or input variables. Here, we will take a look at one such example which takes 2019 as a baseline, then provides 2 separate outcomes – one as a reference case where essentially only the required amount of renewables is added to the energy mix, and then another which is looks at the mix if on top of the renewables, coal is phased out to a zero contribution by 2038.The study's results looks like this:

Installed electricity capacity in reference and conceptual scenarios in the Czech Republic, gigawatts (GW)

Product	Scenario	2019	2033	2038
Coal	Reference Conceptual	10.7	4.89 2.90	2.96 0
Gas	Reference Conceptual	2.30	1.32 2.22	1.32 3.72
Nuclear	Reference Conceptual	4.29	4.06 4.06	5.20 5.20
Renewables	Reference Conceptual	4.69	9.08 9.08	10.55 10.60
Batteries	Reference Conceptual		0.97 0.97	1.18 1.18
Heat producers	Reference Conceptual		1.58 1.58	1.66 1.66
Total	**Reference** **Conceptual**	**21.98**	**21.90** **20.81**	**22.87** **22.36**

Sources: ERU (2021); and information provided by the government from the "Intermediate outputs and recommendations of the Coal Commission (version for interministerial consultation in February 2021)".

Figure 27 Installed electricity capacity in reference and conceptual scenarios in the Czech Republic, gigawatts (GW) (Note: reprinted) [71]

It is interesting to note that in both cases, the nuclear contribution to the energy mix is equal, both in 2033 and 2038 – the extra approximately 1.2 gigawatts of capacity from nuclear is clearly an underlying fundamental to achieving a reduction in coal, and a 'home-grown' approach to electricity production.

Renewables vary very little in each case, but as predicted earlier, it is gas that must increase much more if coal is to reach zero. Though studies may be slightly different to one another, this conclusion is consistent amongst them.

Based on predictions by Bloomberg about the EU ETS price development, coal-powered power stations are likely to become economically non-competitive with other sources of electricity generation by around 2030.[96]

Gas could take this role well within the existing infrastructure of the country as it would use the same transmission network, without the need to upgrade the grid significantly for a diversified grid with lots of renewables in multiple locations.

Of course, such a growth of gas as an interim solution requires a reliable gas network, which is already present in the Czech Republic. Based on the assumption that no further unwanted geo-political situations restrict supply or drive-up price to an uncompetitive level, then the existing gas transmission network could be maintained and improved to tolerate the extra requirements.

Looking at the transmission and distribution networks, the type of smart grid infrastructure required for renewables is not yet present, nor is satisfactory legislation to facilitate users of it. Part of the future scenario in the country must therefore include having such a decentralised smart grid rolled out to allow renewables to grow, and homeowners to become prosumers instead of only consumers.

Modernisation has already started to some extent but will need to continue to accommodate greater connectivity for EV's at peoples' homes, and to allow batteries inside homes to store energy that may be harvested from photovoltaic cells mounted on rooves. Installation of domestic smart meters is expected between 2024 and 2028, and this will allow more efficient energy delivery.[97]

Further expansion of the country's nuclear capacity is already underway. The obvious benefits of this are twofold – firstly, the overall decarbonisation of the grid, and secondly, the relative ease of integrating further nuclear capacity at existing sites. Somewhere between 2030 and 2035, there should be around 2500 megawatts of installed nuclear capacity.[71] In addition, support for nuclear expansion is strong in the Czech population – a survey in 2020 reported that two-thirds of the population are pro-nuclear.[90]

9. PUGH MATRIX ANALYSIS AND RANKING OF HYPOTHETICAL FUTURE SCENARIOS

9.1 Analysis and ranking of hypothetical future scenarios

To make an analysis tool which can be updated in real-time if variables change that influence the best scenario for the future in terms of electricity generation, a Pugh Matrix has been created.[118] This allows each variable to be weighted, and each scenario to be scored. The scores and weightings are multiplied, and then the sum-total of all those multiples is calculated. These final scores can then be ranked against one another to see which scenario is the most favourable.

The benefit of this tool is that once the variables have been defined and scored, outcomes can be explored from different perspectives by simply adjusting the weightings, giving greater importance to certain factors over others.

9.2 Future scenarios and parameters survey

To quantify the pluses and minuses of the various future scenarios, it was decided to use a Pugh Matrix to rate them versus one another. This is a tool which is commonly used in business and professional settings to make quantified and scaled judgements, whilst reducing bias and unfounded opinions. Usually, the matrix is made up of a list of contributing parameters, versus a corresponding list of outcomes or scenarios. Each scenario can then be ranked as to its performance versus each of the input parameters.

To carry out this particular case, a list of parameters was compiled, primarily based on the ones from the analysis in the previous sections.

Each of the parameters was then given a weighting number, selected from 1 (Not Important), 3 (Less Important), 7 (Important) and 9 (Very Important). This number range allows for greater differentiation between parameters than, for example, a scale of 1 to 4. This is because the most influential parameter is then mathematically 9 times more important than the lowest, rather than only 4 times.

To set a baseline, each of the parameters was then weighted by the author based on all the previous research compiled in this report. However, it was also decided that it would be useful to compile a second version of the study based on public opinion to serve as a control over the author's interpretation of the detailed research carried out.

To capture this, a survey was put together in which respondents could provide their own judgement on the 1 to 9 scale described above. In this way, it would be possible to gain an insight into whether public opinion and perception was aligned to the findings of the research carried out by the author or not.

Averages of the respondents' weightings can be taken and fed back into the Pugh Matrix to see if a significant change in the result is seen. The scoring system described below is capable of highlighting such a situation.

For the Pugh Matrix scenarios, performance rankings were given, again based on the previous research findings, and again on the same scale of 1, 3, 7 or 9. In effect, at the extremes, this means that a scenario that performs highly in an important parameter will gain an overall score of 81 (9x9), whereas a scenario performing poorly in an unimportant parameter will only score 1 (1x1). There is therefore no need to use a zero value in the scoring, since an additional 1 point towards the total score of a scenario is negligible compared to a score of 81. The scenario scorings in full can be found in Appendices A and B.

Again, this provides a superior resolution after the overall calculation for differentiating between scenarios. The following table explicitly states the overall score given for each case of parameter weighting versus scenario score:

Table 2 Pugh Matrix calculation - Permutations

Overall score outcomes		**Scenario score**			
		1	**3**	**7**	**9**
Parameter weighting	**1**	1	3	7	9
	3	3	9	21	27
	7	7	21	49	63
	9	9	27	63	81

To calculate an overall score for each scenario, the total of all these weighting and score multipliers is summed. The overall scores can then be ranked to see in which order of preference they fall, but furthermore, the difference between each scenario is also quantified. This allows us to see which scenarios are very close to one another, in which case they may require further research before a decision is taken to choose one over another. Equally, very low scoring scenarios can simply be removed from any further study to avoid excessive discussion on scenarios that are highly unlikely to ever happen.

To demonstrate the Pugh Matrix tool with a simple example, the following can be considered:

Table 3 Pugh Matrix Simple Example

		Scenarios / Scores		
Parameter	**Weighting**	**X**	**Y**	**Z**
A	3	1	7	3
B	9	3	9	9
C	7	1	3	3
D	1	9	9	7
E	9	7	3	7
	Score	21	31	29
	Rank	3	1	2
	Weighted Score	109	159	181
	Weighted Rank	3	2	1

In this example, 3 different scenarios are considered, X, Y, and Z. They are scored related to 5 different parameters, A, B, C, D and E. The importance of the parameters is quantified via the 'Weighting' column and is selected from 1, 3, 7 or 9. The total score in the row labelled 'Score' is simply the sum of all the scores for each scenario. This does not take into consideration the importance of each parameter though (mathematically, it is the same as if the weighting for all the parameters was equal to 1). The 'Weighted Score' row provides the sum of the multiples for each scenario. To be explicit for the example above, the Weighted Score for scenario X is:

Equation 1 Weighted Score Calculation Example

$$(3 \times 1)+(9 \times 3)+(7 \times 1)+(1 \times 9)+(9 \times 7)=109$$

The Weighted Rank gives the final order of preference of the scenarios. It should be noted in the example above that the ranking of 1st and 2nd place switches between 'Rank' and 'Weighted Rank', showing the capability of the tool to reorder the Scenarios based on the priority of the parameters.

Ultimately, four different versions of the Pugh Matrix were made and then combined into a single table in which all the various outcomes can be seen. The baseline version, called 'Research', is the one where the author's research was used to provide weightings and scorings. The second version, referred to as 'Survey – Democratic' uses the results of the survey to provide the most frequent response for each parameter weighting. In this way, it is like a democratic vote which in some cases will be accurate but can also be misleading if the result of the voting was close.

To take this into account, two further versions were created. The third version, referred to as 'Survey – Average', uses the mean values of the voting to provide parameter weighting. The downside to this approach is that it tends to bunch the weightings close together, reducing the spread, and not giving as good resolution across the weighting scale. The final version considered, called 'Survey – With Skew' uses a more complex approach to define the weightings as follows:

The total number of responses was calculated – 39 parameters, multiplied by 119 responses, made 4641. However, 3 responses were missing, leaving a total of 4638 responses. From this, the spread of responses was plotted in a histogram:

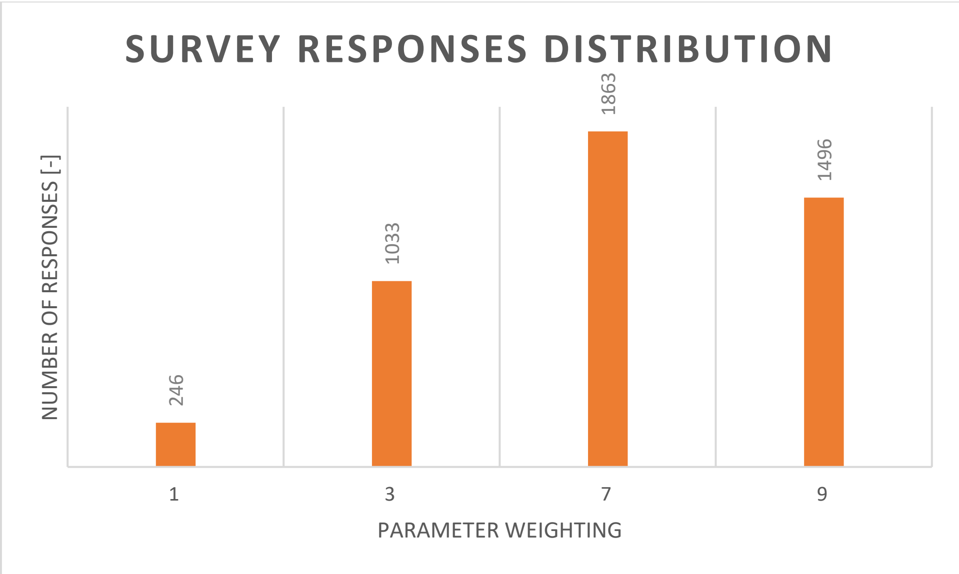

Figure 28 Survey Responses Distribution

From this, the percentage of each response weighting was calculated from the whole, and then the correct number of parameters out of the 39 total was calculated, resulting in the following table:

Table 4 Parameter skew calcution tabulation

Weighting	**1**	**3**	**7**	**9**	**Total**
Number of responses	246	1033	1863	1496	4638
Percentage (%)	5.3	22.3	40.2	32.3	100
Number of parameters	2	9	16	12	39

The list of averaged parameter weightings was then used to order the responses from low to high and assign a weighting to each based on the table above. For clarity, the result was as shown below:

Table 5 Parameters with skew list

Original Parameter Position	Parameter	Parameter Weighting (Average)	Parameter weighting (with skew)
10	Air quality impact	8.08	9
6	Human toxicity	7.91	9
29	Reliability	7.82	9
28	Safety / Low catastrophic risk level	7.77	9
12	Ecological impact	7.76	9
3	Land use	7.62	9
19	Electricity price for consumer	7.57	9
20	Domestic Energy Supply Independence	7.44	9
1	CO2 emissions	7.34	9
2	Greenhouse gas Emissions	7.29	9
18	Cost per unit energy (kW hour)	7.22	9
39	Employment impact	6.82	9
21	Availability of Resources in CZ vs. international	6.76	7
37	Need (to meet energy demand)	6.76	7
11	Visual impact on Landscape	6.65	7
4	Water dissipation	6.56	7
5	Water eutrophication	6.53	7
26	Ease of maintenance/operation	6.43	7
27	Training / Workforce technical education	6.34	7
31	Low electricity storage requirement	6.34	7
23	Energy demand tolerance	6.24	7
22	Domestic fossil fuel depletion	6.21	7
17	EU / State subsidisation	6.19	7
25	Implementation timing	6.19	7
14	Operational and maintenance cost	6.13	7
24	Sensitivity to gas availability	6.01	7
16	EU ETS price	5.94	7
9	Noise	5.90	7
30	Low grid modernisation requirement	5.79	3
32	Ease to implement	5.77	3
33	Construction energy consumption	5.62	3
13	Acquisition / materials cost	5.51	3
8	Rare materials usage	5.40	3
35	International legislative acceptance	5.34	3
7	Non-rare materials usage	5.18	3
36	Political Willingness	5.17	3

34	International acceptance level	5.11	3
38	Legislative requirement	5.10	1
15	Potential drift of total construction cost	5.07	1

Once the four different methodologies of parameter weighting were complete, it was possible to make some interesting observations from the survey responses to see by how much and where they differed from the expected outcome based on the research. The complete Pugh Matrix with all the different methodologies included can be found in Appendices A and B. The following graph shows the results with the parameters ordered from high to low in a left to right direction based on the research weighting:

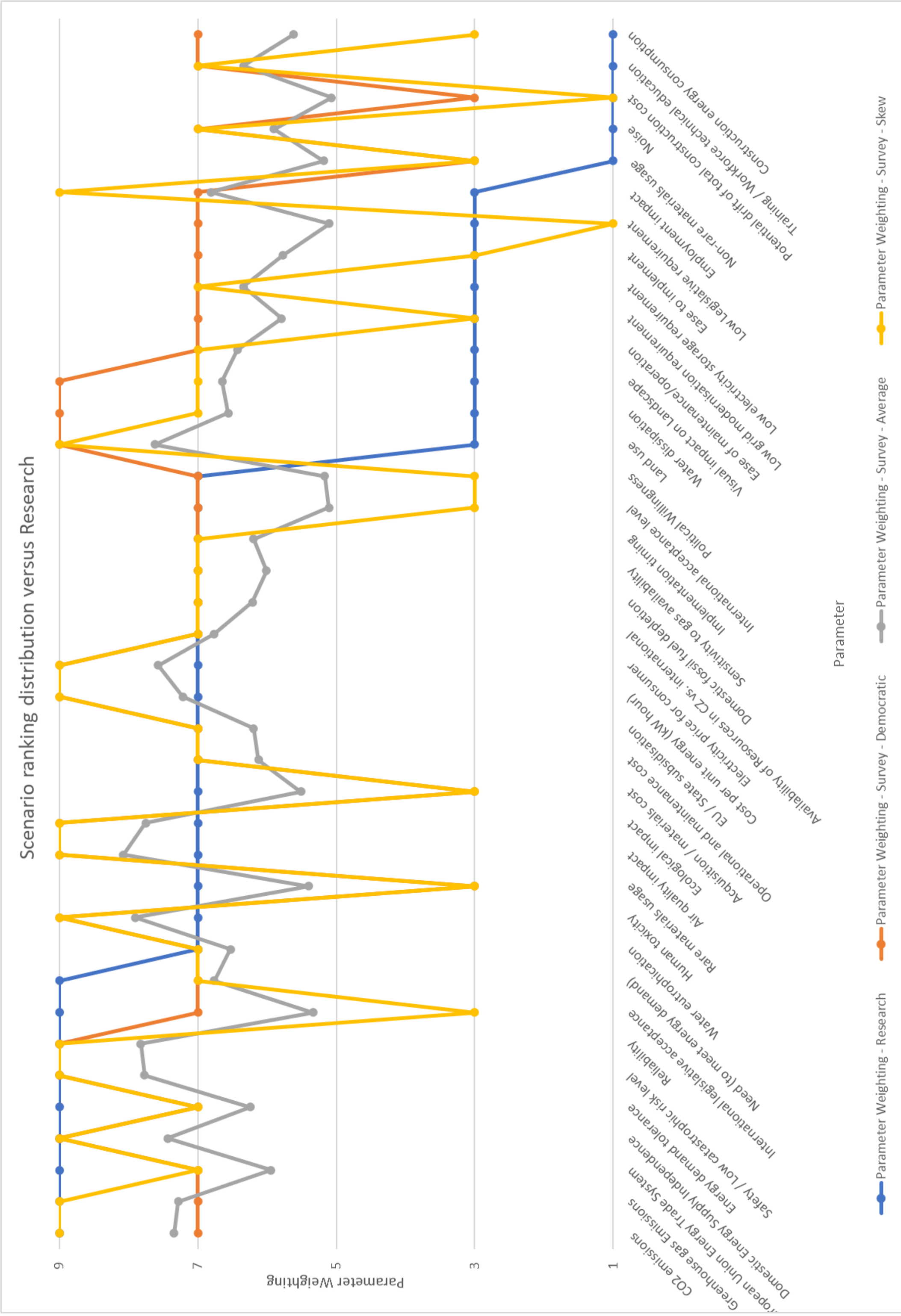

Figure 29 Scenario ranking distribution versus Research

Where weightings differ by more than one response level, observations can be made. Of the parameters weighted as 9 in the research, only one was weighted below 7 or 9 in the survey results, namely ‘International Legislative Acceptance’. It is likely that the public are not exposed to such legislation in normal life and may therefore be unaware of its importance.

Looking at the parameters weighted 7, none differed by more than one response level, but it is nonetheless interesting to note that all the parameters weighted higher in the survey are those that have a direct impact on the public, like ‘Human Toxicity’, ‘Air Quality Impact’, ‘Ecological Impact’, and both Cost and Price per unit of energy. On the other hand, those rated in the survey as 3 are only indirect impacts on the public, namely ‘Rare Materials Usage’ and ‘Acquisition / Materials Cost’.

In the group of parameters weighted 3, four parameters differed by more than one response level, and these were ‘Land Use’, ‘Water Dissipation’, ‘Visual Impact on Landscape’, and ‘Employment Impact’. Again, it is clear to see that the discrepancies occur mostly where the parameters have a direct influence or perceivable impact on the public. A conclusion that could be drawn from this is that if wind turbines are to be constructed in CZ, then their locations and impact on surrounding scenery need to be carefully considered.

Finally, in the group weighted a 1, two parameters differed significantly, those being ‘Noise’ and ‘Training / Workforce technical education’. Once again, noise is a directly perceivable impact, and suggests that wind turbine positioning is important.

To make a judgement on which was the optimum methodology to use for the survey results, a count was made on how many times the survey agreed with the research between the ‘Democratic’ and ‘With Skew’ approaches. It was found that the ‘With Skew’ methodology had the largest frequency of agreement at 15, versus only 12 with the ‘Democratic’ approach. It would therefore be recommended to proceed with the ‘With Skew’ methodology for future studies, but all cases are presented here for transparency, and because important conclusions can be drawn from the differences.

10. PARAMETERS DEFINITION AND SCORING

A description of each of the parameters, as described in the public survey, can be found below, along with the weighting used for the baseline study, and a justification for it based on the author's research.

10.1 CO_2 emissions

Survey parameter description:

CO_2 emissions: Carbon dioxide emissions from burning fossil-based fuels such as coal and gas have a significant impact on the environment due to global warming effects. Coal is the highest producer of CO_2, followed by gas. Nuclear and renewable resources have relatively very low CO_2 emissions.

Parameter data:

The following graph shows the amount of CO_2 produced for each of the technology types during their lifecycle:

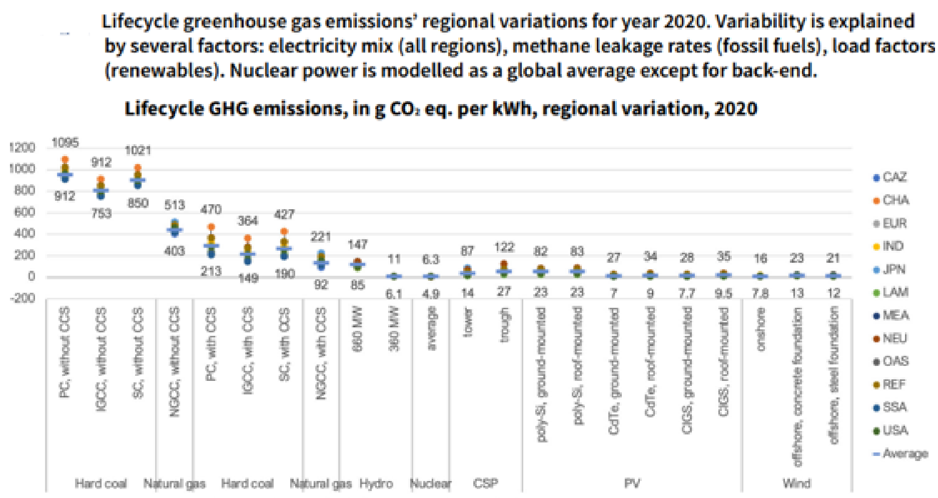

Figure 30 Lifecycle greenhouse gas emissions (Note: reprinted) [60]

To be clear, the results shown do not only include the CO_2 emitted during energy production, but in the complete life cycle of production – including any mining, power plant construction, all the way through to the backend of decommissioning and removal of the plant.

Parameters weighting justification:

This was weighted 9 in the baseline to reflect the important and urgent need to reduce CO_2 emissions globally since they are the primary driver for climate change, and to provide a stark differentiation between fossil-based fuels and renewables. Over 34 billion tonnes of CO_2 is emitted each year today, increased from 22 billion tonnes in 1990, and continuing to grow in spite of slowing down, but still not reaching their peak (OWD).

Scenario scoring:

Increased coal expansion would clearly be the worst-case scenario for increasing CO_2 emissions, and so both scenarios where this occurs scored 1 because power plants burning coal without carbon capture technologies are the worst offenders in terms of carbon dioxide emissions at around 1000 grams of CO_2 equivalent per kilowatt-hour.[60]. At the other end of the scale, energy mixes with heavy renewables use scored 9 because they have such low CO_2 emissions, less than 100g CO_2 eq. per kWh, so approximately 10 times lower. In between existing coal mixes scored 7, and gas mixes scored 3 since they sit in the middle of the other two extremes.

It is interesting to note that the technological improvements mentioned in the previous sections allow coal-fired plants to reach CO_2 levels of natural gas and even hydroelectric plants. It will be seen later though that this does not come without a price in terms of other parameters of interest, and so it is not so obvious as simply switching technologies without question.

Parameters weighting by:

Research: 9

Survey – Democratic: 7

Survey – Average: 7.3

Survey – Skew: 9

A strong correlation between the research and survey is clear here, indicating that the public is well-aware of the impacts of CO_2, which is no surprise considering the high exposure to the topic in today's media.

10.2 Greenhouse gas emissions

Survey parameter description:

This parameter considers creation of other greenhouse gases that trap heat in the earth's atmosphere, such as methane, nitrous oxide, and water vapour.

