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The Puzzle of Energy Security in a Decarbonized World

ΔΙΠΛΩΜΑΤΙΚΗ ΕΡΓΑΣΙΑ

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Αθήνα, 2021

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Τριμελής Επιτροπή

Ζέφη Δημαδάμα, Εργαστηριακό Διδακτικό Προσωπικό (Επιβλέπουσα)

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To Athena, the endless power source, and Maria

For a fairer, healthier world, without energy poverty

List of Abbreviations

AHP - Analytic Hierarchy Process

CAPEX – Capital Expenditure

CO2 – Carbon Dioxide

EU - European Union

GDP – Gross Domestic Product

GHG - GreenHouse Gas

IAEA – International Atomic Energy Agency

IEA - International Energy Agency

IoT – Internet of Things

IPCC - Intergovernmental Panel on Climate Change

MCDM - Multi-Criteria Decision Making or Multiple Criteria Decision Making

OPEC - Organization of the Petroleum Exporting Countries

OPEX – Operational Expenditure

PV – Photovoltaic

RES - Renewables

SDGs - Sustainable Development Goals

SMRs - Small Modular Reactors

TOTEX – Total Expenditure

TSO – Transmission System Operator

UAE – United Arab Emirates

UK - United Kingdom

USA - United States of America

WEC - World Energy Council

WMO - World MeterologicalOrganisation

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Foreword

At the time this thesis was being conducted, it couldn't be more relevant to what was happening in the energy sector and energy security around the world. The entire planet is moving towards a new era in relation to the energy resources exploitation, electricity production and generally the energy demand and supply. The economies try to recover and recap losses from the covid-19 pandemic, using the existing supplies of fossil fuels, with the old means and fashion of infrastructure and subsidies. At the same time, there are international pledges and agreements towards a less fossil-fuel world, with a horizon of net zero carbon emissions. This means that the economies and societies will have to respond to their energy demands using different resources, either because they have understood an anthropogenic negative impact on the environment, deteriorating public health, increasing risks against life, and distinguishing energy resources availability, or because are legally obliged to do so.

In this thesis, I try to define what is energy security, why nowadays is a hot topic, why it seems like a puzzle that has no simple solution. I also try to figure out what is the state of play for energy security in the world, how we can or cannot ensure energy security, while we are moving to a decarbonised world. Through statistics and evidence for resource utilization I managed to map the shares of different resources in the different countries. Through my research, I realised that there are factors and multiple criteria defining energy security and there are no golden standards. I also investigated tools that help policymakers and decision makers design the energy policy and energy security for their country. I concluded that multiple criteria decision making tools are suitable for the energy sector.

In this thesis, I present the outcome of a literature research as for energy security definition. I also present the findings for the state of play for energy security in different regions and countries of the world, supported by figures, tables and maps. I discussed the transition towards a decarbonised world, while ensuring energy security. This means a world with no carbon emissions in the light of international commitments, pledges and agreements. I concluded that energy security is not only a matter of definition, but also a matter of studying the right criteria that determine this for each country, and applied policies together with societies and active citizens.

In order to find the right pieces of the puzzle, place them in the right order, and try to discuss proposals for a solution of the puzzle of the energy security, I based my work on international reports, institutional findings and academic research. For my research, I also participated in different webinars organized by World Energy Council, Politico, European Commission, etc. In addition, my research was based on economical, political, technological and social factors. I didn't try to identify geopolitical games, conspiracy theories and hypothetical military scenarios that might have a power on energy security.

I believe this thesis may be useful to policymakers, decision makers and academic researchers.

Summary

In this thesis, I study the energy security in the world moving to decarbonisation under specific pledges and agreements. Decarbonisation is considered by definition the net zero carbon emissions. Ensuring energy security is by default a puzzle since it covers multiple dimensions and depends on multiple factors. Energy security is linked to political, economical, environmental and social factors. The definition of energy security is not unique. Energy security is being understood, conceptualized and defined in different ways from region to region and from country to country.

In bibliography and other sources, there are different keywords that play a crucial role in energy security definition and the approach followed to ensure this. I have identified the four As: availability, affordability, accessibility, acceptability. In addition, I present the existence of the four Rs: review, reduction, replacement, restriction. Moreover, I comment on the existence of the four Ds: decarbonisation, decentralization, digitalization, democratization but also on the four Is: innovation, infrastructure, implementation and integration. I thoroughly explain, analyse and discuss the role of these letters in energy security.

Scientists and analysts distinguish energy security between short-term and long-term. Short-term energy security is considered the prompt reaction to shocks in supply-demand balance. It is also the availability and low cost of fossil technologies alongside the fuel subsidies. Long-term energy security is considered the investments in energy supply in relation to economic developments and environmental needs. It is also a national security issue with energy efficiency, power grids improvements, digitalization, funding tools, citizens inclusiveness and societal acceptability.

I continue by presenting the statistics that reveal energy security in the world. This is based on figures and visualizations for fossil fuel subsidies alongside energy resource utilization and consumption, provided by international research institutes and governmental authorities. I present the amount of different energy sources exploited in world. I also attach maps of energy production and consumption in different regions and countries of the world. In addition, I present pies of estimated energy demand mix and power generation energy mix for the countries being the "*biggest players*" in energy sector. The subsidies of fossil fuels may support short-term energy

security but of course undermine long-term energy security and the decarbonisation. Each country has different energy demands and of course different capabilities in exploiting different energy resources, based on the size of population, GDP per capita, economic activities and access to energy resources. These factors determine energy security.

I proceed by presenting the state of play for energy security in the world, based on a quantified review of World Energy Council. I present the top 10 countries as best performers and improvers in energy security. Besides, I comment on each region and countries of it in regard to energy security and by what means they are trying to achieve this while trying to move to decarbonisation. In summary, I realized that most European and Asian countries do not have adequate natural energy resources and are dependent on imports. On the contrary, countries like Saudi Arabia and Russia do not depend on imports but they still depend a lot on fossil fuels exploitation. Nowadays, the global energy sector is facing a remarkable change, as a lot of countries try hard to decarbonise and form a decisive energy transition, while trying to recover from the economic shocks and the pandemic. An increasing number of countries have already set net zero carbon emission targets. Energy policies and regulations tend to hold the market changes, but occasionally move forward reframing energy markets and enabling new technologies and business models. It looks that the challenges and opportunities presented by post-pandemic recovery will redefine energy policies and energy security agenda.

For a thorough study on a regional or local level I have found that there are many mathematical tools that can help policymakers and scientists working on energy security. Out of these, the multiple criteria decision making tools are commonly used due to the multiple dependent factors and their superiority over other tools.

For the reasons of energy security, we need more resilient and flexible energy systems, with innovative financing and investment models and legally binding long-term contracts and partnerships. One solution I present is following a total expenditure (TOTEX) approach. Besides, the digitalization of energy sector will facilitate the wide utilization of renewable resources and decarbonisation. The main element for this is smart grids. Along with the increasing use of RES, energy efficient focusing on buildings and bulk, long-term energy storage are crucial. Besides, the production and utilization of hydrogen produced by renewable for long-distance transportation and where electrification is not possible have a crucial role. In the view of not succeeding having net zero carbon emissions, the artificial capture of carbon dioxide (CO2) and other carbon gases is a solution, along with the advancement of forestation. In contributing to energy security, smart modular nuclear reactors are coming as a safe nuclear power, being considered as green technology.

Decisions with citizens and a bottom-up approach will be needed. Better regulations and market transparency is needed for energy security. Otherwise, we risk falling in top-bottom decisions excluding society. Solutions at local level can secure energy sector. This can be achieved with active energy citizen. Energy security is beyond a matter of definition. It is a matter of studying the right criteria that determine a territory, the applied policies, including societies and active citizens.

Introduction

From the title of the thesis we can recognise three fundamental parts that we need to explore and approach their definition. The most important part is energy security itself as a design of a set of policies being applied in the society for the society. However, we have to examine before what is a puzzle and why energy security is considered as a puzzle. Then we need to define the framework of the decarbonised world where we set and examine energy security. We need to define what is decarbonisation.

In the discussion for energy security, the outmost truth is that energy drives economies, people's quality of life and human progress. Securing energy for societies can secure human activities, environmental functioning, social equity and people's life. The challenge is to tackle question like: what, how, for whom and from whom, in relation to energy security, that our planet can have. Since energy security is linked to different factors, from economic to environmental and up to societal, we understand that the design of policies for energy security is to study the right factors and set them in the right order like the pieces for solving a puzzle. The energy sector has changed over the last decades, and larger changes may come the following years of a relevantly higher pace. Transition to other fuels and resources, changing patterns of energy utilization, entry of new technologies, form the puzzle pieces at the forefront of the energy security. Investigating sustainability and success of the designed policies for energy security requires that we go along the dimensions and interconnections of the puzzle pieces. Research in and across those pieces is necessary to solve the puzzle.

Following the discussion for energy security, we need to define what a decarbonised world is. Not all entities, meaning governments, organizations, associations, companies, civil groups, policymakers and decision makers realise and attribute the same meaning to the word “*decarbonisation*”. Decarbonisation as a word is by definition the carbon removal. Besides, many authors refer to the efforts of curbing carbon emissions while others refer to net zero carbon emissions and some others to ultimate end of carbon emissions of fossil fuels by human activity. Net zero carbon emissions do not primarily exclude the carbon emissions. This means that the balance of carbon emitted and absorbed physically or technically should be zero at the end.