Parameter data:

The following graph shows the amount of greenhouse gas emissions produced for the various technologies considered in this report:

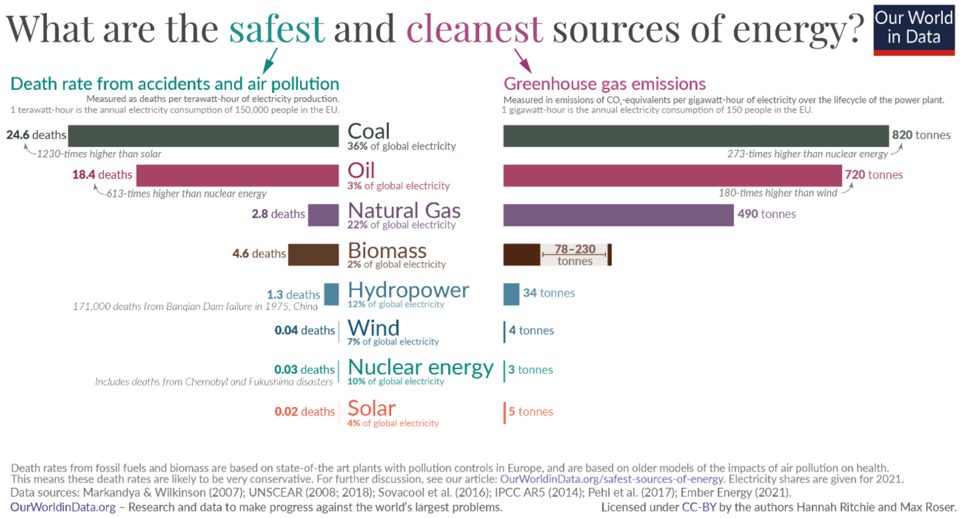

Figure 31 Safest and cleanest sources of energy (Note: reprinted) [119]

Parameters weighting justification:

A weighting of 9 was also given to this parameter, given the significant impact that these emissions have across a range of factors including human respiratory health, global warming, and the environment. Such a weighting allows for significant differentiation between cleaner renewables and their fossil-fuel burning counterparts.

Scenario scoring:

The logic applied to this parameter is almost identical to that of CO2 emissions in that coal biased scenarios score low at 3, and increased coal even lower at 1, since coal produces 820 tonnes of greenhouse gases. The renewable focused scenarios score higher at 7 due to their low greenhouse gas emissions, and the accelerated renewables scores best at 9 since renewables range from 4-5 tonnes for wind and solar up to 78-230 tonnes for biomass.

Parameters weighting by:

Research: 9

Survey – Democratic: 7

Survey – Average: 7.3

Survey – Skew: 9

Again, like CO2, the correlation is strong between research and survey, showing that the public is aligned to the need to reduce greenhouse gas emissions.

10.3Land Use

Survey parameter description:

The centralised energy grid of the Czech Republic currently uses relatively little land, although coal-mining areas do use significant land for their mines. Moving to a decentralised and diversified energy mix of renewables would require taking up land to install solar and wind farms, which take up significant space, as well as having a visual impact on the environment. Although solar panels can be installed on the rooves of houses, large solar farms required to meet EU renewable targets would take up either current farmland or forest areas. Wind farms can be integrated into existing agricultural land, but this does not avoid their visual impact.

Parameter Data:

On the geographic side of considerations, land use is an important parameter to consider. Here the assessment is complex, as each type of resource requires land in different amounts and for different purposes. For example, most of the land use for coal is where it is extracted from the ground, at mines.[61] For solar power, however, the land use is significant for installing the solar energy collectors which take up a lot of space through their working life. One way to express the land use for each technology is as the number of square metres occupied each year per MWh of energy produced.

There are some important interpretations to consider when analysing the data. For example, in the case of underground mines, the land use is high. However, these tend to be reasonably far from inhabited areas and do not cause a noticeable blot on the landscape, at least from a distance. However, at the other end of the scale, though wind energy does not take up much space for the turbines themselves, the story is not quite as simple as that.

The calculations for land use generally consider the fact that such turbines are installed away from inhabited areas, and often in farmland where they allow the land around them to be used constructively for other purposes. Some would argue though that their space claim is much larger as they can be seen from a long distance away and are not very attractive. As a result, green-minded people who argue that we should have more of them equally argue that they do not want them close to where they live, making wind farms something of a 'NIMBY' (Not In My Back Yard) technology.

The following table shows this distribution across the technologies under consideration:

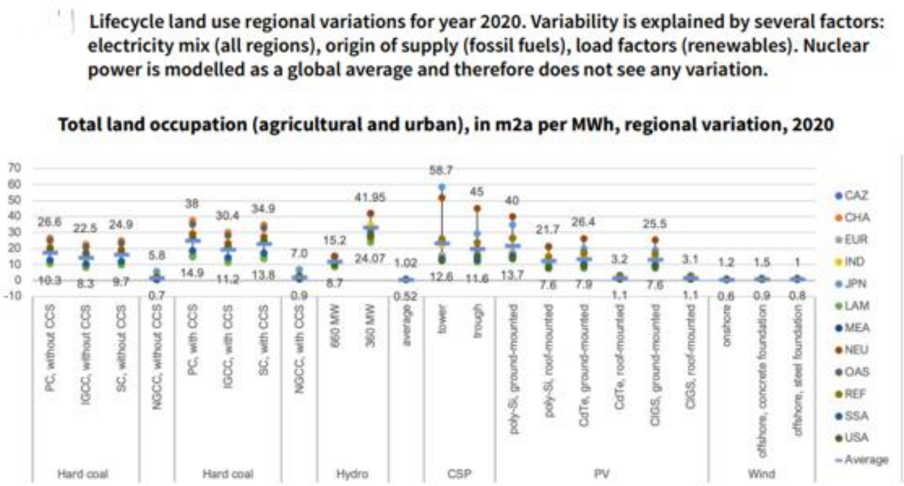

Figure 32 Lifecycle land use (Note: reprinted) [60]

Parameters weighting justification:

Land use was weighted at 3, since there are significant remote spaces available in CZ for siting of renewable energy technologies without making an excessively negative impact on the environment, or jeopardising availability of farmland. This is demonstrated by the map below showing population density with expansive areas available in the southern Bohemian region.

Scenario scoring:

Renewables would require a lot of new land use for solar farms and therefore scored poorly at 1, with around 20-40m2a per MWh, whereas energy mixes using existing or small new sites scored most highly, since they would not require any additional land use. However, where domestic coal would be expanded, the score was also low to account for the extra land use from additional mines being opened (around 20-35m2a per MWh), whereas for imported coal, the score was higher since there would be no new domestic mines.

Parameters weighting by:

Research: 3

Survey – Democratic: 9

Survey – Average: 7.6

Survey – Skew: 9

Land use was consistently weighted higher by the public, showing that Czech people are very keen on protecting their open spaces. This result shows that caution should be taken when planning locations for solar and wind farms which take up a lot of space, because they risk giving a bad image to renewables if put in the wrong places.

10.4 Water dissipation

Survey parameter description:

Power plants that combust fuel such as coal, gas or uranium, require cooling. Water for this cooling process is extracted from rivers but is not returned to them as it is released as steam into the atmosphere. This can have a negative effect on the local ecological system, meaning that rivers risk running dry in the summer, and plant and wildlife may be affected. All combustion-based plants use a lot of water, whereas renewable sources of energy do not.

Parameter Data:

Carbon capture technologies use a large volume of water to process the gases emitted from combustion and trap the CO_2 inside before condensing and final storage. As a result, water from the local environment is not only a requirement, and so must be plentiful, but is also not returned to the nearby area as it is dissipated in the cooling process. The following graph shows water dissipation for the technologies considered in litres per kilowatt-hour:

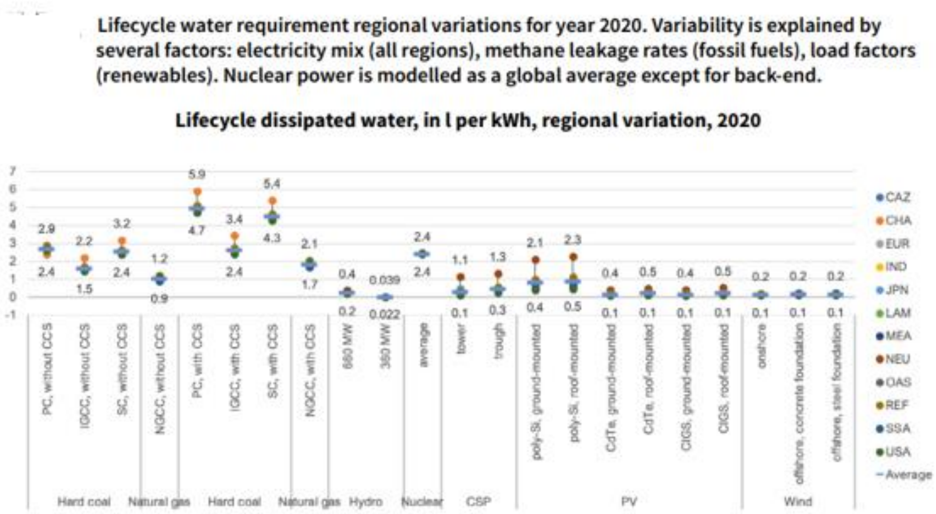

Figure 33 Lifecycle dissipated water (Note: reprinted) [60]

Suddenly, the price to pay in terms of water usage for carbon capture enabled thermal power plants is clear to see, with an approximate doubling of the water dissipation seen. This moves coal-fired plants into what can be described as an extremely thirsty category, and even makes gas-fired plants become similar in consumption of water to standard coal-fired ones. Clearly then, for areas where water is a scarce resource, such 'upgraded' coal-fired thermal plants may not be an appropriate response. As a land-locked country, it is also a significant consideration for the Czech Republic, as plentiful water from a river source would be required.

Parameters weighting justification:

This parameter was weighted as 3 because the Czech Republic benefits from reliable water sources in the regions where power plants are situated, with a low risk of drought leading to absence of water for cooling purposes.

Scenario scoring:

Coal power plant options scored lowly, with existing ones at 3, and expanded ones at 1, because they use a lot of water, specifically around 3 to 6 litres per kilowatt-hour (kWh). Conversely, renewable mixes scored highly, increasingly so as the renewable portion of the mix grew because they use 2 or less litres per kWh, which is 5 to 10 times less. In the middle, nuclear and gas options scored averagely since they use 2 to 3 litres per kWh.

Parameters weighting by:

Research: 3

Survey – Democratic: 9

Survey – Average: 6.6

Survey – Skew: 7

The survey weightings are higher than the research here – this could be because the Czech public has recent memory of hot summers leading to the threat of water shortages, and therefore see this parameter as highly relevant.

10.5 Water eutrophication

Survey parameter description:

This is the effect of making water rich in nutrients, especially nitrates from combustion. Power plants release water into the environment which is very rich in nutrients. This can result in it accumulating in rivers, streams, and lakes, and causing rapid growth of algae. This can then block light from entering the water and have a negative impact on plant and animal life below the surface of the water.

Parameter data:

The following graph compares eutrophication for each technology using units of grammes equivalent of Phosphorus per MWh:

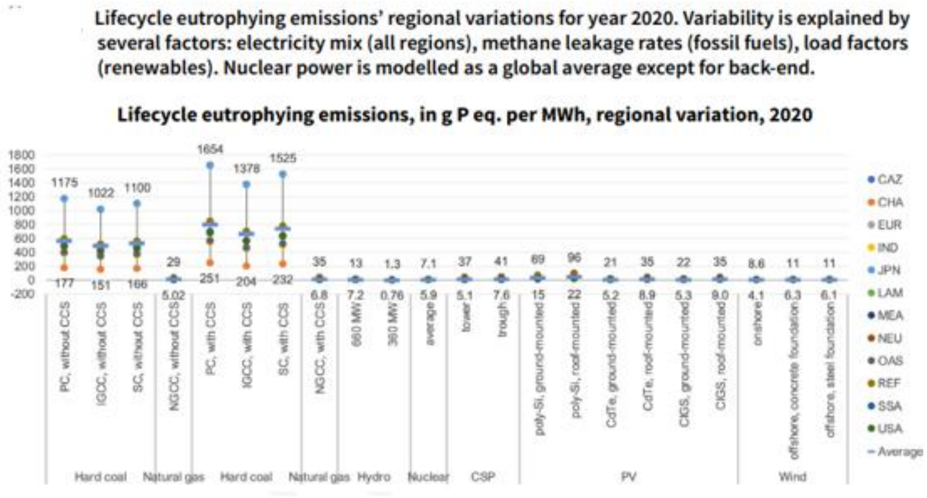

Figure 34 Lifecycle eutrophication (Note: reprinted) [60]

The treatment of residues from mining coal is a major source of compounds of phosphorus which leak into groundwater and rivers, or even the sea.[161] It is important to note though the large difference in eutrophication across different geographic locations, Japan and Australia having very high values compared to China. Thinking specifically of the Czech Republic versus other locations, the level is below the average and so this is not so much of a dramatic concern.

Parameters weighting justification:

The Czech Republic does use many of its rivers for multiple purposes, not only for power plant cooling, but as feeds to lakes where fish are farmed, and for other agricultural purposes. As a result, along with the fact that the graph above shows European coal eutrophication levels around the average, this parameter is important ecologically, but not critical, and was weighted as a 7.

Scenario scoring:

In general, coal power plant heavy scenarios scored lowly at 3, with expansion of coal power even worse at 1 because they are around 600 to 800g of Phosphorous equivalent per megawatt-hour (g P eq. per MWh). Conversely, scenarios which became increasingly less reliant on coal power plants and heavier with renewables scored highly because they had values decreasing down to less than 50g P eq. per MWh.

Parameters weighting by:

Research: 7

Survey – Democratic: 7

Survey – Average: 6.5

Survey – Skew: 7

The survey agreed almost perfectly with the research in this case, demonstrating a correct level of consciousness about this parameter from the public.

10.6 Human toxicity

Survey Parameter description:

This takes into account any toxins that are harmful to humans which are produced as a result of using the energy mix in a particular scenario. It includes both carcinogenic and non-carcinogenic toxins, and radiation.

Parameter Data:

The Czech Republic uses a significant amount of nuclear energy (10% of total electricity supply in 2020). Although ionising radiation is present from natural sources, accounting for a background level of exposure to all humans, it is important to consider the impact of each energy resource in this respect. The following chart shows the exposure for both the general public and workers involved with the energy resource for each source in man-Sievert per gigawatt-annum:

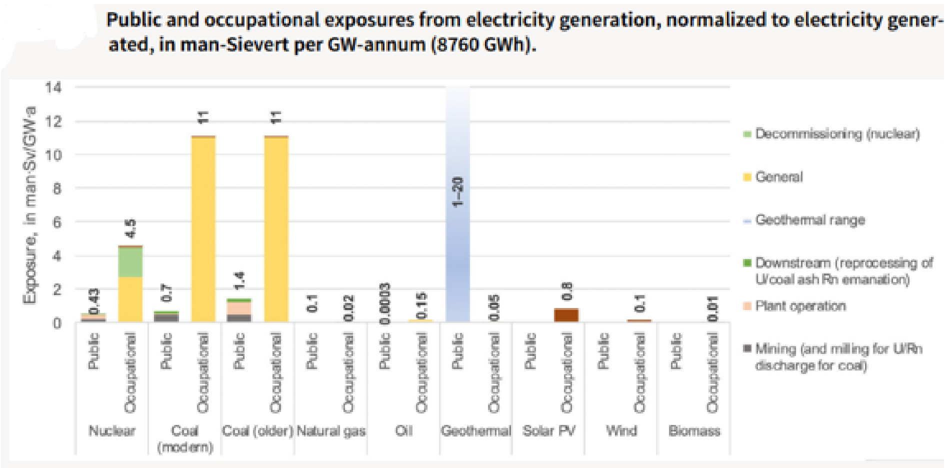

Figure 35 Lifecycle radiation exposure (Note: reprinted) [60]

As expected, nuclear has a relatively high exposure, especially for occupational workers. However, perhaps contrary to initial expectations, nuclear is not at all the highest – both coal and geothermal show much higher values. This is because workers are exposed to collective doses of radiation in ores, the combustion itself, and coal ash deposits. Geothermal has a broad range but can give large amounts of unwanted exposure during operation. Of course, this analysis does not consider potential radioactive exposure from nuclear catastrophes, which would have far greater impacts, but are not considered in an assumed catastrophe-free life cycle – this factor is discussed elsewhere in this report as part of the socio-economic risk and impact.

When it comes to analysing toxicity to humans from each resource and technology, there are two categories to consider – carcinogenic and non-carcinogenic. The carcinogenic category can be simplified to the amount of hexavalent chromium released into water supplies over the life cycle, which is linked to the amount of stainless steel used.[60] This is due to the treatment of associated slag, which is responsible for around 6 grammes of hexavalent chromium pollution into water for every kilogram of slag processed for landfill. The chart below shows carcinogenic toxicity for each technology over its lifecycle:

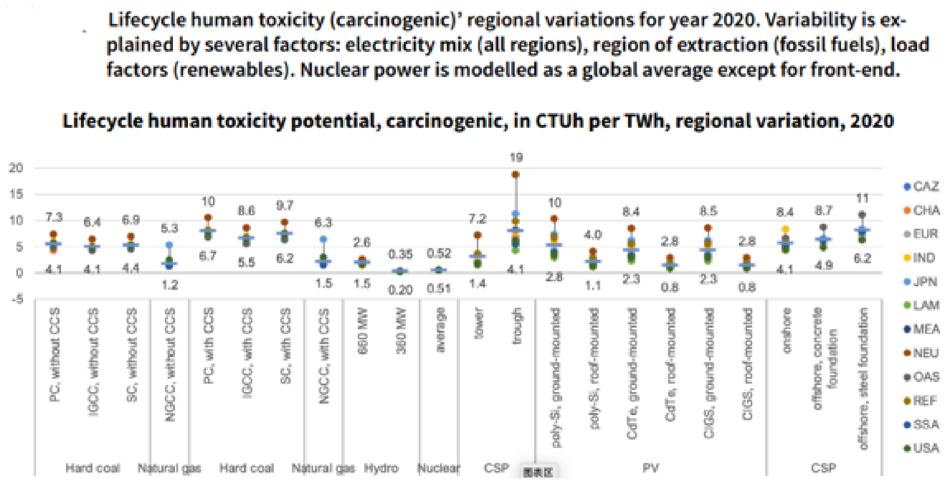

Figure 36 Lifecycle carcinogenic toxicity (Note: reprinted) [60]

As it comes to non-carcinogenic toxicity, the main culprit is arsenic contamination of water. This happens a lot during coal mining and when treating the ash formed after the combustion of coal which is then transferred to landfill sites.[60] Across the world's geography, there is also a strong correlation here to coal which originates from South Africa which has a much higher arsenic content than in other regions. Water sampling in South Africa and its surrounding countries show significant contamination with arsenic. The following graph shows non-carcinogenic toxicity across the range of technologies considered:

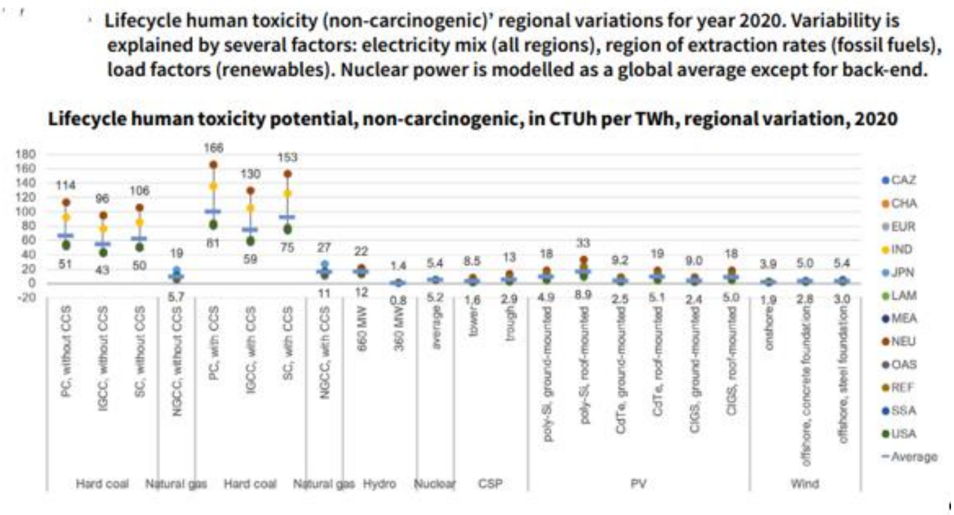

Figure 37 Lifecycle non-carcinogenic toxicity (Note: reprinted) [60]

Parameters weighting justification:

Currently CZ has relatively high rates of respiratory disease, and associated issues relating to the mining and burning of coal, particularly in the areas where miners live and work. Keeping in mind that human health and well-being should always be important when considering technical challenges and their solutions, this parameter was weighted as 7.

Scenario scoring:

Clearly renewable mixes scored more highly due to the lower amount of exposure to humans to any harmful toxins and radiation (less than 1 man-Sievert per gigawatt-annum), whilst fossil-fuel mixes generally scored low at 3, with expanded coal even worse at 1. This was due to the high score of 11 man-Sievert per gigawatt-annum for coal. Nuclear mixes did not score the highest of 9 since they have around 4.5 man-Sievert per gigawatt-annum.

Parameters weighting:

Research: 7

Survey – Democratic: 9

Survey – Average: 7.9

Survey – Skew: 9

Although the research weighted this parameter highly, the survey showed that the public consider it even more critically. This could be because the pro-nuclear population of the country are well-aware of the risks, given the relative proximity of Chernobyl and its lessons learnt.

10.7Non-rare metals usage

Survey parameter description:

Non-rare metals usage: This parameter considers the use of metals which are normally abundant around the world such as iron and aluminium. They may be used in large quantities by certain technologies, but nonetheless are not at risk of being depleted.

Parameter data:

There are two ways to consider material usage. The first methodology is simply to consider each of the materials in question, whether they be rare or not, and quantify the use of them over the lifecycle of each technology. The materials for consideration are specifically selected – they are not necessarily rare metals, but simply the ones that are known to either be rare, or used in large quantities, or of course a combination of both. So too is copper, as it is used not only in the construction of many electrical connections, but also in the canisters used for storing nuclear waste. Aluminium is also used extensively, and although abundant, is of note since it also has important alloying elements too.[60] The following chart shows a breakdown of the most significant elements in grammes per megawatt-hour over the lifecycle of all the technologies:

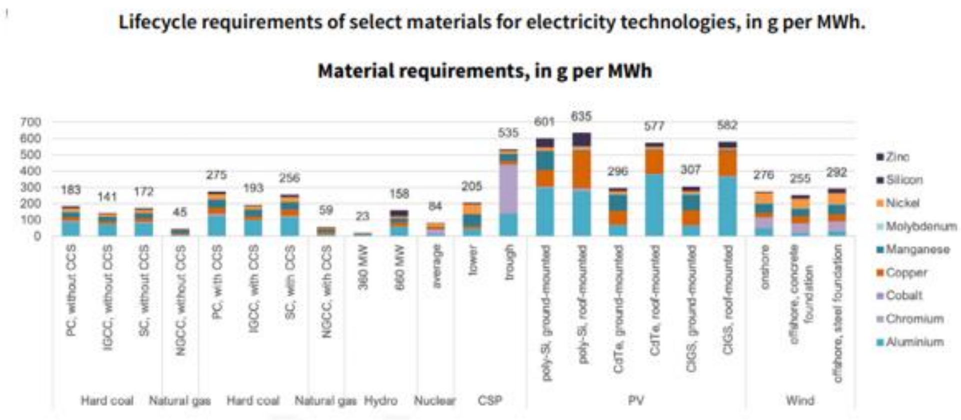

Figure 38 Lifecycle material requirements (Note: reprinted) [60]

Parameters weighting justification:

Non-rare metals are abundant globally, and for all the technologies available, there is little to differentiate. As a result, this parameter was rated as a 1.

Scenario scoring:

This parameter considered the use of iron for steel, and the other elements typically used as alloys for making steel including chromium and molybdenum, among others. It also includes copper which is typically used in all technologies for cabling. Since renewables use a lot of steel for their structure, in wind turbines for example, or in frame structures to support photovoltaic panels in solar farms, the renewable scenarios scored lower at 3 (200-600g per MWh) than the other conventional technology scenarios which scored 7 (100-300g per MWh). This parameter was one which did not use the extremes of the scale as none of the scenarios are significantly better or worse than each other, but simply sit in the middle of the range.

Parameters weighting:

Research: 1

Survey – Democratic: 3

Survey – Average: 5.2

Survey – Skew: 3

Out of all the survey results, this was one of the lowest, which aligns well to the research, showing that it is indeed a parameter that does not need to be worried about too much.

10.8 Rare metals usage

Survey parameters description:

This parameter is similar to the previous one, but this time considers those metals which are rarer or of finite supply.

Parameter data:

Another way to consider material use, is to try to normalise it versus the quantity of reserves remaining of the element in question compared to a reference material. In this case, the reference material is antimony, chemical symbol Sb, and so the units for comparison are kilogram-Sb equivalent. This methodology is good for highlighting outlier technologies in terms of scarce material use, but not necessarily at distinguishing what the scarce elements are. For example, photovoltaic cells and their associated electrical systems do show relatively high values in the chart below due to their use of small amounts of gold and silver in their electronics systems:

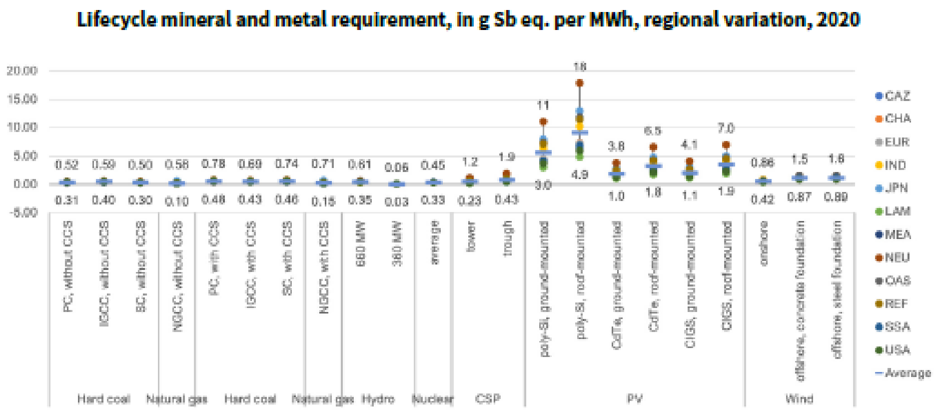

Figure 39 Lifecycle mineral and metal requirement (Note: reprinted) [60]

Parameters weighting justification:

Renewable technologies, in particular photovoltaic cells, use a considerable quantity of rare metals, whereas the current conventional electricity generation plants use much less. Since these metals ultimately have a finite supply, and other countries will also be increasing demand to support their own renewable energy drives, this parameter is quite significant and was therefore weighted as a 7 to recognise its importance.

Scenario scoring:

Renewable energy technologies use a significant quantity of rare metals, in particular photovoltaic panels (5-18g Sb eq. per MWh). As a result, the renewable options scored 3, and the heavy ones scored 1. All other scenarios scored 7, since there were no stand-out scenarios that used so little rare metals as to warrant a score of 9 (0.5-2g Sb eq. per MWh).

Parameters weighting:

Research: 7

Survey – Democratic: 3

Survey – Average: 5.4

Survey – Skew: 3

The survey score here is almost identical to the one from non-rare metals, perhaps showing that the public was not able to differentiate between these two parameters. A conclusion could be that the public needs to be educated a little more about rare-metals and their finite supply.

10.9 Noise

Survey parameter description:

Certain technologies, for example wind turbines, create more noise than others – this parameter takes into account this potential disturbance.

Parameter data:

Quantification of external noise from thermal power plants is difficult to confirm since from the outside they tend to be well-insulated. Inside a thermal power plant's control room, the maximum noise level is around 70dB [123], whereas their fans can exceed 90dB.[123] This level of noise is not relevant to the general population because they do not hear it, whereas for a wind turbine, which cannot be insulated, it is relevant. At a distance of 300m from a wind turbine, noise levels are around 43dB [122], which to give some context is in between a refrigerator (40dB) and an air-conditioner (50dB).[122]

Parameters weighting justification:

Since CZ has remote open spaces to site wind turbines, which are the main contributors to local noise disturbance, this parameter was rated as a 1, since the problem of noise is likely to touch only a very small minority of the population.

Scenario scoring:

The logic followed here is that thermal power plants, though emitting some noise, are relatively concentrated, and purposefully located relatively far away from inhabited areas. Conversely, wind turbines tend to be spread over large areas and can be heard on windy days from quite a distance, especially when there are many of them. As a result, renewable-heavy scenarios scored 3's, and even a 1 for the accelerated renewables case, whereas most thermal plant-based energy mixes scored 7, except for imported coal cases which scored a 9 since they also removed the noise of mining too.

Parameters weighting by:

Research: 1

Survey – Democratic: 7

Survey – Average: 5.9

Survey – Skew: 7

There is an obvious discrepancy here between research and survey. The research weighting was based on the fact that there are many remote areas in CZ where solar and wind farms could be sited. However, it seems that the public is very conscious of noise in the environment, so either they are not aware of how well such technologies could be hidden away from earshot, or simply they are not willing to tolerate their impact even in nature.

10.10 Air quality impact

Survey parameter description:

This is a parameter which is based on the quality of air in terms of its content of ozone, nitrous oxides, particulate matter, carbon monoxide, and sulphur dioxide. Give this a high weighting if you think it's important to protect air quality.

Parameter data:

The following chart shows death rates from accidents and air pollution for each technology:

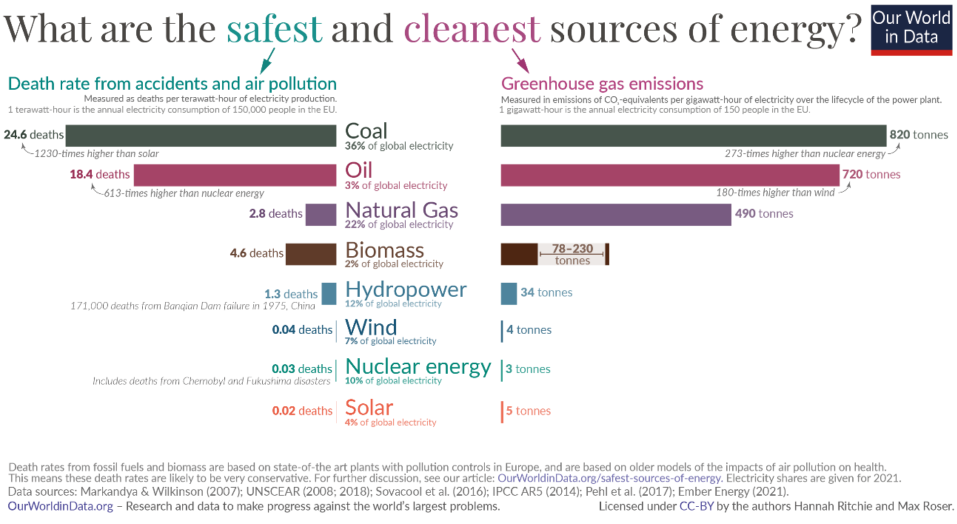

Figure 40 Safest and cleanest sources of energy (Note: reprinted) [119]

Parameters weighting justification:

As previously mentioned, the Czech Republic currently suffers with significant rates of respiratory health complaints and sees relatively high levels of the pollutants which are considered to negatively impact air quality. There is a strong desire to reduce this, and therefore the parameter was rated as a 7 to reflect the importance of it for the portion of the population that it touches.

Scenario scoring:

Renewable energy mixes scored the highest here, with the most renewable-heavy scenario scoring a 9, since their death rates are between 0.02 and 4.6. On the other hand, thermal plants that burn fossil fuels scored poorly, with the increased coal expansion options at the bottom of the scale due to their increased emissions leading to lower air quality and death rates of 24.6.

Parameters weighting by:

Research: 7

Survey – Democratic: 9

Survey – Average: 8.1

Survey – Skew: 9

This was another case where the research's high rating was surpassed by the public's. It shows that the public is very well educated about air quality and has a strong desire to improve it. This would add weight to the argument to invest in renewables, if good locations can be found for them.

10.11 Visual impact on landscape

Survey parameter description:

Most energy generation technologies have some level of visual impact, whether it be large wind turbines that are visible on the horizon from far away, to cooling towers of thermal power plants or farms of solar panels, none are particularly desirable – this parameter takes this into account.

Parameter data:

Figure 41 Brno Dam (Note: reprinted) [125]

Figure 42 Ralsko power plant (Note: reprinted) [128]

Figure 43 Dukovany power plant (Note: reprinted) [126]

Figure 44 Wind power plant (Note: reprinted) [127]

Parameters weighting justification:

Again, CZ benefits from having a lot of open spaces and remote locations where the installation of renewable technologies could take place without an overly negative impact on the environment. Nevertheless, any technology used potentially creates a visual disturbance, and to reflect this, the parameter was weighted at 3.

Scenario scoring:

The baseline case scored a 7, and all other scenarios were then compared to that. As a result, renewable-heavy scenarios scored lower at 3, and even a 1 for the accelerated renewables, due to the number of wind turbines and solar farms that would have to be employed. At the other end of the scale, the two imported coal scenarios scored 9's since additional domestic mining would not be required, further saving the landscape from visual scarring.

Parameters weighting by:

Research: 3

Survey – Democratic: 9

Survey – Average: 6.6

Survey – Skew: 7

As noted in the introduction to this section, human factors seemed to be weighted highly in the survey, and this is another case. It serves to highlight the point that even though the public may wish to reduce emissions and drive the energy mix in a renewable direction, they are not willing to sacrifice even the visual aspect of their environment to do so.

10.12 Ecological impact:

Survey parameter description:

Deforestation, pollution, and destruction of the natural habitats of animals are all examples of negative ecological impacts – this parameter accounts for the gravity of such impacts in each scenario.

Parameter Data:

As a final approach to simplifying the environmental impact of each technology, a methodology was created to normalise the summation of the combined factors discussed so far into a single value. This has been done for the European region in 2020 and can be further refined through weighting of the different factors to take account of reversibility and spread of impact for each factor. The following graphs show the normalisation without and then with weighting:

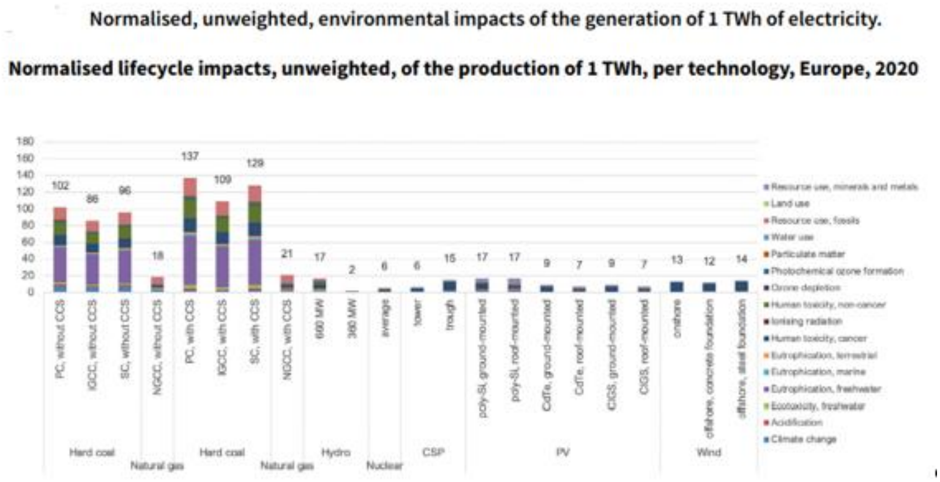

Figure 45 Normalised lifecycle environmental impacts (unweighted) (Note: reprinted) [60]

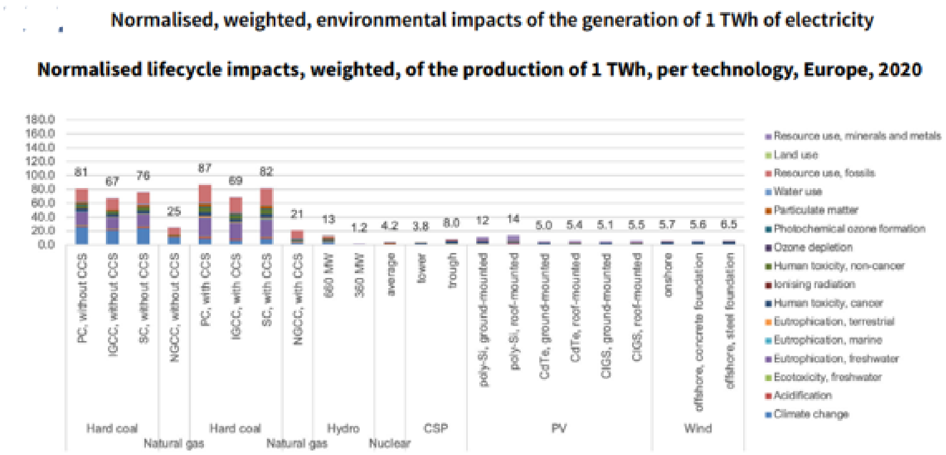

Figure 46 Normalised lifecycle environmental impacts (weighted) (Note: reprinted) [60]

Fossil fuels score badly in both instances, however, in the version without weighting, this is mainly due to eutrophication, and after that radiation and fossil fuel resource use of course. However, in the weighted analysis, the impact of climate change becomes more significant, and reversibility of factors such as eutrophication is accounted for. Through this analysis, if a deeper study were to be required, then the contribution of each parameter to the overall score can be seen, and it can be used as a pareto to assist in prioritising which factors should be targeted for improvement first.

Parameters weighting justification:

The impact of energy generation technologies on the ecosystems around them has been well documented now for decades and is already proven to be significant. Any future technologies must be considered with this in mind, and any potential improvements must be taken into account. As a result, this parameter was weighted as a 7.

Scenario scoring:

The baseline case scored 3 here due to the high scores for coal ranging from around 70 to 140 in the lifecycle impact charts, whereas renewable scenarios rated higher at 7, and even 9 for the accelerated case, due to scores in range of 1 to 17, around 10 times less. Most of the fossil fuel thermal plant-based scenarios scored 3, similar to the baseline, with the exception of the further domestic coal expansion which scored a 1 as it would be ecologically harmful even more so than the current situation.

Parameters weighting by:

Research: 7

Survey – Democratic: 9

Survey – Average: 7.8

Survey – Skew: 9

Czech people in general love the outdoors, and this is reflected in the survey once again putting nature towards the top of the priority list. We can conclude that whatever the energy split selected, its integration into the environment should be done as carefully as possible.

10.13 Acquisition / materials cost

Survey parameter description:

This parameter accounts for the financial cost of acquiring the land, and paying for the materials, to install the technologies for each scenario’s energy mix.

Parameter Data:

The following chart shows the investment cost for each technology for the neighbouring country of Poland since data was not available for the Czech Republic. Data is presented as cost in millions of PLN per 1MW of power:

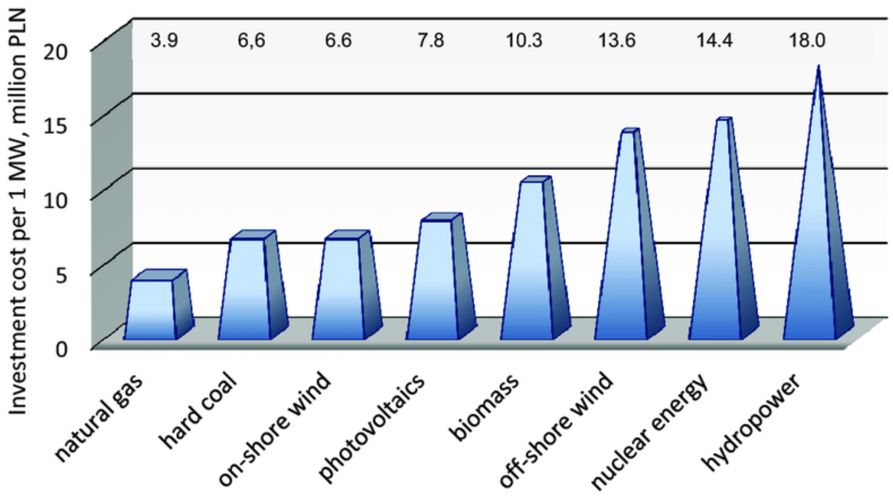

Figure 47 Construction costs of a power plant calculated for maximum power based, 2013 (Note: reprinted) [129]

Parameters weighting justification:

Ultimately, there is no avoiding the fact that economic feasibility of any energy solution is critical, and this includes the upfront costs of acquiring suitable land, constructing the technologies themselves, and so on. It has already been seen that some new technologies are either slow to start, or non-starters due to their associated economics, and therefore this parameter has been weighed as a 7 to reflect the importance of this.

Scenario scoring:

The baseline case scored 9 here, as no significant further acquisition of land or material would be required. The increased domestic expansion also scored highly since the land for mining is already owned by the Czech Republic. Conversely, the more heavily the other scenarios relied on renewables, the lower they scored, since land would need to be acquired for siting wind and solar farms, and money spent on constructing the infrastructure to support them. The lowest score of 1 was reserved for heavy nuclear based scenarios due to their high cost.

Parameters weighting by:

Research: 7

Survey – Democratic: 3

Survey – Average: 5.5

Survey – Skew: 3

In this case, it seems that the survey results are less sensitive to cost for acquisition and materials, giving the sense of delivering the right solution, no matter how high the cost.

10.14 Operational and maintenance cost

Survey parameter description:

This factors in the cost of any ongoing repairs and maintenance required during the life of a particular electricity generation technology, and the day to day running costs of the technologies in each scenario. An example of such variation is the increased cost of running a nuclear plant over that of a coal-fired plant due to the increased safety protocols required for nuclear plants.

Parameter Data:

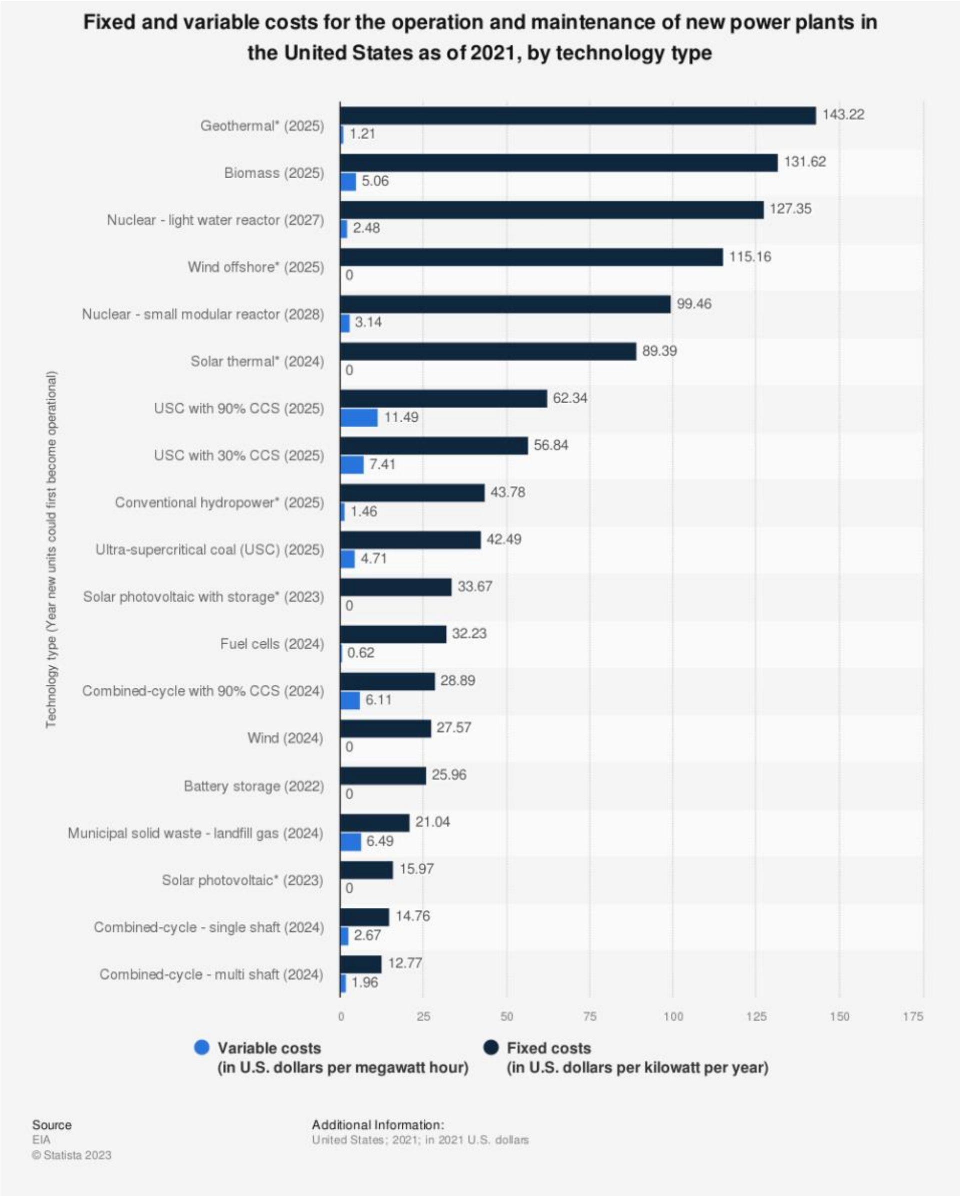

Figure 48 Power plant operation and maintenance costs (Note: reprinted) [130]

Parameters weighting justification:

Like the arguments presented for the item above, but this time focussed on ongoing costs, economics are important – as a result, this parameter has been given a weighting of 7.

Scenario scoring:

It is well-known that due to the complexities and required levels of redundancy for safety, nuclear plants have high running costs (127.35 USD/MW-hr).[130] As a result, all the scenarios with nuclear scored either 3, or even 1 for the heaviest cases. The other scenarios all scored 7 due to their relatively low costs, except for the accelerated renewables case which scored a 9 due to the relatively low costs associated with solar farms (15.97 USD/MW-hr).[130] There is an argument to also score this case as a 7 due to the maintenance costs of wind farms, but it was decided to use the scale to its full and differentiate this case and not to penalise wind since it would not be offshore in the Czech Republic (onshore wind, 27.57 USD/MW-hr).[130]

Parameters weighting by:

Research: 7

Survey – Democratic: 7

Survey – Average: 6.1

Survey – Skew: 7

There is an excellent alignment here, showing that the survey respondents have a correct understanding of the importance of this parameter.