Net zero also assumes that there are no limits to compensate emissions with carbon removal. For some others, net zero refers to the balance between the amount of greenhouse gas (GHG) produced and the amount removed from the atmosphere. Reducing drastically carbon emissions to net zero or balancing emissions through offsetting and the purchase of carbon credits is understood the same way. In the context of no straight forward and unique definition of the decarbonisation, I presume the common concept as usually defined even in lexicons. This means that I refer to zero carbon emissions of the GHG, following all efforts for absolute net zero carbon emissions, while eliminating all negative environmental impacts that may cause. This conceptualises the meaning of the decarbonised world and would be the reference.

While the world population increases and living standards keep rising, we see a greater demand for energy than ever before. Climate phenomena are getting intensified, as being reported by the World Meterological Organisation (WMO) and the Intergovernmental Panel on Climate Change (IPCC). The global carbon emitters have announced their will to reduce carbon emissions by 2050 (Paris Agreement) or further to 2060 (ie China). At the end of 2015 in Paris, the leaders of most countries agreed to make the effort to hold the increase in global temperature below 2 degrees Celsius or even 1.5 degrees Celsius, connecting this with ambitious carbon emissions reductions. This was the cornerstone that starting a new era for the energy future to a decarbonised world.

Researchers and policymakers have tried from different angles to "*conceptualize energy security in a universal and applicable way*"[1]. While the concept of energy security appeared in the 60s[2], energy security emerged in the 70s' as a result of oil crisis. In our days, energy security has become a multi-dimensional field. It has to take into account climate extreme phenomena, globalization, uncertain inventories of fossil fuels, mitigation of greenhouse gas emissions, etc. The concept of energy security has become interconnected with political, economic, environmental, and social factors.

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[1]Blazev, A. (2015). Energy security for the 21st century. CRC Press. ISBN 0-88173-739-9.
[2]Lubell, H. (1961). Security of Supply and Energy Policy in Western Europe, World Politics, vol. 13(3). Cambridge University Press, pp. 400-422.

In the need to take care of the security of energy sector, the term energy security was formed. This means anticipation, planning, and prevention of any interruptions in the energy sector, regardless of their source, magnitude, or intentions[3].

Trying to define energy security, the literature refers to the definition provided by the International Energy Agency (IEA). Energy security is defined as "*the reliable, affordable access to all fuels and energy sources*"[4]. However, this sounds oversimplified. It contains hidden messages that are not obviously seen and can change over time. Taken this definition for granted, in order to have complete energy security, we need plentiful supply of all fuels, so we can switch from one to the other accordingly. This means we need to have the choice of energy sources, offering us absolute independence in producing and consuming fuels.

While energy is an important element in our lives, securing this is a fundamental issue. If we get closer to the question what is energy security, and why it is so important, it is not that simple to give a clear answer. In the IEA definition, it is clear that the light is shed on the access, being reliable and affordable. But, is access enough to describe energy security? Blazev[5] reports that energy security is "*the task of ensuring an uninterrupted and sufficient energy supply today and tomorrow, by employing efficient and safe internal and external risk prevention measures*". He comments on this definition as it incorporates complex technological, logistical, social, political and other aspects of national and international importance. He also adds that our world focuses on doing whatever possible to ensure energy supplies even if the fossil fuels are in finite supply. Moreover, Blazev concludes that the energy security means: "*a) ensuring present-day energy supplies, while at the same time, b) preserving the environment, and c) planning the post-fossils energy future, in that order and with equal importance*". I must admit that Blazev has a point. It is meaningless to have a lot of energy by destroying the environment, causing deadly pollution. While there is no separation between the environment and energy, the environment is affected by power production and utilization. This, directly or indirectly affects also our long-term energy security.

[3]Blazev, A. (2015). Energy security for the 21st century. CRC Press. ISBN 0-88173-739-9.
[4] IEA. Energy Security. (2021): https://www.iea.org/topics/energy-security.
[5]Blazev, A. (2015). Energy security for the 21st century. CRC Press. ISBN 0-88173-739-9.

For Blazev, energy security is also distinguished between short-term energy security and long-term one. For short-term security, the goal is to account for and eliminate the short-term risks, sometimes at all costs, and produce and use as much energy as needed for normal functioning. We can experience this situation, while phasing-out the covid-19 pandemic. However, this cannot approach the idea of risk-free energy, reliable energy supplies and affordable prices of energy.

For the long-term security, the main pillars are the energy of tomorrow and the environment. The environmental pillar is the most tricky in the "*how to secure energy*" equation. If we don't consider the environment with the same importance of producing and consuming energy, we will not be able to talk about energy security, as we have to exploit new resources highly dependent on the environmental conditions and affecting the environment. Besides, energy security is interwoven with energy independence, which in turn directly affects national security, which all directly are dependent on a number of internal and external factors and risks. What happens around the world affects all of us, in one way or another. Figure 1[6] depicts schematically the energy-related dependencies.