10.15 Potential drift of total construction cost

Survey parameter description:

All new technology installations have the possibility of running over budget – this parameter takes into account the risk of such a situation arising, as well as the magnitude of the potential over budget amount.

Parameter Data:

The article referenced is one of many that can be found in the public domain documenting the overrunning of costs for complex constructions like nuclear plants.[131]Simplicity like repeated photovoltaic cells of the same type minimise the risks of going over budget, whereas large and complex thermal plants can suffer from unforeseen costs such as geographic issues at the construction site, changes in regulations, and last minute design changes due to local changes in circumstances.[131]

Parameters weighting justification:

Though there can be variability in the construction cost of large and complex solutions such as nuclear power plants, the long-term benefit of the overall project outweighs potential drifts in construction costs, especially when the efficiency of the solution will be representing an economic saving for many years. As a result, this parameter was only weighed at 1.

Scenario scoring:

The baseline and imported coal scenarios do not require significant, or arguably any, construction and therefore scored the highest possible at 9. Renewable cases scored 7, unless they incorporated nuclear expansion, in which case they dropped to 3 to reflect the higher costs of nuclear plant construction and their historical tendency to drift in cost. Scenarios focussed highly on nuclear scored 1, particularly the hypothetical nuclear fusion case since the risk of cost creep here is the highest.

Parameters weighting by:

Research: 1

Survey – Democratic: 3

Survey – Average: 5.1

Survey – Skew: 1

The survey aligns well with the research here, once again underlining the approach of ‘right solution no matter the cost’.

10.16 The European Union Energy Trade System

Survey parameter description:

(EU ETS) sets a price for emissions from energy generation which essentially acts as a taxation against heavily greenhouse gas emitting resources such as coal. It is anticipated that the price for coal credits will rise over time, penalising it for being an emissions-heavy fuel, which would in turn make coal an expensive fuel option, and drive-up energy prices for end users.

Parameter Data:

The following chart shows the Czech Republic versus its neighbours and France and the United Kingdom to show the variation between coal-heavy nations, such as Germany, Poland, Slovakia, and the Czech Republic, versus those with either heavy nuclear (France) and those with nuclear and renewables (offshore wind), such as the UK.

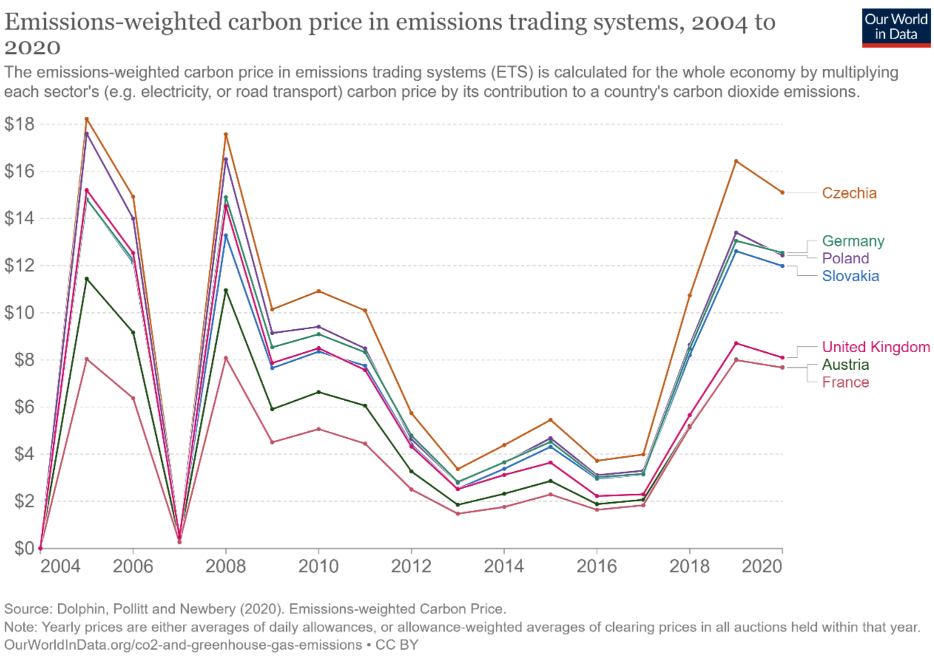

Figure 49 wighted carbon price in ETS (Note: reprinted) [132]

Parameters weighting justification:
As a member state of the EU, the ETS credit price is a highly significant parameter to consider in any future energy mix. The impact can go so far as to even render some solutions as completely uneconomic, which in turn would force end-users into excessively inflated prices due to penalisation. For these reasons, this parameter takes a weighting of 9, since it is very important, and even not fully under the control of the country itself, but open to outside influence.
Scenario scoring:
This parameter was very easy to score as there is a direct correlation between CO2 emissions and the ETS credit price. It is clear from the chart that coal is heavily penalised and therefore all coal options scored the lowest possible at 1, since these would magnify the penalisation. Renewables were given the best scores due to their avoidance of ETS costs, and so scored 9. Other cases scored 7 if they still moved towards renewables, and 3 if they employed gas, as it is still penalised, just not as much as coal. If the Czech Republic could update its energy mix in the same way as France and the United Kingdom, then it could expect, based on 2020 prices, for its ETS costs to drop from around 15 USD to 8 USD, almost half.
Parameters weighting by:
Research: 9
Survey – Democratic: 7
Survey – Average: 5.9
Survey – Skew: 7
There is a slight undervaluing of the potential negative impact on energy costs from this parameter by the public, suggesting that they may not recognise how bad the result could be if the Czech energy mix was exposed to high penalisation for its carbon emissions.

10.17 EU / State subsidisation

Survey parameter description:
Certain electricity generation technologies benefit from, and are likely to continue to benefit from, subsidisation from both the Czech government and EU. In almost all cases, this will be for renewable technologies as the governing bodies wish to promote the use of green energy.
Parameter Data:
The LIFE Clean Energy Transition programme has a budget of almost 1 billion Euros for the period of 2021 to 2027.[133] Further investment in fossil-fuel technologies will not gain access to this fund, and so if a nation like the Czech Republic wants to benefit from it, they need to focus on renewables.
Parameters weighting justification:

Not quite as influential as the item above, but nonetheless significant, this parameter received a weighting of 7 to reflect the fact that any subsidisation can have a strong impact on driving the public in the direction of one solution over another.

Scenario scoring:

In general, scenarios with a renewable bias were assumed to benefit from this parameter and so scored highly (7), whereas those where coal persists as a fuel score poorly (3), even as low as 1 for the cases where coal is expanded. The best case at 9 was the accelerated renewables as this would maximise the benefit of subsidisation.

Parameters weighting by:

Research: 7

Survey – Democratic: 7

Survey – Average:6.2

Survey – Skew: 7

The correlation for this parameter is high, showing that the public recognises the need to subsidise new technologies to help them make progress, and that they prioritise this correctly.

10.18 Cost per unit energy (kW hour)

Survey parameter description:

Across the various types of resources that can be used to produce electricity, there is a variety of cost for each unit of fuel, production cost, and efficiency. This parameter allows the study to differentiate between these costs.

Parameter Data:

The following chart shows the cost per MWh in USD for each of the technologies:

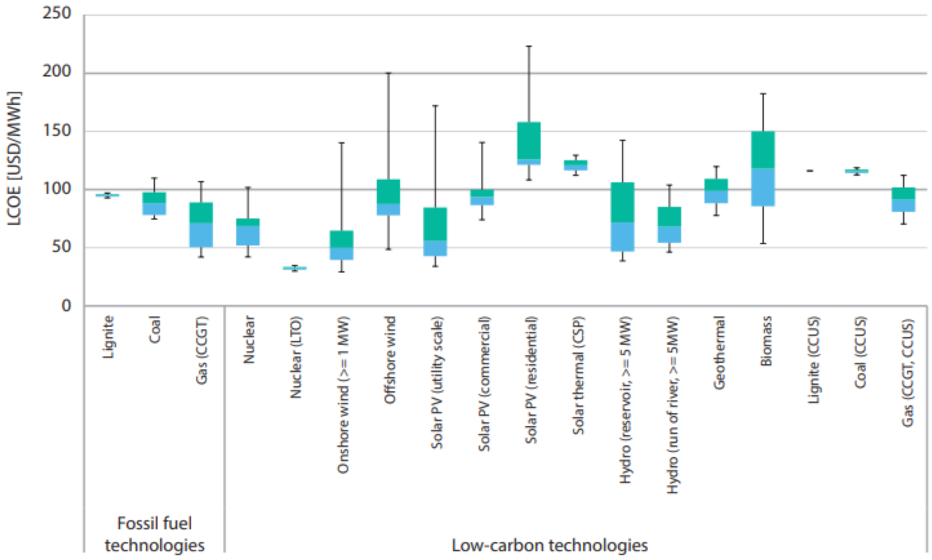

Figure 50 Cost per MWh in USD for each of the technologies (Note: reprinted) [134]

Parameters weighting justification:
Costs of the fuel or resources used to generate electricity have a significant impact on the overall price to the end user. Coal may be locally available and therefore relatively cheap, but uranium can also be imported at a relatively low cost, or mined domestically if this situation changes. Clearly renewables are free in terms of source energy, but still have running costs associated. Bearing all these factors in mind, this parameter was weighed at 7.
Scenario scoring:
The lowest score was not used here as none of the scenarios were seen to be significantly worse than the others, as can be seen in the chart. However, gas options were rated at 3 since CZ does not benefit from its own gas resources and has to import them at higher cost then coal as a fuel – this is in contradiction to the chart, since evidence throughout research showed that in fact coal is cheapest in CZ. The two scenarios scoring highest were the accelerated renewables, since in this case much of the fuel source would be natural and therefore essentially free, and the coal expansion case, since from an unbiased perspective, coal is currently plentiful and cheap in the Czech Republic. To put these values in perspective, onshore wind and commercial scale solar can reach the economy levels of coal and gas in the best cases, but nuclear is the cheapest and benefits from the smallest range.
Parameters weighting by:
Research: 7
Survey – Democratic: 9
Survey – Average: 7.2
Survey – Skew: 9
The survey was very clear that this is a critical parameter to the public, even more so than weighted by the research.

10.19 Electricity price for consumer

Survey parameter description:
Though there tends to be a correlation between this parameter and the original fuel cost, this parameter takes into account the impact on final electricity cost to the end user, since this can also be affected by other factors such as taxation or penalties for using certain types of fuel. The final price that the consumer pays for electricity is made up of a variety of factors. Firstly, there is the basic price of the fuel, then the cost of burning (or harvesting in the case of renewables) it, distributing it, and finally any taxation or penalty applied due to CO_2 emissions. Currently, coal is relatively cheap, but its price is expected to rise as EU ETS credits go up. Gas is also plentiful, is not penalised as heavily for CO_2 as coal, but has to be imported – it has a competitive price. Nuclear energy is relatively expensive due to the cost of fuel, and the increased personnel required to safely run a plant versus other sources. Though the source of energy is free for renewables, they are

currently not competitive versus alternatives unless they are subsidised as the cost of technology, its installation, and maintenance, along with modernisation of the energy grid all have to be factored into its cost – this means that in the short-term it can be considered expensive, but in the long-term more expensive.

Parameter Data:

Final price to the consumer is complex to calculate by technology type, as research data presents the information as an end result of the total mix, but not separated by technology type. The total price is made up of the production cost, plus any taxes or penalties paid to offset carbon emissions. Generally, this means that nuclear plants produce low-cost energy, since their production cost is low, and their carbon emissions are low.[135] Whilst coal and gas have roughly similar production costs to onshore wind and commercial solar energy, coal and gas are increasingly penalised, making their total price higher.

Parameters weighting justification:

The final cost of energy for end users has far-reaching consequences, even influencing the economy of the country as a whole. For this reason, this parameter gets a weighting of 7 to reflect that although not critical, it is still a very strong factor to consider in any future energy mix.

Scenario scoring:

To score this parameter, certain assumptions had to be made for what the future may look like from a global energy perspective and how this would then in turn affect the Czech Republic. The assumption was made that coal would be heavily penalised by EU ETS credit prices, and that it would eventually not be a viable economic solution to the future energy mix. As a result of this assumption, increased coal expansion scenarios scored the lowest at 1, and mixes that retained some level of coal or gas scored 3. Mixes that moved to renewables and nuclear scored higher at 7, with increased nuclear dependence scoring the highest at 9 due to its historically consistent price, and avoidance of penalisation.

Parameters weighting by:

Research: 7

Survey – Democratic: 9

Survey – Average: 7.6

Survey – Skew: 9

Predictably, the survey gave this an even higher weighting than the research, showing that the ultimate impact on the public of end-user cost is very important to them.

10.20 Domestic Energy Supply Independence:

Survey parameter description:

This parameter means that a country is able to provide energy resources which are available from its own territory, without the need to import them. CZ still has approximately 50 years of coal supply remaining and is around 90%+ energy independent today. Oil and gas are not readily available domestically in CZ, but any existing or future nuclear or renewable sources would count as domestic. Note that if moving to a non-fossil-fuel-based energy mix, a transition phase of increased international reliance will likely be necessary until more nuclear plants and / or renewable energy sources are commissioned.

Parameter Data:

The Czech government set two constraints related to self-sufficiency and energy security: 1) to maintain 90% self-sufficiency of annual domestic electricity consumption; and 2) limiting electricity imports to a 10% maximum in any given year.[136]

Parameters weighting justification:

As a result of the government target being so high, and the obvious pressure to maintain it when moving away from coal, which will be a challenge due to coal being available domestically and currently making up around 50% of the electricity generation supply, this parameter is weighed at 9.

Scenario scoring:

This parameter saw all domestic coal expansion, renewables, and an increased nuclear mix scored highly since all of these would be domestically resourced. Importing of coal scored 1 since this is the exact opposite of the target to remain energy independent. Gas reliant mixes also received low scores at 1, unless mixed with other solutions, in which case they were given a 3.

Parameters weighting by:

Research: 9

Survey – Democratic: 9

Survey – Average: 7.4

Survey – Skew: 9

There could be many explanations why the survey ranked this highly, whether it be pride, or a fear of being dependent on others, but either way, the alignment with the research is very clear.

10.21 Availability of Resources in CZ vs. International

Survey parameter description:

Not all sources of energy are equally abundant or readily available in the Czech Republic – this factor takes into account this variation of ease of access to certain fuel types.

Parameter Data:

There are 164 uranium ore deposits currently not mined in the Czech Republic. There are 206 million tonnes of hard coal reserves, and 863 million tonnes of brown coal and lignite.[138] The Czech Republic has below average sunshine hours annually, at a normal amount for a temperate climate in Europe:

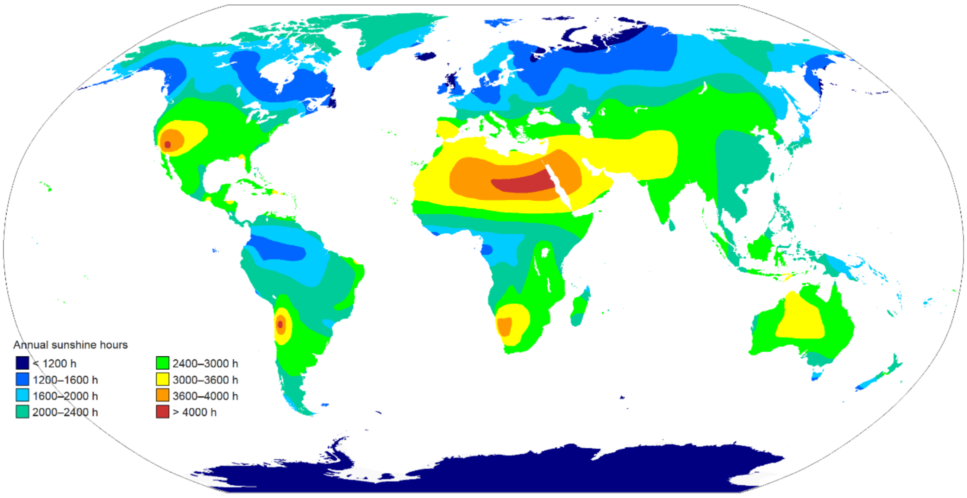

Figure 51 Annual sunshine (Note: reprinted) [140]

Parameters weighting justification:

This parameter is similarly important as the previous one in that it considers the availability of the resources for the technologies required for each scenario. It does not consider reaching a certain target, but simply the abundance of each resource domestically, whether that be the plentiful coal supply, currently untapped nuclear fuel supply, or even simply hours of sunshine per year. Since this is important for any solution, it is weighted as a 7.

Scenario scoring:

The current baseline was scored at 7, and then other scenarios scored relative to it. This meant that gas scored the lowest possible at 1, due to it being 100% imported, nuclear scored relatively low (3) since it is currently imported too due to it not making economic sense to mine Czech uranium, and renewables scored relatively low due to the import of materials for photovoltaic cells. Finally, increased domestic coal expansion scored highest since coal is readily available in CZ, at least in the near-term.

Parameters weighting by:

Research: 7

Survey – Democratic: 7

Survey – Average: 6.8

Survey – Skew: 7

An almost perfect alignment across all the weightings shows that this parameter is well understood and prioritised to the right level.

10.22 Domestic fossil fuel depletion

Survey parameter description:

There is a finite amount of fossil fuels existing within the Czech Republic. Once they have been consumed, then other sources need to be imported. Coal is the only abundant fuel source in CZ other than uranium (although this is not currently mined as it is cheaper from abroad), whereas renewable energy will not run out.

Parameter Data:

Another argument against the use of fossil fuels, beyond the fact that they emit the most greenhouse gases, is that their supply is ultimately finite.[1] We must therefore consider the demand of each technology on its supply resource, since this, along with the plant's efficiency, will dictate how quickly non-renewables are used up. The following graph shows the energy demand of fossil fuel resources in megajoules per kilowatt-hour (MJ per kWh):

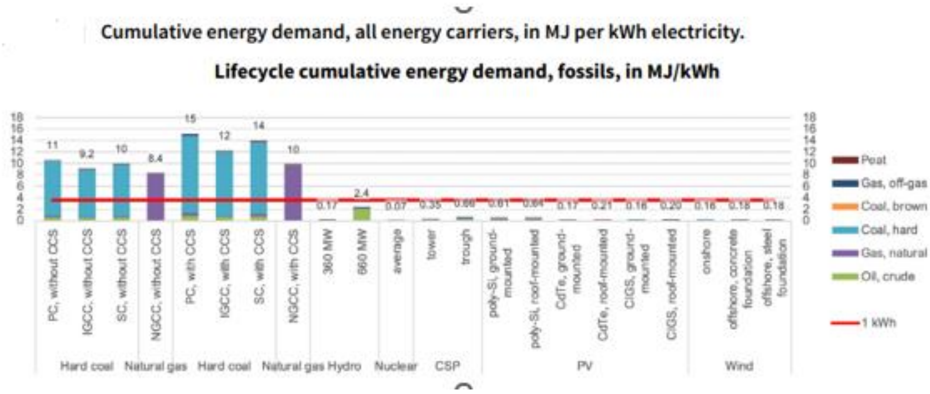

Figure 52 Lifecycle fossil fuel depletion (Note: reprinted) [60]

Here we can see that although carbon capture technologies are beneficial in terms of carbon emissions reduction, there is a penalty to pay in that the technology itself uses up more of the original resource. Taking the Czech Republic as an example, and approximating carbon capture technology employment for hard coal-fired thermal power plants with an average of 14MJ/kWh, with assumptions of 29GJ/tonne of coal as per the resources section of this document and 3.6 billion tonnes of coal remaining in the country, then we can approximate that with 32% of the nation's energy supply coming from coal, that the resource will last for a further 50 years until it is depleted.[60] Of course, there are many approximations and assumptions in this calculation, but nonetheless, it serves to provide an order of magnitude for the number of years that the country can be reliant on the resource until it needs to buy it from elsewhere.

It could be questioned why the renewable energy sources show a consumption of fossil fuel resources – this accounts for the fact that energy is required to produce them, and that currently such energy itself comes from fossil fuel reserves, at least in part.

Parameters weighting justification:

The Czech Republic has a relatively large amount of coal remaining, but no significant gas reserves, and currently unmined sources of uranium. Although burning fossil fuels is not good in terms of air pollution and CO2 emissions, it may nonetheless be prudent to keep a certain amount of fossil fuels available for the future just in case they are required. This is an important resource to have in case of unforeseen events such as war or acts of

God such as storms etc. To ensure an important weighting for this backup supply, this parameter is weighted as a 7.

Scenario scoring:

Scenarios that continue to use domestic coal scored 3, except those where coal was domestically expanded, where the score was 1 – this allowed differentiation between the coal usage cases which range from 10-15MJ per kWh. Outside of coal, the other scenarios scored 7, except for renewable cases which scored 9 to reflect their non-use of fossil fuels, since they use significantly less than 1MJ per kWh.

Parameters weighting by:

Research: 7

Survey – Democratic: 7

Survey – Average: 6.2

Survey – Skew: 7

Again, a very close agreement between the weightings shows that maintaining some domestic fossil fuel supply is important to the public.

10.23 Energy demand tolerance

Survey parameter description:

Due to the availability of certain resources, and the current state of infrastructure to support them, different energy mixes will be able to tolerate an increased demand for electricity in the future better than others. For example, increasing the output of coal would be relatively easy, as existing sites are present, and it would simply be a case of mining more of it. Conversely, renewables are not able to offer supply at all times, for example solar panels do not work at night, so their ability to support a growing demand in electricity output is limited – they need to be supported by peaking plants.

Parameter Data:

The following map shows locations of power plants in the Czech Republic in 2022:

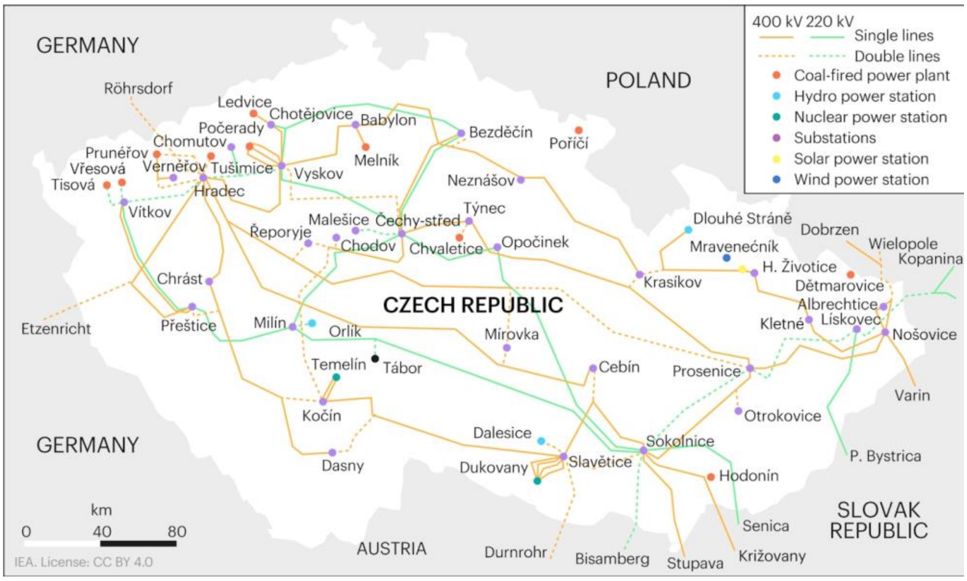

Figure 53 Location of electricity power plants (Note: reprinted) [141]

Coal plants are seen clearly in the north-west of the country around the coal mining region of North Bohemia. The following chart shows electricity imports and exports in the Czech Republic in TWh[141]:

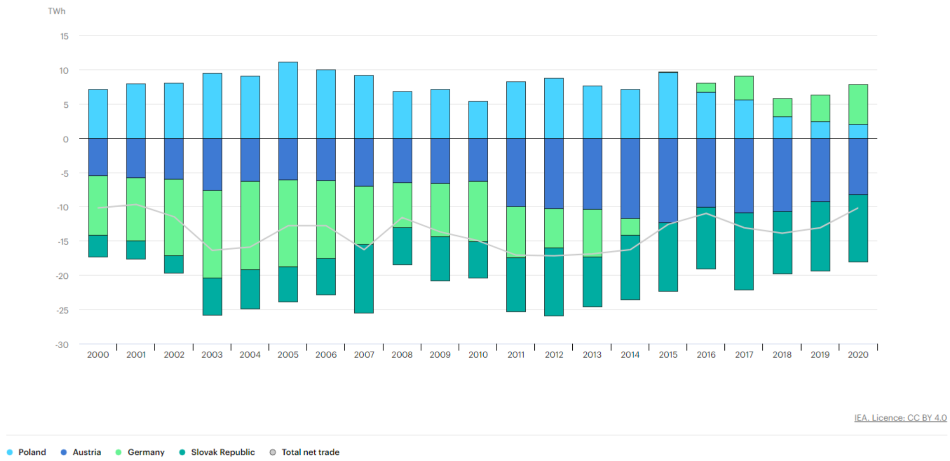

Figure 54 Electricity imports and exports in the Czech Republic (Note: reprinted) [141]

Along the borders, energy is traded with exported nuclear power to Austria, and imported coal power from Poland and Germany. If coal power is to decline, then to retain energy demand capability, nuclear baseload plants will need to be made in the same regions where coal is removed.

Parameters weighting justification:

Historically over the past decades, the economy of the Czech Republic has expanded in such a way that GDP per capita has increased whilst maintaining similar levels of energy use which have been used to drive growth in industry. Since this is likely to continue, and further expansion is planned, it is important to weight with some focus the ability to tolerate increased energy demand – as a result, this parameter is weighted as a 9, because without this capability, the Czech economy risks stagnation.

Scenario scoring:

Due to the variability of supply from renewables, these were put to the lower end of the scale since peaking power plants would be required to sustain demand during periods of low renewables output. It should be remembered that a low score in this parameter does not necessarily an inability of a given scenario to sustain demand, but more that backups could be required. Nuclear solutions scored highest due to their strong capability to provide base load and beyond, and hence were given 9.

Parameters weighting by:

Research: 9

Survey – Democratic: 7

Survey – Average: 6.2

Survey – Skew: 7

The survey scores are consistently lower than the research here which may suggest that the public is not aware of the stresses put on the energy grid by different energy mix solutions. This would be completely understandable as most electricity users know little about where their energy comes from or how it's distributed, so it's unlikely to be at the forefront of their mind.

10.24 Sensitivity to gas availability

Parameters description:

If the Czech Republic makes a transition away from coal towards nuclear and renewable energy sources, and complies with EU emissions targets, then a transition phase of using internationally sourced gas will likely be required. The price of this gas will not be under the control of the country and could be affected by geo-political events.

Parameter Data:

The following map shows interconnection points in the Czech gas network. Research shows that gas is almost entirely sourced from Russia. During the conflict with Ukraine, in order to avoid imports from Russia, it was accepted to temporarily burn more coal.

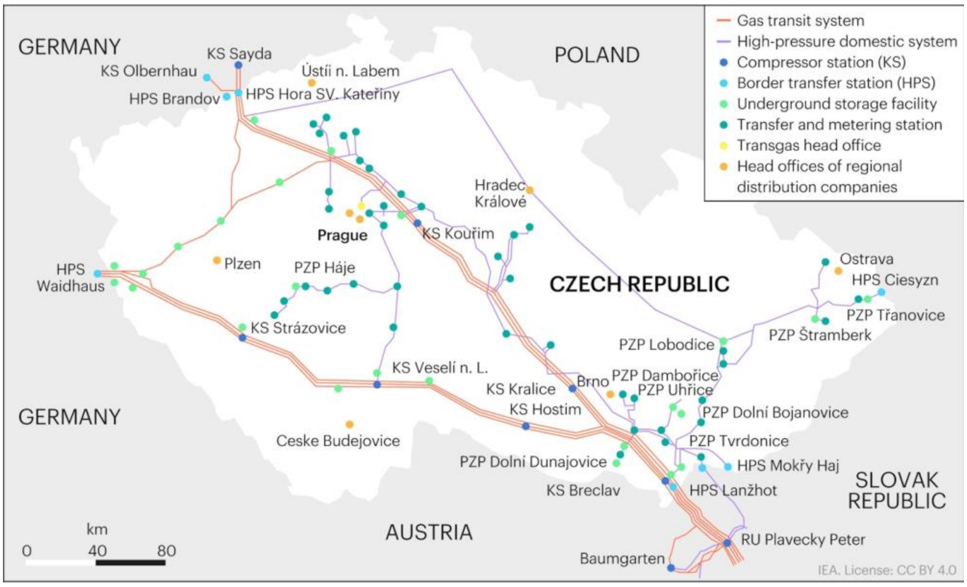

Figure 55 Interconnection points in the Czech gas network (Note: reprinted) [142]

Parameters weighting justification:

The Ukraine / Russia conflict starting in 2022 highlighted the dramatic impact that geo-political tensions can have on energy supply globally. This is one of the reasons that the Czech Republic wishes to retain a high level of energy independence. Certain scenarios that lean more heavily on gas than others leave the country exposed to potential increases in price or even lack of availability of gas, which is primarily provided by Russia. To ensure that this parameter is given adequate focus, it is weighted as a 7 to signify its importance.

Scenario scoring:

Partial energy mixes including gas were rated as a 7, whilst those with increased amounts of gas dropped to 3 or even 1 in the case of replacing all coal with gas. Scenarios focusing on renewables and longer-term nuclear mixes scored even higher at 9 due to their domestic independence allowing CZ to avoid any price fluctuations from imported gas.

Parameters weighting by:

Research: 7

Survey – Democratic: 7

Survey – Average: 6

Survey – Skew: 7

Recent events between Russia and Ukraine will have put this topic into recent memory for everyone, and so it is unsurprising that the survey weighted this parameter highly, similar to the research.

10.25 Implementation timing

Survey parameter description:

Complex technologies such as nuclear plants take much longer to construct and commission than simpler technologies. This parameter takes this into account and gives a higher ranking to those which are able to be brought online quicker.

Parameter Data:

The char below shows average construction time in years for thermal versus renewable power plants:

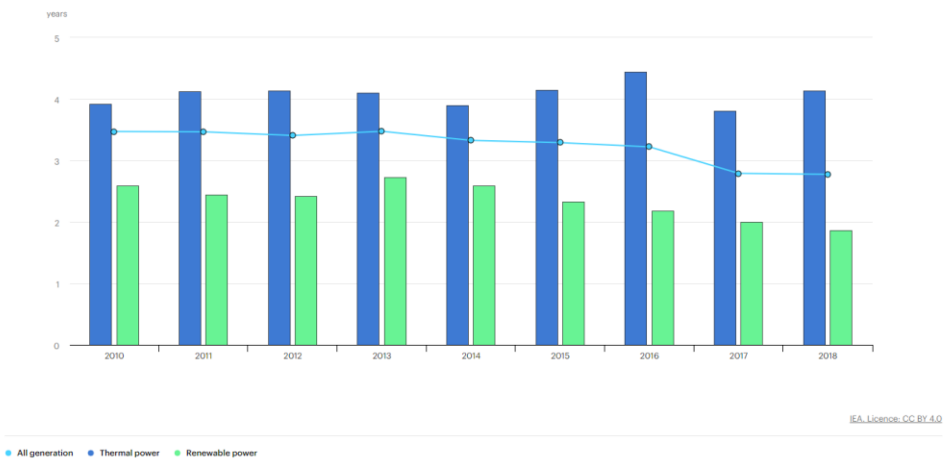

Figure 56 Average construction time in years for thermal versus renewable power plants (Note: reprinted) [143]

Parameters weighting justification:

Time is of the essence when it comes to transformation of the energy mix in the Czech Republic, as there are time pressures relating to multiple factors including EU ETS credit prices which may increase, and targets laid down by the EU for CO_2 and greenhouse gas emissions reductions. To reflect the importance of this impending time limitation, this parameter received a weighting of 7.

Scenario scoring:

Clearly the baseline scored the maximum of 9, as it is immediately available. This score was also given to both imported coal scenarios as coal is easily available to import over the border from Poland. Energy mixes with a need for increased nuclear reactors were given a lower score since these historically take a relatively long time to implement compared to other technologies. Conversely, mixes with renewables got high scores since the implementation time is relatively short.

Parameters weighting by public:

Research: 7

Survey – Democratic: 7

Survey – Average: 6.2

Survey – Skew: 7

The perception of the urgency or need to take action is shared between the research and survey with very close results.

10.26 Ease of maintenance / operation

Survey parameter description:

Highly complex electricity generation solutions tend to be more difficult to maintain in a good working order. This parameter scores highly those which are easily maintained without frequent need of maintenance and with a relatively low operator skill level required to carry out the maintenance.

Parameter Data:

The following table shows the number of jobs per MW for Operation and Maintenance of each type of energy plant:

Sector	**Construction times (Years)**	**Construction/ Installation (Job years /MW)**	**Manufacturing (Job years /MW)**	**Operation & Maintenance (Jobs/MW)**	**Primary fuel supply (Jobs/PJ)**
Coal	5	11.2	5.4	0.14	39.7 (1)
Oil and gas	2	1.3	0.93	0.14	15.1 (1)
Nuclear	10	11.8	1.3	0.6	0.001 jobs/GWh final demand
Biomass	2	14.0	2.9	1.5	29.9
Hydro-large	2	7.4	3.5	0.2	
Hydro-small	2	15.8	10.9	4.9	
Wind onshore	2	3.2	4.7	0.3	
Wind offshore	4	8.0	15.6	0.2	
Solar PV	1	13.0	6.7	0.7	
Geothermal	2	6.8	3.9	0.4	
Ocean	2	10.2	10.2	0.6	

(1) World average.

Source: (Rutovitz et al., 2015)

Figure 57 Number of jobs per MW for Operation and Maintenance of each type of energy plant (Note: reprinted) [144]

Parameters weighting justification:

The Czech Republic has significant historical experience with complex energy solutions like nuclear plants and hydroelectric dams, and already knows how to maintain them and operate them. As a result, this parameter was weighted at 3 to reflect the fact that complexity of solution would not be a significant challenge for the country.

Scenario scoring:

The baseline case was scored at 7 and all others related to this (0.14 jobs). None of the scenarios scored 9, as all come with a reasonable level of complexity and required maintenance, so it was not seen as appropriate to make such a big differentiation between 1 and 9. More intensive scenarios like nuclear (0.6 jobs) were given a score of 3, and nuclear fusion was assumed to be complex and maintenance heavy due to it being in its infancy and was therefore given a 1.

Parameters weighting by:

Research: 3

Survey – Democratic: 7

Survey – Average: 6.4

Survey – Skew: 7

It is interesting that the survey scored higher than the research here as the Czech public is generally pro-nuclear and most people understand this to be complex technology, requiring higher than average skills to maintain.

10.27 Training / workforce education

Survey parameter description:

New and highly technical solutions require high levels of training and education. However, education in the Czech Republic is very good, and so operators qualified to a high level are not so difficult to come by as in some other less developed countries. This parameter nonetheless takes account of the skill level required for each scenario's technologies.

Parameter Data:

STEM subjects attract by far the greatest number of students in the Czech Republic, with 134,351 students and 25,373 graduates in the 2021/22 academic year.[145]

Parameters weighting justification:

The Czech Republic has significant historical experience with complex energy solutions like nuclear plants and hydroelectric dams. As a result, this parameter was weighted at 1 to reflect the fact that it would be relatively easy for the country, with its excellent technical universities, to train a workforce adequately to support any kind of technology and energy mix.

Scenario scoring:

The baseline was scored at 9 since all training is already in place and only needs to be maintained for that scenario to continue. Continued coal-reliant scenarios were also scored high since no new technological skills would be required. Other mixes scored 3 or 7 depending on their level of complexity, except for nuclear fusion which was given a 1 due to the level of training that would be required to bring the workforce up to the level required to implement it.

Parameters weighting by:

Research: 1

Survey – Democratic: 7
Survey – Average: 6.3
Survey – Skew: 7
There is a definite offset between the research and survey, which put a much higher priority on appropriate training and skills.

10.28 Safety / Low catastrophic risk level

Survey parameter description:
This is clearly an important parameter for all electricity generation technologies. The scenario ratings here are based on real-world safety figures for technologies, not perceived values. As a result, there can be some conflict between reality and perception. For example, nuclear is statistically very safe, even if to some it may not be perceived to be, since real-world accident rates per giga-watt hour of production is low. However, it is well-known that historical nuclear catastrophes have been far-reaching and extremely damaging.
Parameter Data:
Research has shown that severe nuclear disasters are likely to occur every 10 to 20 years, which is 200 times more likely than estimated in the past.[146][147][148]
Parameters weighting justification:
The relatively recent nuclear disasters of Fukushima, and more close-by, Chernobyl, highlight the need to consider safety and potential for catastrophe when decided upon future energy mixes. To ensure that this parameter has the significant impact it deserves, it was weighted as 9.
Scenario scoring:
Heavy nuclear scenarios were scored at 1 to reflect the potentially huge impact of a nuclear catastrophe. At the opposite end of the scale, accelerated renewables was scored at 9 to reflect the low risk of this solution in terms of disasters, due to the decentralisation and small size of each unit. Scenarios in between were scored either 3 or 7 depending on their risk level, with mixed renewable and nuclear solutions scoring 3.
Parameters weighting by:
Research: 9
Survey – Democratic: 9
Survey – Average: 7.8
Survey – Skew: 9
In a country with a strong existing nuclear resource, and a commitment to expand it in the future, it should be no surprise that the survey put this parameter at the top of the scale, similar to the research.

10.29 Reliability

Survey parameter description:

The reliable operation and output of any electricity generation technology is critical, as this ensures consistent delivery of power to end users.

Parameter Data:

Reliability of energy sources, from most to least reliable is as follows: Nuclear; gas; coal; hydro; wind; solar. Nuclear plants can provide power for more than 90% of the time, which is around twice as reliable as coal and gas, and 2.5-3.5 times more reliable than wind and solar.[149]

Parameters weighting justification:

A reliable electricity network is critical for the safety of the population, and for the continued productivity of the Czech economy. For this reason, there is no question that this parameter should be weighted as a 9.

Scenario scoring:

Renewable-heavy scenarios were rated the lowest, but at 3, as using 1 would have been too extreme, and the differentiation on this parameter did not warrant full use of the scale. The reason for this was their lower relative reliability in times when the sun is not shining, or the wind is not blowing. Thermal plant solutions were generally rated at 7, and nuclear ones at 9 due to their high reliability and ease of output control in all situations.

Parameters weighting by:

Research: 9

Survey – Democratic: 9

Survey – Average: 7.8

Survey – Skew: 9

There is an excellent correlation here showing that the public prioritises a consistent electricity supply over almost everything else.

10.30 Low grid modernisation requirement

Survey parameter description:

The electricity grid is currently what is described as centralised in the Czech Republic. Infrastructure which allows diversification of the energy grid is not yet installed, and to accommodate more renewables such as photovoltaic cells on house rooves and wind farms in the countryside, plus electric car charging points, significant money will need to be spent on upgrading the network.

Parameter Data:

The grid of the future will have the capability for users to benefit from a two-way flow of energy, taking their excess energy when produced, and providing them with backup energy when they have peaks in demand which they cannot satisfy themselves.[101] Extra reserves will exist in such a grid, and the network will be capable of smart distribution of electricity at all times to react to changes in demand both at a local and regional level effectively and reliably.

Parameters weighting justification:

The modernisation of the Czech electricity grid is almost inevitable to facilitate the roll out of diversified and decentralised technologies in the renewable field. As a result, although this modernisation is worthy of consideration, it should not be considered as a show-stopper – for this reason it has been weighted as a 3.

Scenario scoring:

Modernisation of the electricity grid is required for renewable energy sources which decentralise it and require smart grid technologies to be implemented. This comes at a cost, and therefore the renewable-heavy scenarios got low scores – 1 for the most accelerated case, and 3 for the others. Conversely, scenarios that used a lot of thermal power plants, which would continue to be centralised and likely at the same locations as currently, scored highly, even up to a 9 for the baseline and other coal intensive solutions, since they would not require such expenditure on modernisation.

Parameters weighting by:

Research: 3

Survey – Democratic: 7

Survey – Average: 5.8

Survey – Skew: 3

This parameter is one which changed its score between the democratic and skew versions of the survey result, showing that it sat on the tipping point in the averaged list of weightings. Bearing that in mind, the correlation is still quite good, with the research and skew result agreeing with one another. It would be wise to keep public education on grid modernisation towards the top of the agenda when rolling out a renewable energy mix.

10.31 Low electricity storage requirement

Survey parameter description:

Some technologies, particularly renewable ones, do not produce energy on demand, but rather when the source (sun, wind, tidal) is available. As a result, contrary to power plants that burn controlled amounts of fuel, they require energy storage in the form of batteries or other. This requires additional investment and space, and so this parameter accounts for this extra requirement.

Parameter Data:

In a study made in Germany, which has a similar climate as the Czech Republic, assuming a 100% renewable energy system, the storage duration required was found to be 23 days of hydrogen, 6 days of pumped hydroelectric power, and 6 hours of battery power.[150] To implement this level of energy storage for CZ would take considerable time and investment.

Parameters weighting justification:

Like grid modernisation, an increase in energy storage is also inevitable in order to store energy produced by renewables for use when they are required. For the same reasons, this has been weighted as a 3, since although it does not exist today, it is something that is feasible to implement.

Scenario scoring:

This parameter is very similar in scoring to the previous one, but has slightly different scores for the thermal plants, especially nuclear. Essentially, it is renewable energies that require storage facilities, and so they got low scores compared to the thermal plants which got high scores since they would need little to no money spending on storage.

Parameters weighting by:

Research: 3

Survey – Democratic: 7

Survey – Average: 6.3

Survey – Skew: 7

The survey results show that the public has a slightly bigger desire to avoid battery use or other storage types than is perhaps necessary for renewables to become the primary energy source in the country. A fair conclusion would be to ensure that the combination of renewables plus storage is well understood in the public domain.

10.32 Ease to implement

Survey parameter description:

The technical challenges of implementing different technologies varies widely – nuclear plants for example are highly complex and have many levels of redundancy, whereas solar panels can even be installed at home with minimal monitoring.

Parameter Data:

Nuclear plants regularly have 3 or 4 levels of redundancy in them, and a larger number of employees than other types of thermal plant who double-check correct activities.[151] This makes them more complex to implement in the first place, as updates to regulations can occur whilst they are being built too.

Parameters weighting justification:

The Czech Republic has a strong history in implementing complex technical energy solutions such as nuclear plants, and has all the infrastructure, strength of economy, and skill pool required to take on the challenge of any energy mix. For these reasons, this parameter was weighted as a 3, since none of the scenarios represent a hurdle that cannot be passed.

Scenario scoring:

Clearly the baseline scored 9 as it requires no implementation at all. 9 was also given to the coal-based scenarios that would not require expansion, and 7 to those which were coal-based but would require some expansion. Renewables and expanded nuclear would take more time and effort to implement and therefore got increasingly lower scores depending on their complexity.

Parameters weighting by:

Research: 3

Survey – Democratic: 7

Survey – Average: 5.8

Survey – Skew: 3

This parameter is another to switch score between Democratic and Skew results, with the skew result agreeing with the research. The parameter sits roughly in the middle to lower part of the range, and so we can conclude that it is not so important to make sure the technologies in the future energy mix are easy to implement.

10.33 Construction energy consumption

Survey parameter description:

Each different electricity generation technology consumes energy as part of its initial production – for example, to build power plants, construction vehicles are used which run on oil-based fuels like Diesel, or factories that make photovoltaic cells use energy to produce them. The amount of energy consumed for each technology varies.

Parameter Data:

The following chart shows construction / investment, fuel and operating and maintenance cost splits for key power sources:

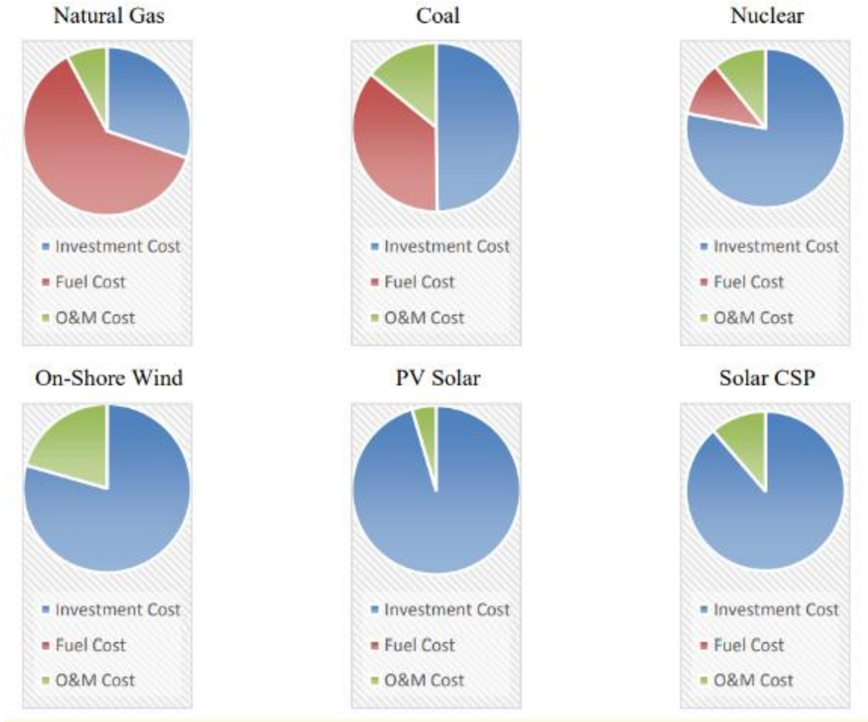

Figure 58 Construction / investment, fuel and operating and maintenance cost splits (Note: reprinted) [152]

Parameters weighting justification:
Due to the long-term payback of energy of all available technologies, combined with the available energy sources for construction, this parameter is relatively insignificant compared to the others, and has therefore been weighted 1.
Scenario scoring:
Since existing technologies like coal-powered thermal plants would not need to be constructed, the scenarios using these scored highly at 7 or 9, depending on whether they did (7) or did not require expansion (9). Renewable energy technologies need to be constructed and therefore scored lower at 3, as did increased nuclear scenarios, but none of the scenarios were scored at 1, as it was felt that none of the scenarios were so much more energy intensive to warrant that.
Parameters weighting by:
Research: 1
Survey – Democratic: 7
Survey – Average: 5.6
Survey – Skew: 3
The survey weightings were higher than the research, perhaps suggesting that the public does not consider the long-term payback of the energy invested in construction over the life of a technology compared to the data-driven value given by the research.

10.34 International acceptance level

Survey parameter description:
All energy solutions come under international scrutiny. Different technologies have different levels of acceptance internationally. For example, Austria and Germany have voiced negative opinion in the past over CZ having nuclear plants relatively close to their borders.
Parameter Data:
Austria has a zero nuclear policy for their own energy production and has argued against Czech nuclear expansion in both Dukovany and Temelín. Nonetheless, Austria continues to import energy from the Czech Republic which could be argued is contradictory to the point of hypocrisy. Germany dramatically reduced its nuclear program after the Fukushima disaster, but the Czech government continues to push forward its plans for nuclear expansion, upsetting some of its neighbours.[153][154]429]

As already mentioned, the EU offers subsidies for renewables and effectively penalises coal and other fossil-fuel based energy production.
Parameters weighting justification:
As a member state of the EU, international acceptance of the Czech energy mix is important – for this reason it was weighted at 7.
Scenario scoring:

Internationally, especially in the EU, there is a strong drive to phase out coal, and therefore the continued and extended coal use scenarios scored only 1. There is a clear drive for renewables and so the scenarios favouring those scored 7, or 9 in the case of the accelerated renewables. Nuclear power, though generally accepted as a long-term future requirement internationally, does meet some negativity from CZ's neighbours, and therefore this scored 7 in general, but only 3 for extended nuclear scenarios.

Parameters weighting by:

Research: 7

Survey – Democratic: 7

Survey – Average: 5.1

Survey – Skew: 3

The survey suggests that the public considers the opinions of neighbouring countries less significant than expected.

10.35 International legislative acceptance

Survey parameter description:

The Czech Republic is a member state of the EU, and as such needs to abide by legislation which relates to electricity generation. Some technologies enjoy positive legislation, such as renewables that generally attract subsidies, whereas others, such as coal, are increasingly punished in an attempt to make them more expensive and less attractive.

Parameter Data:

The Paris Agreement targets to make the EU the first climate-neutral society by 2050. It also aims to reduce emissions by a minimum of 55% of the levels in 1990 by 2030. [156] The reason for this is the belief that doing these things will limit global warming to below 2°C above pre-industrial levels.[156]

Parameters weighting justification:

Even more important than international acceptance is the impact of international legislation. Since the Czech Republic is directly impacted by EU mandates, this parameter was weighted as a 9.

Scenario scoring:

The scoring here was very similar to the acceptance parameter above, and for similar reasons. However, the scoring differed in that the extended nuclear scenarios scored higher than in the acceptance case, since legislation already exists for nuclear energy, whereas it does not in a detailed manner for renewables yet.

Parameters weighting by:

Research: 9

Survey – Democratic: 7

Survey – Average: 5.3

Survey – Skew: 3

The survey results are noticeably lower than the research. This could be explained by the fact that this is a less human factor and therefore less in the consciousness of the public, or because they are simply not exposed to such legislation in general life and so are unaware of its potential impact.

10.36 Political willingness

Survey parameter description:

Though not always driven by science, politics can play an important role in making decisions on the future energy mix.

Parameter Data:

As noted previously, Czech feelings towards nuclear energy are positive – this was confirmed in a 2009 survey by ČEZ that reported 77% of the public supporting the construction of new nuclear reactors.[158] The Czech government is aligned with this sentiment too. The Ministry of Labour does not support the phase out of coal due to fears over high levels of unemployment, whilst the Ministry of Environment supports an early coal phase out.[71]

Parameters weighting justification:

Politics has a significant influence on domestic policy and decisions that directly affect the Czech energy mix via, for example, subsidisation and taxation. As a result, this parameter is weighted as a 7 since it will be important for any technology to have government backing to be a success.

Scenario scoring:

Politically there is a strong drive for continued nuclear growth in the Czech Republic, which as noted previously in the research is also supported by public opinion – as a result the nuclear scenarios scored highly at 7, with only accelerated renewables enjoying more political push at 9. The continued coal scenarios received only 3, except for imported coal scenarios which scored 1 as it would be highly politically unpopular to shut down the Czech coal industry whilst continuing to support the industry in Poland.

Parameters weighting by:

Research: 7

Survey – Democratic: 7

Survey – Average: 5.2

Survey – Skew: 3

The survey scored slightly lower here suggesting that the public doesn't see politics as important in the energy mix decision, or perhaps that they have sufficient trust in their government to make the right decision that they give it a lower priority.

10.37 Need (to meet energy demand)

Survey parameter description:

Though it may be desirable from an economical or ecological point of view to have certain types of electricity generation such as renewables, nonetheless, there is a critical point of realism to accept which is that energy demands of the country need to be met. Certain types of electricity generation can deliver high amounts of energy at any time, without the need for storage.

Parameter Data:

The following table shows the future needs for alternative fuel vehicles, including electric, with the number of vehicles and associated public charging stations:

Type of vehicle	2020	2025	2030
Electric vehicles	17 000	101 000	250 000-500 000
Public charging stations	1 300		19 000-35 000
CNG vehicles	49 820	130 000	250 000
Refuelling stations	200	300	340-400
LNG vehicles	180	500	1 300
Refuelling stations	0	5	14/30
Hydrogen vehicles		95	40 000-50 000
Refuelling stations		15	80

Sources: MIT (2015); MIT (2019).

Figure 59 The future needs for alternative fuel vehicles (Note: reprinted) [71]

A large amount of infrastructure will be needed to support this, much of it reliant on the electricity network, and significant increases in baseload.

Parameters weighting justification:

Growth of the Czech economy and further need for energy to sustain the positive direction of GDP is a critical factor in any decision – for this reason, this was weighted as a 9.

Scenario scoring:

This parameter weighted the need for a particular energy mix in terms of its ability to meet energy demand. Strong base load technologies like coal rank highly at 7, and nuclear even more so at 9. Less reliable technologies for consistent energy delivery scored lower, so lighter renewable mixes at 3, and the strongest at 1.

Parameters weighting by:

Research: 9

Survey – Democratic: 7

Survey – Average: 6.8

Survey – Skew: 7

The survey gave a lower priority to this parameter than the research, maybe because the public might not be aware of the magnitude of the problem faced by the energy grid if electric vehicles are to become the most common mode of transport.

10.38 Low legislative requirement

Survey parameter description:

The growth of renewable energies which rely on a modernised and de-centralised energy grid has been slow in the Czech Republic. As a result, detailed government legislation has not been created to support prosumers (end-users that both provide to and consume energy from the network). It will require some time to introduce such legislation, and no doubt there will be teething problems.

Parameter Data:

Although a draft of a new legislation for the legal and regulatory framework for the development of renewable energy sources in the Czech Republic has been made, it has not yet been approved by the government. As a result, growth of renewables in the country is slow, per the chart below:

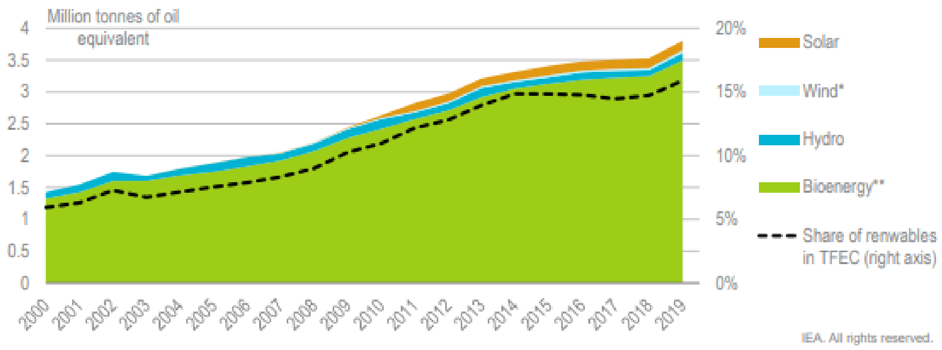

Figure 60 Growth of renewables in the country (Note: reprinted) [71]

Parameters weighting justification:

Examples of other neighbouring countries embracing renewables and putting in place the required legislation exist for the Czech Republic to use as a guide and to learn from. As a result, although important to implement, this parameter should not pose a big problem as it is not the case that CZ will be the lone pioneer. To reflect this, the parameter was weighted at 3 so that the impact is not too high on the overall score.

Scenario scoring:

This parameter relates to domestic policy rather than international. CZ has all legislation in place for the current energy mix and so this scored 9. Continued thermal power production scenarios also scored highly at 7. Nuclear energy also has a strong foothold in Czech power production, and so legislation is already in place, except for nuclear fusion which may require some differentiation and so scored 3. Legislation for renewables is currently very much behind the trend in CZ, and so the scenarios incorporating this into their energy mix scored 1.

Parameters weighting by:

Research: 3

Survey – Democratic: 7

Survey – Average: 5.1
Survey – Skew: 1

This parameter is the only one that dropped two levels between democratic and skew results in the survey, meaning that it was one of the lowest averages. This is unusual, but once again points to the fact that legislation is probably not at the front of the public's mind.

10.39 Employment impact

Survey parameter description:

Versus the baseline or current energy mix of the Czech Republic, changing to other mixes could be disruptive to the workforce and require re-employment for current employees. For example, if coal is phased out, many people will lose their jobs and need retraining and redeployment.

Parameter Data:

The table below shows the data relating to coal mining in the Karlovy Vary region of the Czech Republic as an example of the magnitude of reemployment that would be needed if coal was phased out:

Regional employment in coal mining and coal power plants			
Employment	**Number**	**Share of total regional employment [%]**	**Date**
Coal mining (direct employment)	2,700	1.3%	2019
Coal power plants (direct employment)			
SUAS subsidiaries and direct suppliers to SUAS	600 - 800	0.3% - 0.4%	
Other coal-related activities	5,000 – 8,000 regional jobs presently related to the mining and related industry	2% - 4%	
Employment by age group [% of total employment]	**<= 30 years**	**>60 years**	**Date**
Coal mining (direct employment)	5%	9%	2019
Coal power plants (direct employment)			

Figure 61 Regional employment in coal mining and coal power plants (Note: reprinted) [160]

Parameters weighting justification:

Though some of the scenarios would have a short to medium term impact on employment in the country, none of them are so significant that they cannot be fixed via investment in new job opportunities and subsidisation of appropriate training courses. To ensure that this relative ease of retraining does not over-influence the overall score, this was weighted at 3.

Scenario scoring:

The coal industry is currently a large employer in the Czech Republic. Maintaining the current baseline and not disturbing this employment sector scored 7, and increasing the coal industry scored 9, as it would result in more domestic jobs. Most of the other scenarios scored 3 as they tended to phase out coal, except for the final IEA prediction which scored 1 for its long and protracted phase out of coal.

Parameters weighting by:

Research: 3

Survey – Democratic: 7

Survey – Average: 6.8

Survey – Skew: 9

This parameter is probably the best example of one which has a much higher survey score due to its direct impact on the public. This could be because the public is not aware of the actual number of people employed in the coal industry, or the timeframe which is available for them to be retrained in.

11. SCENARIOS DESCRIPTIONS

This section describes the scenarios that were scored for each parameter in more detail. It also provides the rankings of the scenarios from the public survey and compares them to the ranking calculated via inserting the survey parameter weightings into the Pugh Matrix whilst keeping the research-based scoring for each scenario. This allows us to compare the outcomes from a) asking the respondents to give their own opinion on the scenario ranking versus b) calculating the respondents ranking based purely on their prioritisation of the parameters.

This allows us to work out if the Pugh Matrix tool is correctly calibrated such that it can output the right decision based only on input parameters, or if there is a discrepancy in the result it gives when compared to direct questioning.

Realistic scenarios descriptions

11.1 Baseline

Scenario description:

Baseline – business as usual, with today's energy mix: Prioritise this if you think that the Czech Republic should maintain its current energy mix. This means continued domestic coal burning until the supply is exhausted, maintaining current nuclear resources, and limited investment into renewables. This option would maintain a centralised electricity grid for the foreseeable future, reducing investment needs, but not allowing any substantial expansion of renewables in the future without significant investment later down the line.

Scenario ranking from Research: 8
Scenario ranking from Survey - Democratic: 6
Scenario ranking from Survey - Average: 4
Scenario ranking from Survey – With Skew: 8
Scenario ranking from Survey - Ranking: 7

Observations:

This scenario ranked in the middle of the scale in most of the rankings. This shows that the current energy mix is by no means the worst-case scenario, and dramatic change is not necessarily required to provide an adequate energy mix. This is due to the significant nuclear portion of the energy mix, which is low carbon and satisfies many of the parameters in the Pugh Matrix with an adequate score. The key takeaway here is that the Czech Republic is by no means in a panic situation and can take time to make a correct decision without terrible consequences from somewhat delayed action.

11.2 Reduced coal and gradual shift to renewables

Scenario description:

Reduced coal and gradual shift to renewables: Prioritise this if you think that the Czech Republic should make a gradual shift towards renewable energy technologies such as solar and wind. Gradual means that the shift will occur over a period of around 15-20 years, allowing step by step upgrades of the electricity grid to decentralise and modernise it.

Scenario ranking from Research: 6
Scenario ranking from Survey - Democratic: 4
Scenario ranking from Survey - Average: 5
Scenario ranking from Survey – With Skew: 5
Scenario ranking from Survey - Ranking: 3

Observations:

In the Pugh Matrix results, this scenario scored consistently well into the upper half of options. However, in the direct survey ranking, it scored even higher at 3rd place. This may be because renewable energy strategies are highly visible in the media of today's society, and this helps to push renewable-focused scenarios up the ranking.

11.3 Early coal phase out (accelerated renewables only)

Scenario description:

Early coal phase out (accelerated renewables only): Prioritise this if you think that the Czech Republic should focus spending on renewable power sources. This means upgrading the electricity grid to support diversification and non-centralisation, with the benefit of much reduced CO_2 emissions in a shorter time frame. Early phase out means that by around 2030 the country would no longer be burning any coal, but would need heavy investment into the electricity grid, and rapid definition of legislation to allow the renewable rollout at pace. This would likely require significant subsidisation from the government to incentivise both industry and homeowners alike to prefer renewable energy solutions.

Scenario ranking from Research: 1
Scenario ranking from Survey - Democratic: 1
Scenario ranking from Survey - Average: 1
Scenario ranking from Survey – With Skew: 1
Scenario ranking from Survey - Ranking: 6

Observations:

The result here is very interesting because the scenario scored 1st place in all the Pugh Matrix ranking results, but only 6th in the direct survey ranking. This result must make us question several things – firstly, the calibration of the Pugh Matrix tool. It is likely that the tool is not capable of differentiating between timelines of renewable introduction, for example between this scenario and the previous one with a gradual shift to renewables. This could result in it mixing up the renewable options. Also, it suggests that perhaps the Pugh Matrix design is inappropriate, and that it is too heavy with renewable focused parameters – this will be discussed later, after the scenario descriptions. Despite these potential flaws of the tool though, it is clear from the overall results that renewables are favoured by the public, but that they are not necessarily how many they want, or how quickly.

11.4 Early coal phase out (accelerated renewables plus nuclear)

Scenario description:

Early coal phase out (accelerated renewables plus nuclear): Prioritise this if you think that the Czech Republic should focus spending on both renewables and nuclear as a combined solution to replacing coal. This is similar to the previous scenario, with the difference being that further nuclear expansion could take place at existing sites, and this would reduce the pressure on modernisation of the electricity grid to implement quite so many renewable sites.

Scenario ranking from Research: 5
Scenario ranking from Survey - Democratic: 7
Scenario ranking from Survey - Average: 9
Scenario ranking from Survey – With Skew: 6
Scenario ranking from Survey - Ranking: 2

Observations:

Here we see something of the reverse from the previous scenario in that the public survey ranked the option much higher than Pugh Matrix did. The conclusion to draw here is that although the Czech people would like to move to clean energy, perhaps their preference is in fact to do so via a focus on nuclear energy, rather than accepting the drawbacks of renewables such as the negative visual impact on the environment, noise, and an energy storage requirement. A 2nd place ranking here reinforces the positive view that the public have about nuclear energy in CZ.

11.5 IEA Proposal – Transition to increased nuclear and renewables via gas

Scenario description:

IEA Proposal – Transition to increased nuclear and renewables via gas: Prioritise this if you think the Czech Republic should follow the IEA proposal to remove coal from the energy mix in line with EU guidelines, using international gas as an interim solution, whilst waiting for new nuclear and renewable domestic resources to be online. Benefits are longer term CO_2 reduction, and less exposure to potential penalties for continued coal burning, along with maintaining current coal power plant locations which would be replaced by coal over time. End user energy costs could be lower than with coal in the interim period until nuclear is online, but the risks are the exposure to international price fluctuations and availability of gas which would need to be imported.

Scenario ranking from Research: 3
Scenario ranking from Survey - Democratic: 5
Scenario ranking from Survey - Average: 6
Scenario ranking from Survey – With Skew: 4
Scenario ranking from Survey - Ranking: 1

Observations:

The first observation that must be made is the 1st place ranking on the direct survey, combined with the 3rd place ranking based on the research carried out. This alignment is significant and demonstrates that the public are not ready to jump to an accelerated renewables solution but would prefer to take more time to arrive at a more satisfactory mix of renewables plus nuclear power. They are also willing to make the compromise of accepting a transition via gas, even if this comes with some negatives such as a short to medium term exposure to energy dependency. In all cases, this scenario scored well above average and so must be considered as one of the potential best routes forward for the country.

11.6 Increased nuclear (beyond IEA Proposal)

Scenario description:

Increased nuclear (beyond IEA Proposal): Prioritise this if you think the Czech Republic should further increase its reliance on nuclear energy beyond the IEA proposal by planning and commissioning even more new nuclear plants and reactors than currently anticipated. Benefits are long-term CO_2 reduction via avoidance of fossil-based fuels, and less need to install renewable energy sites like solar and wind farms – this would in turn maintain the current centralised electricity grid for the most part, avoiding such high investment costs for the modernisation required for renewables. Downsides to this approach are the low but potentially catastrophic risks associated with nuclear power plants, and the relatively long construction and commissioning time for nuclear plants.

Scenario ranking from Research: 4
Scenario ranking from Survey - Democratic: 2
Scenario ranking from Survey - Average: 3
Scenario ranking from Survey – With Skew: 2
Scenario ranking from Survey - Ranking: 4

Observations:

The overall results for this scenario are high showing that it is favourable. The main remark to make comparing to the previous scenario is that the lower ranking here suggests that balance is important. Both the research and direct survey prefer the IEA proposal without increased nuclear, showing that although accelerated renewables are not the preferred option, there is an acceptance of them in moderation, and people are willing to accept them more than an over-reliance on nuclear.

Hypothetical scenarios

11.7 Successful implementation of nuclear fusion

Scenario description:

Successful implementation of nuclear fusion: Prioritise this if you think that the Czech Republic should invest heavily into the potential commercialisation of nuclear fusion as an energy solution. This scenario represents high risk, but potential high reward – in the worst case, the country could invest heavily and delay action on alternatives and end up with no reward at the end. Conversely, if successful, this scenario could be capable of securing the nation's energy needs if the technology can be optimised and commercialised.

Scenario ranking from Research: 7

Scenario ranking from Survey - Democratic: 9

Scenario ranking from Survey - Average: 10

Scenario ranking from Survey – With Skew: 7

Scenario ranking from Survey - Ranking: 5

Observations:

This scenario is clearly hypothetical and was therefore not expected to rank very highly, which it did not, consistently scoring below average. This does not necessarily mean it should be ruled out if the technology becomes available, but that the public is not willing to bet on a technology that may not work out positively and would prefer to rely on proven technologies.

Unlikely scenarios

11.8 Gas only – replacement of all coal

Scenario description:

Gas only – replacement of all coal: Prioritise this if you think that the Czech Republic should replace all coal-fired power plants by those fuelled by gas. The benefits of this are the increased efficiency of gas plants, reduced CO_2 emissions from gas versus coal, avoidance of such high potential penalties via EU ETS credit pricing for coal (though gas is still penalised, albeit at a reduced rate), and maintaining a similar centralised energy network which would require less infrastructure investment and modernisation than the implementation of renewables would. Downsides are that this would leave the country as a net importer of energy and exposed to any potential price fluctuations and availability of gas in the future.

Scenario ranking from Research: 12

Scenario ranking from Survey - Democratic: 12
Scenario ranking from Survey - Average: 12
Scenario ranking from Survey – With Skew: 12
Scenario ranking from Survey - Ranking: 9
Observations:
This option ranked lowest in all the Pugh Matrix results, and well into the bottom half from the direct survey. The simple conclusion here is that the option is heavily non-preferred and should likely be removed from any future discussion.

11.9 Nuclear only – replacement of all coal

Scenario description:
Nuclear only – replacement of all coal. Prioritise this if you think that the Czech Republic should replace all coal-fired power plants by new nuclear plants. The benefits of this are reduced CO2 emissions versus coal, avoidance of EU ETS credit since fossil-based fuels would not be used at all, and maintaining a similar centralised energy network which would require less infrastructure investment and modernisation than the implementation of renewables would. Downsides are that this would be relatively slow to implement and costly, as the levels of redundancy required in a nuclear plant are high in order to keep it safe and minimise the risk of catastrophes.
Scenario ranking from Research: 2
Scenario ranking from Survey - Democratic: 3
Scenario ranking from Survey - Average: 2
Scenario ranking from Survey – With Skew: 3
Scenario ranking from Survey - Ranking: 8
Observations:
Although this option was a consistent high performer in all the Pugh Matrix results, it only ranked 8th in the direct survey. This may again be due to a bias towards low-emissions solutions in the design of the Pugh Matrix model, which could be questioned once more. Nonetheless, the direct survey result once again suggests that everything in moderation is the preferred approach of the public, and not the previously mentioned over-reliance on nuclear energy.

11.10 Baseline – imported coal

Scenario description:
Baseline – imported coal: Prioritise this if you think that after the baseline scenario is no longer possible due to the depletion of coal reserves within the Czech Republic, the country should simply shift to importing coal instead whilst maintaining the same energy mix. The coal would likely be imported from Poland and would result in CZ being a net importer of energy. Benefits are that there would be no need to modernise the existing

electricity grid, which would minimise investment risk. Downsides are that the price of energy in the country could become very high due to the expected increase in price for EU ETS credits which would be at their highest for increased coal-burning in the long-term. CO2 and other greenhouse gas emissions would also continue to remain high.
Scenario ranking from Research: 10
Scenario ranking from Survey - Democratic: 10
Scenario ranking from Survey - Average: 8
Scenario ranking from Survey – With Skew: 10
Scenario ranking from Survey - Ranking: 10
Observations:
This scenario scored low in all cases, even in the direct survey which agrees very well with the Pugh Matrix. There are several obvious explanations for this – the public do not want to rely on international imports for their power, they do not want to move jobs abroad, and they do not accept a stagnation in emissions reduction.

11.11 Increased domestic coal expansion

Scenario description:
Increased domestic coal expansion: Prioritise this if you think that the Czech Republic should continue to expand its coal powered sector of the energy mix beyond the baseline of today. Benefits are that in the short to medium term, the country could retain its current energy grid and not need to modernise it and would also remain energy dependent until coal reserves run out. Downsides are potentially expensive electricity in the future due to penalisation through EU ETS credit price increases, CO2 and greenhouse gas emissions increasing, and the time when coal in the country is depleted being brought closer to the present day.
Scenario ranking from Research: 9
Scenario ranking from Survey - Democratic: 8
Scenario ranking from Survey - Average: 7
Scenario ranking from Survey – With Skew: 9
Scenario ranking from Survey - Ranking: 11
Observations:
The public direct survey scored this option even worse than the Pugh Matrix, highlighting that it is an unattractive option and can be discarded in any future discussions on energy mix. The scenario exposes CZ to too many risks for it to be viable.

11.12 Increased imported coal expansion

Scenario description:
Increased imported coal expansion: Prioritise this if you think that the Czech Republic should expand its coal burning sector of the energy mix, but rather than through mining

more coal domestically, by importing it from abroad. This option's benefits are that it allows the country to start shifting its workforce away from coal mining and retains the same centralised energy grid as today with limited investment. Downsides are potentially expensive electricity in the future due to penalisation through EU ETS credit price increases, and CO2 and greenhouse gas emissions increasing.

Scenario ranking from Research: 11

Scenario ranking from Survey - Democratic: 11

Scenario ranking from Survey - Average: 11

Scenario ranking from Survey – With Skew: 11

Scenario ranking from Survey - Ranking: 12

Observations:

The almost perfect alignment between the Pugh Matrix results and the public survey ranking confirm without doubt that this scenario is not supported and should be removed from future discussion. Once again, it has far too many downsides to represent an attractive option, with risks of high energy prices and loss of domestic jobs among other things.

12. SCENARIOS DISCUSSION

The following chart shows the survey scenario rankings versus the Research rankings:

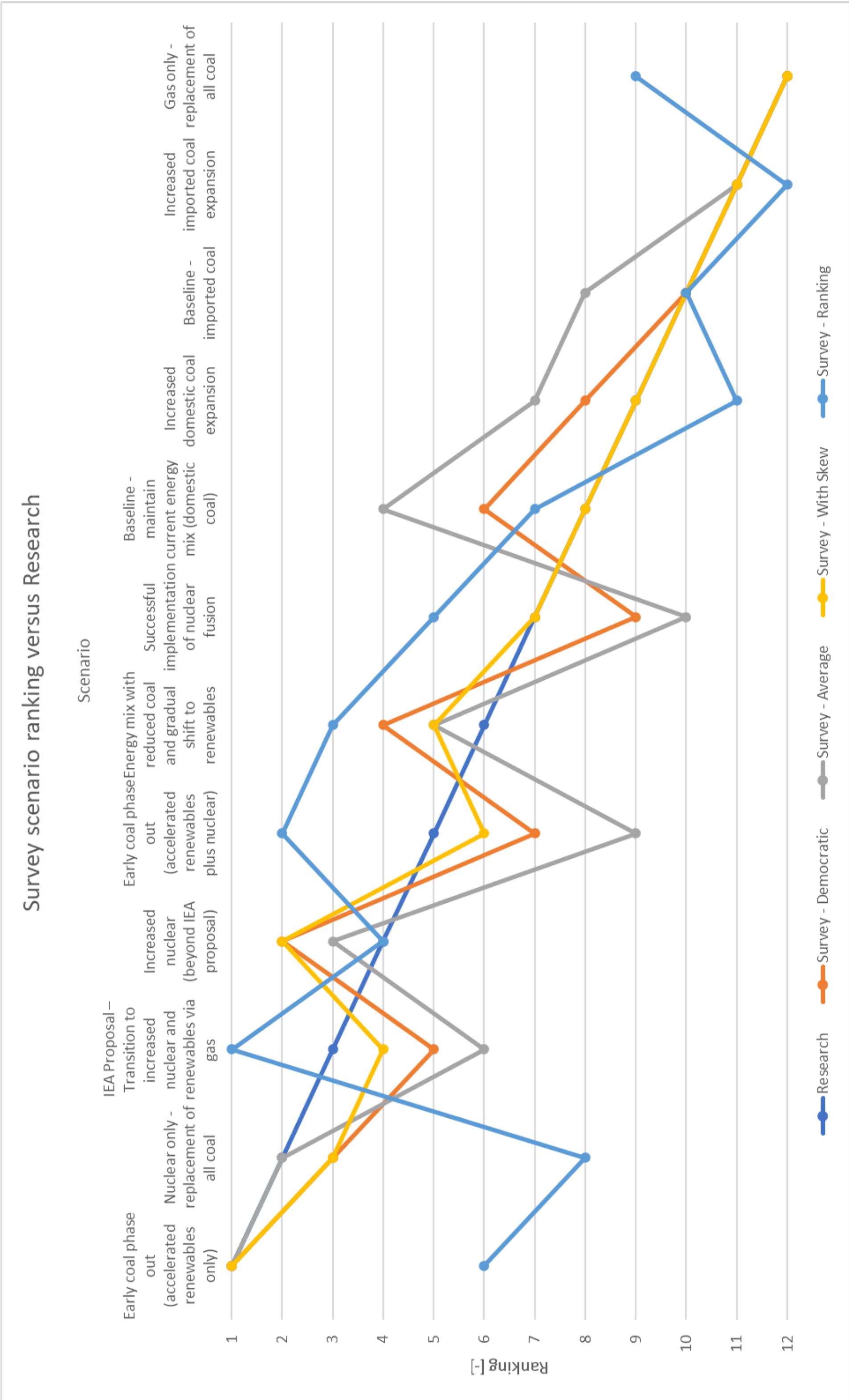

Figure 62 Survey scenario ranking versus Research

By sorting the ranking data from first to last by the order of the ‘Research’ result, it is possible to see how each of the survey scenario ranking methodologies compares to it. The primary observation is that the ‘With Skew’ ranking result has the best-fit versus the ‘Research’. In the lower rankings, it follows with a perfect fit, and in the upper rankings there is only a small offset from 2nd to 6th place with some of the scenarios switching positions slightly versus the ‘Research’ result. Nonetheless, the final result of 1st place is the same. It can be concluded that the ‘With Skew’ methodology is a strong contender for continued use in any further study and offers the best-fit when attempting to make a good correlation between the ‘Research’ result and the outcome from the public when they are confronted only with prioritisation of parameters, but not a direct list of scenarios. This is an important observation, because often respondents give conflicting results in surveys between what they prioritise, and what they think they should choose as a final outcome.

Both the ‘Democratic’ and ‘Average’ survey results from the Pugh Analysis vary more significantly from the ‘Research’ result than the ‘With Skew’ result, although the ‘Average’ result shows the biggest variation from expectation. This adds weight to the argument that the ‘Average’ methodology could be discarded in any future study, and that the ‘Democratic’ and ‘With Skew’ results are the most credible versus the ‘Research’. Interestingly though, in all cases, the ‘Early Coal Phase Out’ is ranked first.

This consistent first place of ‘Early Coal Phase Out’ suggests that the Pugh Matrix design may be biased towards the renewable scenarios, and that this merits further investigation. This suspicion is further backed up by the direct survey ranking results, which put the ‘Early Coal Phase Out’ down in 6th place, with the more conservative timing approach of the ‘IEA Proposal’ ranking 1st.

As it comes to reducing the number of scenarios for a future study, the consistency of the low ranking of the last four scenarios suggests that they could be removed from consideration in the future. Such a removal would be beneficial for a repeat survey because it would give greater clarity for the respondents in terms of their options.

The chart above has its limitations in terms of resolution – it is not possible to see how much better or worse any particular scenario ranked than the others. This is important when confirming the removal of low-ranked scenarios from the study, and for understanding how clear the differentiation is between scenarios which are placed high in the ranking. One way to achieve more clarity is to list the results by total weighted score in the Pugh Matrix analysis. The only downside to this is that the direct survey result cannot be plotted since it does not have any parameter scoring.

Nonetheless, a chart showing this scored listing is as follows:

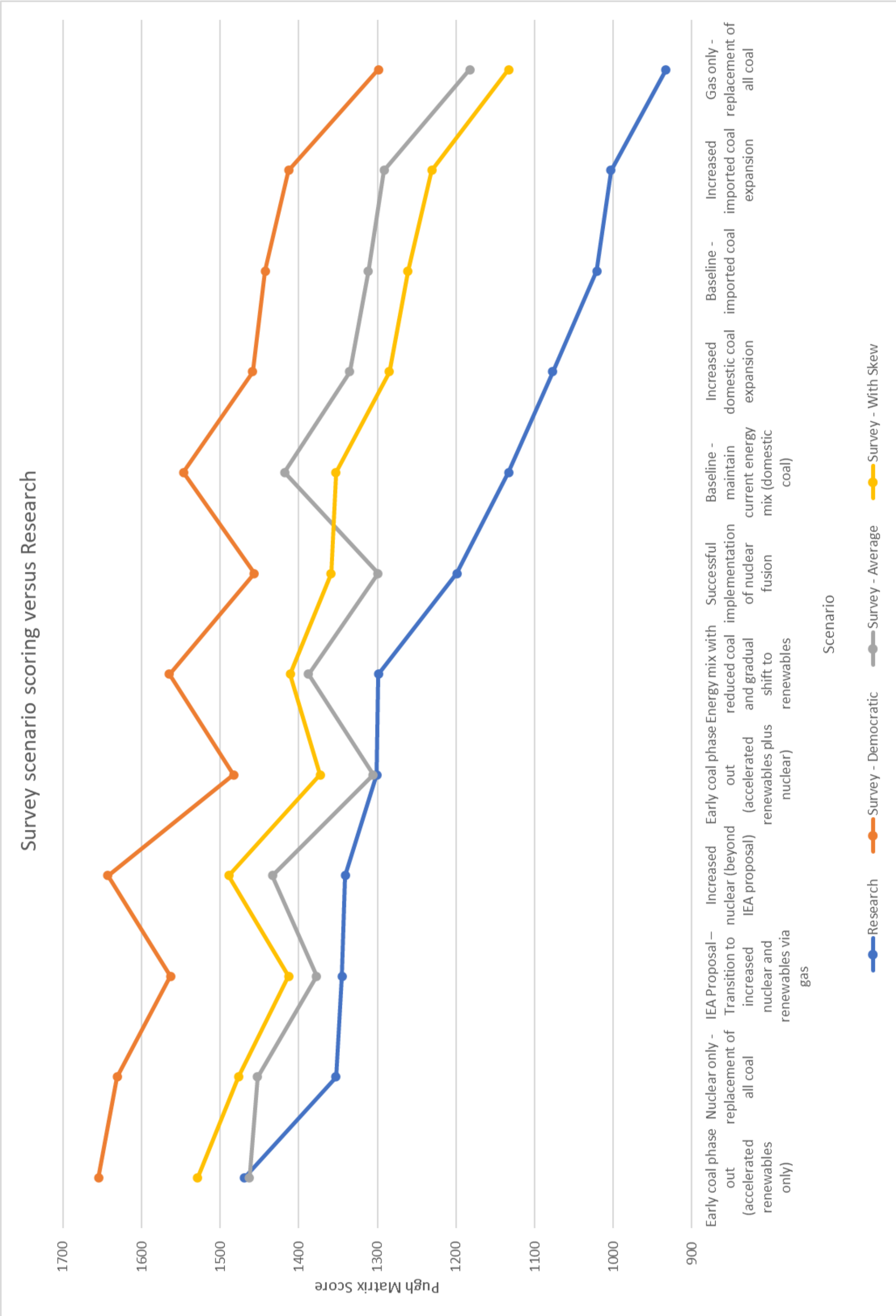

Figure 63 Survey scenario scoring versus Research

The chart above is worthy of some comments as it provides some interesting insights to the data. Firstly, the ‘Research’ result provides the greatest range and standard deviation, showing that the author’s selection of parameter weighting and scenario scoring was most successful in attempting to maximise the full range of available results. This can be quantified easily and is presented in the table below:

Table 6 Research and Survey Statistical Analysis

	Research	Survey - Democratic	Survey – Average	Survey - With Skew
Maximum	1469	1655	1463	1529
Average	1206	1513	1355	1360
Minimum	933	1299	1183	1133
Range	263	142	108	170
Standard deviation	170	107	82	116

It is clear both visually from the graph above, and the tabulation, that the 'Survey – Average' result is not as capable as the 'Democratic' and 'With Skew' results, as it has a very narrow band of differentiation, and this could explain why it shows the most variation in the rankings too. In any statistical study which is intended to be used to drive decisions, it is best to have as much differentiation as possible, and so again, the 'Average' methodology could be discarded. From the methodologies considered, 'With Skew' achieves the widest range and largest standard deviation.

As mentioned previously, the Pugh Matrix tool design appears not to be well calibrated to the direct survey and is at risk of driving a biased result. Consideration was given to the parameters and how to potentially avoid this in a future study. It was found that some of the parameters, although not repeats of each other, give very similar results – given their similarity of factor and result, they could be combined, so that non-renewable scenarios were not double-penalised.

Examples of this include the CO2 and Greenhouse Gas Emissions parameters, which correlate with each other anyway, and could simply be rolled up into a single parameter called 'Emissions'. There is even an argument to say that both could be combined with 'Air Quality', in which case the non-renewable scenarios may have been penalised three times instead of once.

Another example of this potential double-penalisation is the 'European Union Energy Trade Survey' and 'EU / State Subsidisation' parameters. It is logical that if ETS will penalise carbon emitting technologies, and subsidisation will only be for low-carbon technologies, then both parameters effectively give the same result.

In summary to this discussion, the recommendations are:

1) Conduct a repeat survey.
2) Remove the lowest 4 ranking scenarios to provide greater clarity.
3) Remove the 'Average' methodology from the analysis to improve range.
4) Combine parameters that share logics to avoid double-penalisation and remove bias from the results.

13. CONCLUSION

Based on the research carried out in this report, and on the results of the public survey, the following conclusions can be made:

1) The current baseline situation of energy mix in the Czech Republic is not in bad shape and represents an acceptable starting point from which to make progress
2) Further expansion of coal as an energy source should not be considered and can be ruled out as a future energy mix, both for domestic and imported coal
3) A complete shift from coal to gas can be discarded as an option
4) Diversification of the energy mix is desirable to avoid taking too much risk with a single dominant energy resource
5) Both renewables and nuclear represent desirable options to the public, and excellent choices to reduce overall emissions of the future energy mix
6) Caution should be taken in ensuring that renewables are not over-deployed, as they risk negative impacts to the public such as visual and noise disturbance
7) Even if nuclear fusion develops as a technology, it should not be prioritised over other options in the future
8) Caution should be taken when designing any new Pugh Matrix models for future energy mix definition to ensure that certain technologies are not biased against by double-penalisation in the parameter list
9) Survey respondents tend to prioritise parameters that they can perceive in day to day life, rather than more abstract concepts such as legislation that they do not directly encounter

As an overall conclusion to the report, the recommendation is to gradually phase out coal power, steadily replacing it with a diverse mix of renewables and increased nuclear capacity.

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SYMBOLS AND ABBREVIATIONS

Abbreviations:

CCS:	Carbon Capture and Storage
ČEZ:	České Energetické Zavody
CNG:	Compressed Natural Gas
CO_2:	Carbon Dioxide
CO2eq:	Carbon Dioxide equivalent
CTUh:	Comparative Toxic Unit for human
CZ:	Czech Republic
dB:	Decibel
DH:	District Heating
ETS:	Energy Trading System
EU:	European Union
EV:	Electric Vehicle
GDP:	Gross Domestic Product
GHG:	Green House Gas
GJ:	Gigajoule
g P eq.:	grams of Phosphorus equivalent
g Sb eq.:	grams of Antimony equivalent
GtC:	Gigatonnes Carbon
Gtoe:	Gigatonnes of oil equivalent
IEA:	International Energy Agency
IGCC:	Integrated Gasification Combined Cycle
LNG:	Liquified Natural Gas
m^3:	Cubic metre
mS per GW-annum:	man-Sievert per Gigawatt-annum
Mt:	Million tonnes
MWe:	Megawatt-electric
NGCC:	Natural Gas Combined Cycle
NIMBY:	Not In My Back Yard
OECD:	Organisation for Economic Cooperation and Development
O&M:	Operation and Maintenance
PLN:	Polish Zloty
SEP:	State Energy Policy
STEM:	Science, Technology, Engineering, and Mathematics
TFC:	Total Final Consumption
TJ:	Terajoule
TWh:	Terawatt-hour
USD:	United States Dollar

V: Volt

W: Watt

LIST OF APPENDICES

Příloha A - Appendix A – Online Appendices

This Appendix, stored online at the Brno University of Technology (BUT) website, consists of a Microsoft Excel xls format file which contains the following data and tools:

1) Data collected from the respondents in the survey scoring the parameters and ranking the scenarios (SURVEY DATA)
2) Calculation of the weightings for the parameters for the 'With Skew' dataset (NUMBER OF RESPONSES)
3) Calculation of the scenario ranking based on the survey respondents' data (SURVEY SCENARIO RANKING)
4) Calculation of the parameter weighting for the 'Democratic' and 'Average' datasets (SURVEY PARAMETERS RANKING)
5) Calculation of the redistributed parameter weightings for the 'With Skew' model (SURVEY SKEW ANALYSIS)
6) Final Pugh Matrix tabulation with weighted scoring and ranking for all results (Research, Democratic, Average, With Skew) (PUGH MATRIX)
7) Reordering of the parameters from highest to lowest ranked based on Research group, with plot of all results versus this baseline (PUGH MATRIX ORDERED)
8) Reordering of the scenarios from highest to lowest ranked based on Research group, with plot of all results versus this baseline (SCENARIOS RANKING – COMPARISON)
9) Reordering of the scenarios from highest to lowest scored based on Research group, with plot of all results versus this baseline (SCENARIOS SCORING – COMPARISON)
10) Example of a simple Pugh Matrix (SIMPLIFIED PUGH EXAMPLE)

The online address for the content can be found at:
https://www.vut.cz/studenti/zav-prace/detail/151343

Příloha B - Appendix B - Pugh Matrices Values

							Scenarios (12)											
							Realistic scenarios						Hypothetical	Unlikely scenarios				
							1	2	3	4	5	6	7	8	9	10	11	12
Evaluation Criteria	Category (9)	Parameter (39)	Parameter Weighting - Research	Parameter Weighting - Survey - Democratic	Parameter Weighting - Survey - Average	Parameter Weighting - Survey - Skew	Baseline - maintain current energy mix (domestic coal)	Energy mix with reduced coal and gradual shift to renewables	Early coal phase out (accelerated renewables only)	Early coal phase out (accelerated renewables plus nuclear)	IEA Final (2038)	Increased nuclear (beyond IEA proposal)	Successful implementation of nuclear fusion	Gas only - replacement of all coal	Nuclear only - replacement of all coal	Baseline - imported coal	Increased domestic coal expansion	Increased imported coal expansion
	Environmental and ecological impact	CO2 emissions	9	7	7.3	9.0	3	7	9	9	7	7	7	3	7	3	1	1
		Greenhouse gas Emissions	9	7	7.3	9.0	3	7	9	9	7	7	7	3	7	3	1	1
		Land use	3	9	7.6	9.0	7	3	1	3	3	7	9	9	9	7	7	9
		Water dissipation	3	9	6.6	7.0	3	7	9	7	7	7	7	1	1	3	1	1
		Water eutrophication	7	7	6.5	7.0	3	7	9	7	7	7	7	3	7	3	1	1
		Human toxicity	7	9	7.9	9.0	3	7	9	7	7	7	7	3	7	3	1	3
		Non-rare materials usage	1	3	5.2	3.0	7	3	3	3	3	3	7	7	7	7	7	7
		Rare materials usage	7	3	5.4	3.0	7	3	1	3	3	3	7	7	7	7	7	7
		Noise	1	7	5.9	7.0	7	3	1	7	3	7	7	9	9	9	7	9
		Air quality impact	7	9	8.1	9.0	3	7	9	7	7	7	7	3	7	3	1	1
		Visual impact on Landscape	3	9	6.6	7.0	7	3	1	3	3	7	7	7	7	7	7	9
		Ecological impact	7	9	7.8	9.0	3	7	9	7	7	3	3	3	7	3	1	3
	Economics	Acquisition / materials cost	7	3	5.5	3.0	9	3	3	1	3	1	1	3	1	3	9	7
		Operational and maintenance cost	7	7	6.1	7.0	3	7	9	3	7	3	1	7	1	7	7	7
		Potential drift of total construction cost	1	3	5.1	1.0	9	7	7	3	3	1	1	7	3	9	7	9
		European Union Energy Trade System	9	7	5.9	7.0	1	7	9	9	7	9	7	3	9	1	1	1
		EU / State subsidisation	7	7	6.2	7.0	1	7	9	7	9	7	7	1	3	1	1	1
		Cost per unit energy (kW hour)	7	9	7.2	9.0	7	7	9	7	7	7	7	3	7	7	9	7
		Electricity price for consumer	7	9	7.6	9.0	3	7	7	9	7	9	7	3	9	1	1	1
	Independence	Domestic Energy Supply Independence	9	9	7.4	9.0	7	7	9	9	7	7	9	1	9	1	9	1
		Availability of Resources in CZ vs. international	7	7	6.8	7.0	7	3	3	1	3	1	1	1	3	3	9	3
		Domestic fossil fuel depletion	7	7	6.2	7.0	3	7	9	9	7	7	7	7	7	7	1	7
		Energy demand tolerance	9	7	6.2	7.0	7	3	1	3	7	9	7	7	9	7	7	7
		Sensitivity to gas availability	7	7	6.0	7.0	7	7	9	9	7	9	7	1	9	7	9	9
	Implementation	Implementation timing	7	7	6.2	7.0	9	3	7	3	3	3	1	7	1	9	7	9
	Operation	Ease of maintenance/operation	3	7	6.4	7.0	7	7	7	3	3	3	1	7	3	7	7	7
		Training / Workforce technical education	1	7	6.3	7.0	9	7	3	3	7	7	1	7	3	9	9	9
		Safety / Low catastrophic risk level	9	9	7.8	9.0	7	7	9	3	3	1	1	3	1	7	7	7
		Reliability	9	9	7.8	9.0	7	7	3	3	9	9	7	7	7	7	7	7
	Technical challenges	Low grid modernisation requirement	3	7	5.8	3.0	9	3	1	3	3	7	7	7	7	9	9	9
		Low electricity storage requirement	3	7	6.3	7.0	9	3	3	1	3	7	9	9	9	9	9	9
		Ease to implement	3	7	5.8	3.0	9	3	1	1	3	7	1	7	3	9	7	9
		Construction energy consumption	1	7	5.6	3.0	9	7	3	3	7	3	3	7	3	9	7	7
	International concerns	International acceptance level	7	7	5.1	3.0	1	7	9	7	7	3	3	3	3	1	1	1
		International legislative acceptance	9	7	5.3	3.0	1	7	9	9	7	7	3	3	7	1	1	1
	Willingness and need	Political Willingness	7	7	5.2	3.0	3	7	9	7	7	7	3	1	7	1	3	1
		Need (to meet energy demand)	9	7	6.8	7.0	7	3	1	7	7	9	9	7	9	7	7	7
		Low Legislative requirement	3	7	5.1	1.0	9	3	1	1	3	3	3	7	7	7	9	7
	People	Employment impact	3	7	6.8	9.0	7	3	3	3	1	1	1	3	1	3	9	3
				Unweigh	SUM of SCENARIO PARAMETERS	TOTAL												

People	Employment impact	3	7	6.8	9.0	7	3	3	3	1	1	1	3	1	3	9	3
			Unweighted Sum	SUM of SCENARIO PARAMETERS RANKING	TOTAL	223	213	223	199	211	219	197	187	223	207	211	205
				RANK of Scenarios from SUM	Rank	1	5	1	10	6	4	11	12	1	8	6	9
			Research	WEIGHTED TOTAL = Parameter weighting * Scenarion ranking	WEIGHTED TOTAL	1133	1299	1469	1301	1345	1341	1199	933	1353	1021	1077	1003
				RANK of Scenarios based on Weighted total	Weighted Rank	8	6	1	5	3	4	7	12	2	10	9	11
			Survey - Democratic	WEIGHTED TOTAL = Parameter weighting * Scenarion ranking	WEIGHTED TOTAL	1547	1565	1655	1483	1563	1643	1457	1299	1631	1443	1459	1413
				RANK of Scenarios based on Weighted total	Weighted Rank	6	4	1	7	5	2	9	12	3	10	8	11
			Survey - Average	WEIGHTED TOTAL = Parameter weighting * Scenarion ranking	WEIGHTED TOTAL	1418.2	1388.1	1463.2	1305.3	1377.4	1433.7	1299.5	1182.5	1452.8	1311.6	1335.4	1291.4
				RANK of Scenarios based on Weighted total	Weighted Rank	4	5	1	9	6	3	10	12	2	8	7	11
			Survey - With Skew	WEIGHTED TOTAL = Parameter weighting * Scenarion ranking	WEIGHTED TOTAL	1353	1411	1529	1373	1413	1489	1359	1133	1477	1261	1285	1231
				RANK of Scenarios based on Weighted total	Weighted Rank	8	5	1	6	4	2	7	12	3	10	9	11
			Survey - Ranking	RANK of Scenarios based on Survey	Survey Rank	7	3	6	2	1	4	5	9	8	10	11	12

Příloha C - Appendix C – Survey questionnaire

Energy Resource Research – Public Opinion Survey

Parameters:

Description of Key Parameters:

1) CO2 emissions: Carbon dioxide emissions from burning fossil-based fuels such as coal and gas have a significant impact on the environment due to global warming effects. Coal is the highest producer of CO2, followed by gas. Nuclear and renewable resources have relatively very low CO2 emissions.
Put a high weighting for this if you think that it's important to avoid CO2 emissions.

2) Greenhouse gas emissions: This parameter considers creation of other greenhouse gases that trap heat in the earth's atmosphere, such as methane, nitrous oxide, and water vapour.
Weight this highly is you think it's important to avoid greenhouse gas creation.

3) Land use: The centralised energy grid of the Czech Republic currently uses relatively little land, although coal-mining areas do use significant land for their mines. Moving to a decentralised and diversified energy mix of renewables would require taking up land to install solar and wind farms, which take up significant space, as well as having a visual impact on the environment. Although solar panels can be installed on the rooves of houses, large solar farms required to meet EU renewable targets would take up either current farmland or forest areas. Wind farms can be integrated into existing agricultural land, but this does not avoid their visual impact.
Weight this highly if you think that additional land use should be avoided.

4) Water dissipation: Power plants that combust fuel such as coal, gas or uranium, require cooling. Water for this cooling process is extracted from rivers but is not returned to them as it is released as steam into the atmosphere. This can have a negative effect on the local ecological system, meaning that rivers risk running dry in the summer, and plant and wildlife may be affected. All combustion-based plants use a lot of water, whereas renewable sources of energy do not.
Weight this highly if you think it's important to reduce water dissipation to minimise the local impact of cooling thermal plants.

5) Water eutrophication: This is the effect of making water rich in nutrients, especially nitrates from combustion. Power plants release water into the environment which is very rich in nutrients. This can result in it accumulating in rivers, streams and lakes, and causing rapid growth of algae. This can then block light from entering the water and have a negative impact on plant and animal life below the surface of the water.
Weight this highly if you think that it's important to minimise water eutrophication.
6) Human toxicity: This takes into account any toxins that are harmful to humans which are produced as a result of using the energy mix in a particular scenario. It includes both carcinogenic and non-carcinogenic toxins, and radiation.
Weight this highly if you think such toxins should be avoided.

7) Non-rare metals usage: This parameter considers the use of metals which are normally abundant around the world such as iron and aluminium. They may be used in large quantities by certain technologies, but nonetheless are not at risk of being depleted.
Give this a high weighting if you think that it is important to avoid using non-rare metals as much as possible.
8) Rare metals usage: This parameter is similar to the previous one, but this time considers those metals which are rarer or of finite supply.
Give this a high weighting if you think that it is important to avoid using rare metals as much as possible.
9) Noise: Certain technologies, for example wind turbines, create more noise than others – this parameter takes into account this potential disturbance.
Weight this highly if you think that noise disturbance is important to avoid.
10)Air quality impact: This is a parameter which is based on the quality of air in terms of its content of ozone, nitrous oxides, particulate matter, carbon monoxide, and sulphur dioxide.
Give this a high weighting if you think it's important to protect air quality.

11)Visual impact on landscape: Most energy generation technologies have some level of visual impact, whether it be large wind turbines that are visible on the horizon from far away, to cooling towers of thermal power plants or farms of solar panels, none are particularly desirable – this parameter takes this into account.
Weight this highly if you think it's important to avoid excessive visual impact of energy generation technologies.
12)Ecological impact: Deforestation, pollution, and destruction of the natural habitats of animals are all examples of negative ecological impacts – this parameter accounts for the gravity of such impacts in each scenario.
Give this a high weighting if you think that minimising ecological impact is important.
13)Acquisition / materials cost: This parameter accounts for the financial cost of acquiring the land, and paying for the materials, to install the technologies for each scenario's energy mix.
Weight this highly if you think that minimising these costs is important.
14)Operational and maintenance cost: This factors in the cost of any ongoing repairs and maintenance required during the life of a particular electricity generation technology, and the day to day running costs of the technologies in each scenario. An example of such variation is the increased cost of running a nuclear plant over that of a coal-fired plant due to the increased safety protocols required for nuclear plants.
Weight this highly if you think such costs should be minimised.
15)Potential drift of total construction cost: All new technology installations have the possibility of running over budget – this parameter takes into account the risk of such a situation arising, as well as the magnitude of the potential over budget amount.
Give this a high weighting if you think that scenarios that risk running over budget should be avoided.

16)The European Union Energy Trade System: (EU ETS) sets a price for emissions from energy generation which essentially acts as a taxation against heavily greenhouse gas emitting resources such as coal. It is anticipated that the price for coal credits will rise over time, penalising it for being an emissions-heavy fuel, which would in turn make coal an expensive fuel

option, and drive-up energy prices for end users.
Weight this highly if you think that it's important to be mindful of likely penalties against coal use in the future and to avoid them.
17)EU / State subsidisation: Certain electricity generation technologies benefit from, and are likely to continue to benefit from, subsidisation from both the Czech government and EU. In almost all cases, this will be for renewable technologies as the governing bodies wish to promote the use of green energy.
Weight this highly if you think that it's important to maximise the benefit of such subsidies.
18)Cost per unit energy (kW hour): Across the various types of resources that can be used to produce electricity, there is a variety of cost for each unit of fuel, production cost, and efficiency.
This parameter allows the study to differentiate between these costs. **Weight this highly if you think that cost per unit energy is important.**
19)Electricity price for consumer: Though there tends to be a correlation between this parameter and the original fuel cost, this parameter takes into account the impact on final electricity cost to the end user, since this can also be affected by other factors such as taxation or penalties for using certain types of fuel. The final price that the consumer pays for electricity is made up of a variety of factors. First of all, there is the basic price of the fuel, then the cost of burning (or harvesting in the case of renewables) it, distributing it, and finally any taxation or penalty applied due to CO2 emissions. Currently, coal is relatively cheap, but its price is expected to rise as EU ETS credits go up. Gas is also plentiful, is not penalised as heavily for CO2 as coal, but has to be imported – it has a competitive price. Nuclear energy is relatively expensive due to the cost of fuel, and the increased personnel required to safely run a plant versus other sources. Though the source of energy is free for renewables, they are currently not competitive versus alternatives unless they are subsidised as the cost of technology, its installation, and maintenance, along with modernisation of the energy grid all have to be factored into its cost – this means that in the short-term it can be considered expensive, but in the long-term more expensive.
Give this a high rating if you think that low electricity prices are important.
20)Domestic Energy Supply Independence: This parameter means that a country is able to provide energy resources which are available from its own

territory, without the need to import them. CZ still has approximately 50 years of coal supply remaining and is around 90%+ energy independent today. Oil and gas are not readily available domestically in CZ, but any existing or future nuclear or renewable sources would count as domestic. Note that if moving to a non-fossil-fuel-based energy mix, a transition phase of increased international reliance will likely be necessary until more nuclear plants and / or renewable energy sources are commissioned.
Rate this highly if you think it's important to maintain domestic energy independence.

<u>21)Availability of Resources in CZ vs. international:</u> Not all sources of energy are equally abundant or readily available in the Czech Republic – this factor takes into account this variation of ease of access to certain fuel types.
Weight this parameter highly if you think it's important to use energy resources which are easily available.

<u>22)Domestic fossil fuel depletion:</u> There is a finite amount of fossil fuels existing within the Czech Republic. Once they have been consumed, then other sources need to be imported. Coal is the only abundant fuel source in CZ other than uranium (although this is not currently mined as it is cheaper from abroad), whereas renewable energy will not run out.
Weigh this highly if you think it's important not to deplete the sources of fossil fuel in CZ and keep some in reserve.

<u>23)Energy demand tolerance:</u> Due to the availability of certain resources, and the current state of infrastructure to support them, different energy mixes will be able to tolerate an increased demand for electricity in the future better than others. For example, increasing the output of coal would be relatively easy, as existing sites are present, and it would simply be a case of mining more of it. Conversely, renewables are not able to offer supply at all times, for example solar panels do not work at night, so their ability to support a growing demand in electricity output is limited – they need to be supported by peaking plants.
Weight this highly if you think it's important to prioritise and tolerate increased energy demand.

24)Sensitivity to gas availability: If the Czech Republic makes a transition away from coal towards nuclear and renewable energy sources, and complies with EU emissions targets, then a transition phase of using internationally sourced gas will likely be required. The price of this gas will not be under the control of the country and could be affected by geo-political events.
Give this a high weighting if you think it's important to avoid using gas so as not to expose the country to unavoidable costs.
25)Implementation timing: Complex technologies such as nuclear plants take much longer to construct and commission than simpler technologies. This parameter takes this into account and gives a higher ranking to those which are able to be brought online quicker.
Give this a high weighting if you think that faster commissioning times are important.
26)Ease of maintenance / operation: Highly complex electricity generation solutions tend to be more difficult to maintain in a good working order. This parameter scores highly those which are easily maintained without frequent need of maintenance and with a relatively low operator skill level required to carry out the maintenance.
Weight this highly if you think this is an important factor to consider.
27)Training / workforce education: New and highly technical solutions require high levels of training and education. However, education in the Czech Republic is very good, and so operators qualified to a high level are not so difficult to come by as in some other less developed countries. This parameter nonetheless takes account of the skill level required for each scenario's technologies.
Give this a high rating if you think that it's important to minimise training and education needs of energy solutions.
28)Safety / Low catastrophic risk level: This is clearly an important parameter for all electricity generation technologies. The scenario ratings here are based on real-world safety figures for technologies, not perceived values. As a result, there can be some conflict between reality and perception. For example, nuclear is statistically very safe, even if to some it may not be perceived to be, since real-world accident rates per giga-watt hour of production is low. However, it is well-known that historical nuclear catastrophes have been far-reaching and extremely damaging.
Weight this highly if you think it's important to focus on safety and minimise the risk of catastrophes.

<u>29)Reliability:</u> The reliable operation and output of any electricity generation technology is critical, as this ensures consistent delivery of power to end users.

Vote for this if you think reliability should be a key focus for CZ's energy mix solutions.

<u>30)Low grid modernisation requirement:</u> The electricity grid is currently what is described as centralised in the Czech Republic. Infrastructure which allows diversification of the energy grid is not yet installed, and to accommodate more renewables such as photovoltaic cells on house rooves and wind farms in the countryside, plus electric car charging points, significant money will need to be spent on upgrading the network.

Weight this highly if you think that such spending should be avoided.

<u>31)Low electricity storage requirement:</u> Some technologies, particularly renewable ones, do not produce energy on demand, but rather when the source (sun, wind, tidal) is available. As a result, contrary to power plants that burn controlled amounts of fuel, they require energy storage in the form of batteries or other. This requires additional investment and space, and so this parameter accounts for this extra requirement.

Give this a high weighting if you think that avoiding costs on energy storage is important.

<u>32)Ease to implement:</u> The technical challenges of implementing different technologies varies widely – nuclear plants for example are highly complex and have many levels of redundancy, whereas solar panels can even be installed at home with minimal monitoring.

Rate this highly if you think that it's important to prioritise simple energy solutions that are not complicated to install.

<u>33)Construction energy consumption:</u> Each different electricity generation technology consumes energy as part of its initial production – for example, to build power plants, construction vehicles are used which run on oil-based fuels like Diesel, or factories that make photovoltaic cells use energy to produce them. The amount of energy consumed for each technology varies.

Give this a high weighting if you think that it's important to compose an energy mix that minimises the energy spent to install the selected technologies in the first place.

<u>34)International acceptance level:</u> All energy solutions come under international scrutiny. Different technologies have different levels of acceptance internationally. For example, Austria and Germany have voiced negative opinion in the past over CZ having nuclear plants relatively close to their borders.

Weight this parameter highly if you think it's important to create an energy mix that not only satisfies domestic energy needs, but also meets with international acceptance.

35)International legislative acceptance: The Czech Republic is a member state of the EU, and as such needs to abide by legislation which relates to electricity generation. Some technologies enjoy positive legislation, such as renewables that generally attract subsidies, whereas others, such as coal, are increasingly punished in an attempt to make them more expensive and less attractive.

Weight this parameter highly if you think it's important to create an energy mix that follows as positively as possible international legislation.

36)Political willingness: Though not always driven by science, politics can play an important role in making decisions on the future energy mix.

Give a high weighting to this parameter if you think that it is important to select energy technologies that have a positive political standing in order to facilitate implementation of them.

37)Need (to meet energy demand): Though it may be desirable from an economical or ecological point of view to have certain types of electricity generation such as renewables, nonetheless, there is a critical point of realism to accept which is that energy demands of the country need to be met. Certain types of electricity generation are capable of delivering high amounts of energy at any time, without the need for storage.

If you think that it's important to select technologies based primarily on their capability to satisfy energy demand, then give this a high weighting.

38)Low legislative requirement: The growth of renewable energies which rely on a modernised and de-centralised energy grid has been slow in the Czech Republic. As a result, detailed government legislation has not been created to support prosumers (end users that both provide to and consume energy from the network). It will require some time to introduce such legislation, and no doubt there will be teething problems.

Give a high weighting to this parameter if you think it's important to avoid energy resources that will require complex legislation.

39)Employment impact: Versus the baseline or current energy mix of the Czech Republic, changing to other mixes could be disruptive to the workforce

and require re-employment for current employees. For example, if coal is phased out, many people will lose their jobs and need retraining and redeployment.
Rate this highly if you think that it's important not to risk people losing their jobs when planning for future energy mixes.

Scenarios:

Realistic scenarios descriptions:

1) Baseline – business as usual, with today's energy mix: Prioritise this if you think that the Czech Republic should maintain its current energy mix. This means continued domestic coal burning until the supply is exhausted, maintaining current nuclear resources, and limited investment into renewables. This option would maintain a centralised electricity grid for the foreseeable future, reducing investment needs, but not allowing any substantial expansion of renewables in the future without significant investment later down the line.

2) Reduced coal and gradual shift to renewables: Prioritise this if you think that the Czech Republic should make a gradual shift towards renewable energy technologies such as solar and wind. Gradual means that the shift will occur over a period of around 15-20 years, allowing step by step upgrades of the electricity grid to decentralise and modernise it.

3) Early coal phase out (accelerated renewables only): Prioritise this if you think that the Czech Republic should focus spending on renewable power sources. This means upgrading the electricity grid to support diversification and non-centralisation, with the benefit of much reduced CO_2 emissions in a shorter time frame. Early phase out means that by around 2030 the country would no longer be burning any coal, but would need heavy investment into the electricity grid, and rapid definition of legislation to allow the renewable rollout at pace. This would likely require significant subsidisation from the government to incentivise both industry and homeowners alike to prefer renewable energy solutions.

4) Early coal phase out (accelerated renewables plus nuclear): Prioritise this if you think that the Czech Republic should focus spending on both renewables and nuclear as a combined solution to replacing coal. This is similar to the previous scenario, with the difference being that further nuclear expansion could take place at existing sites, and this would reduce the pressure on modernisation of the electricity grid to implement quite so many renewable sites.

5) IEA Proposal – Transition to increased nuclear and renewables via gas: Prioritise this if you think the Czech Republic should follow the IEA proposal to remove coal from the energy mix in line with EU guidelines, using international gas as an interim solution, whilst waiting for new nuclear and renewable domestic resources to be online. Benefits are longer term CO2 reduction, and less exposure to potential penalties for continued coal burning, along with maintaining current coal power plant locations which would be replaced by coal over time. End user energy costs could be lower than with coal in the interim period until nuclear is onling, but the risks are the exposure to international price fluctuations and availability of gas which would need to be imported.

6) Increased nuclear (beyond IEA Proposal): Prioritise this if you think the Czech Republic should further increase its reliance on nuclear energy beyond the IEA proposal by planning and commissioning even more new nuclear plants and reactors than currently anticipated. Benefits are long-term CO2 reduction via avoidance of fossil-based fuels, and less need to install renewable energy sites like solar and wind farms – this would in turn maintain the current centralised electricity grid for the most part, avoiding such high investment costs for the modernisation required for renewables. Downsides to this approach are the low but potentially catastrophic risks associated with nuclear power plants, and the relatively long construction and commissioning time for nuclear plants.

Hypothetical scenario:

7) Successful implementation of nuclear fusion: Prioritise this if you think that the Czech Republic should invest heavily into the potential commercialisation of nuclear fusion as an energy solution. This scenario represents high risk, but potential high reward – in the worst case, the country could invest heavily and delay action on alternatives and end up with no reward at the end. Conversely, if successful, this scenario could be capable of securing the nation’s energy needs if the technology can be optimised and commercialised.

Unlikely scenarios:

8) Gas only – replacement of all coal: Prioritise this if you think that the Czech Republic should replace all coal-fired power plants by those fuelled by gas. The benefits of this are the increased efficiency of gas plants, reduced CO_2 emissions from gas versus coal, avoidance of such high potential penalties via EU ETS credit pricing for coal (though gas is still penalised, albeit at a reduced rate), and maintaining a similar centralised energy network which would require less infrastructure investment and modernisation than the implementation of renewables would. Downsides are that this would leave the country as a net importer of energy and exposed to any potential price fluctuations and availability of gas in the future.

9) Nuclear only – replacement of all coal. Prioritise this if you think that the Czech Republic should replace all coal-fired power plants by new nuclear plants. The benefits of this are reduced CO_2 emissions versus coal, avoidance of EU ETS credit since fossil-based fuels would not be used at all, and maintaining a similar centralised energy network which would require less infrastructure investment and modernisation than the implementation of renewables would. Downsides are that this would be relatively slow to implement and costly, as the levels of redundancy required in a nuclear plant are high in order to keep it safe and minimise the risk of catastrophes.

10)Baseline – imported coal: Prioritise this if you think that after the baseline scenario is no longer possible due to the depletion of coal reserves within the Czech Republic, the country should simply shift to importing coal instead whilst maintaining the same energy mix. The coal would likely be imported from Poland and would result in CZ being a net importer of energy. Benefits are that there would be no need to modernise the existing electricity grid, which would minimise investment risk. Downsides are that the price of energy in the country could become very high due to the expected increase in price for EU ETS credits which would be at their highest for increased coal-burning in the long-term. CO_2 and other greenhouse gas emissions would also continue to remain high.

11)Increased domestic coal expansion: Prioritise this if you think that the Czech Republic should continue to expand its coal powered sector of the energy mix beyond the baseline of today. Benefits are that in the short to medium term, the country could retain its current energy grid and not need to modernise it and would also remain energy dependent until coal reserves run out. Downsides are potentially expensive electricity in the future due to penalisation through EU ETS credit price increases, CO_2 and greenhouse gas emissions increasing, and the time when coal in the country is depleted being brought closer to the present day.

12)Increased imported coal expansion: Prioritise this if you think that the Czech Republic should expand its coal burning sector of the energy mix, but rather than through mining more coal domestically, by importing it from abroad. This option's benefits are that it allows the country to start shifting its workforce away from coal mining and retains the same centralised energy grid as today with limited investment. Downsides are potentially expensive electricity in the future due to penalisation through EU ETS credit price increases, and CO_2 and greenhouse gas emissions increasing.

Příloha D - Appendix D – Survey responses sheet

Energy Resource Research – Public Opinion Survey

Please fill out the following section in order to capture your demographic profile:

Age	0-18	19-29	30-49	50-69	70+
Sex	Man	Woman	I prefer not to say		
Education					
Employment status					

Parameters voting:

Instructions:

Please read the separate sheet provided to understand the definition of each parameter.

Please note that there are 39 parameters to provide a weighting for, and 4 categories ranging from 'Not important' to 'Very important'.

In order to provide clearer resolution between parameters, you are requested to try to fit approximately 10 parameters to each rating.

This is an approximate guide, and you are free to weigh the parameters as you see fit, but please try to maximise your use of the scale.

		Scaling			
Number	**Parameter**	**Not important**	**Less important**	**Important**	**Very important**
1	CO2 emissions				
2	Greenhouse gas Emissions				
3	Land use				
4	Water dissipation				
5	Water eutrophication				
6	Human toxicity				
7	Non-rare materials usage				
8	Rare materials usage				
9	Noise				
10	Air quality impact				

11	Visual impact on Landscape				
12	Ecological impact				
13	Acquisition / materials cost				
14	Operational and maintenance cost				
15	Potential drift of total construction cost				
16	EU ETS price				
17	EU / State subsidization				
18	Cost per unit energy (kW hour)				
19	Electricity price for consumer				
20	Domestic Energy Supply Independence				
21	Availability of Resources in CZ vs. international				
22	Domestic fossil fuel depletion				
23	Energy demand tolerance				
24	Sensitivity to gas availability				
25	Implementation timing				
26	Ease of maintenance/operation				
27	Training / Workforce technical education				
28	Safety / Low catastrophic risk level				
29	Reliability				
30	Low grid modernization requirement				
31	Low electricity storage requirement				
32	Ease to implement				
33	Construction energy consumption				
34	International acceptance level				
35	International legislative acceptance				

36	**Political Willingness**				
37	**Need (to meet energy demand)**				
38	**Legislative requirement**				
39	**Employment impact**				

Scenarios voting:

Instructions:

Please read the separate sheet provided to understand the definition of each scenario.

Please note that there are 12 scenarios.

Please provide your ranking of the scenarios from 1 (Best) to 12 (Worst), by putting a number from 1 to 12 in the 'Ranking' column.

	Scenarios	**RANKING 1-12**
Realistic scenarios	**Baseline - maintain current energy mix (domestic coal)**	
	Energy mix with reduced coal and gradual shift to renewables	
	Early coal phase out (accelerated renewables only)	
	Early coal phase out (accelerated renewables plus nuclear)	
	IEA Proposal – Transition to increased nuclear and renewables via gas	
	Increased nuclear (beyond IEA proposal)	
Hypothetical	Successful implementation of nuclear fusion	
Unlikely	Gas only - replacement of all coal	
	Nuclear only - replacement of all coal	
	Baseline - imported coal	
	Increased domestic coal expansion	
	Increased imported coal expansion	