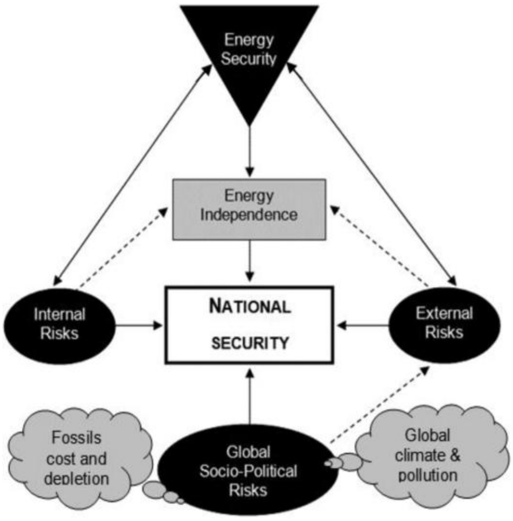


Figure 1. Energy-related dependencies

In the future, energy security might be in the centre of the previous figure, replacing national security, whereas energy security will be the condition for national security. For the long-term security, it is not enough to only take care of the energy supply of

[6]Blazev, A. (2015). Energy security for the 21st century. CRC Press. ISBN 0-88173-739-9.

the existing energy resources. Energy efficiency, improvement of grids and interconnectivity of them, increase of different energy resources, forming a better energy mixture, physical and digital safety of infrastructures, funding tools and long-term contracts between suppliers and consumers, between exporters and importers will most likely form the energy security of the future.

The presence of internal and external risks can affect energy security. These risks can disrupt the production, transport, energy utilization, which may have catastrophic results for the economy, and the safety of the population. On the one hand, internal risks include non-reliable fuel transportation and grids, non-reliable and expensive power generation, non-adequate market regulations, and volatile energy prices. On the other hand, external risks include insufficient global access to energy supplies, unsafe global energy supplies, acute natural disasters, energy resources depletion. However, when energy security is ensured this means that nations can ensure a healthy and undamaged energy sector, which means energy independence, which in turn contributes to a national security.

Different threats go through global and local levels, and relate to security of energy systems. Many of these threats, such as those concerning fossil fuels, nuclear power, hydroelectric dams, renewable energy technologies, are specific to each energy system. The complicated aspect of these threats is that they are generally impacted by multiple reasons and events, occurring at the local, state, national, regional, or global level. For instance, energy market volatilities are a result of unforeseen changes in geopolitical terrain but also due to political issues, conflicts, trade discontinuities, and unsuccessful negotiations for deals at the national or local level. Moreover, technical system failures can include power outages caused by grid malfunction, faults in supply systems, accidents or human errors, or shortages of fuel and disruptions in transit. Physical or digital security threats such as terrorism and extreme weather events, sabotage, theft, piracy, earthquakes, hurricanes, volcanoes, and extreme climate phenomena can also affect the supply chain, power stations, transmission lines, networks, terminals and ports. Such threats become more important when pipelines, cables, and offshore installations concern multiple countries and cross international boundaries[7].

In a nutshell, short-term energy security is related to the ability of energy systems to react effectively to shocks in the supply and demand balance. Long-term energy security has to do with investments in energy supply, in relation to economic developments and environmental needs. At global level, energy security has continued to attracting an increased attention. This is based on Sustainable Development Goal 7 of the United Nations that requires countries to ensure access to affordable, reliable, sustainable, and modern energy for all[8].

As energy security discussion is getting intense on world's chessboard, we find out that energy security is quite different from region to region, or from country to country. For example, most European and Asian countries do not have adequate natural energy resources and are dependent on imports. This put pressure on them to reconsider their energy policies, try to increase their energy mix and rely more and more on alternative energy sources. Besides, the energy sources distribution and utilization is not equal around world. There are countries that may import over half of their total primary energy resources. This includes all kinds of energy imports such as coal, natural gas, and crude oil. These countries depend totally on the international energy markets which are dominated by financial, logistical, and political issues.

If we go through the regions we see that, for example, the European Union (EU) countries are struggling with energy security, and energy independence. The EU is having the hardest time with energy supplies, and is trying hard to establish energy security. From the Member States, France tries to rely on nuclear power for electricity, while being a world leader in nuclear energy reactors commissioning and operation. Germany imports a lot of its net primary energy. In the meantime, Germany struggles with fossil fuels, having declared its will to decommission nuclear reactors. It has also declared major incentives for RES, while trying to export know-how and sell technology. The EU has an energy policy for many years now, which

[7]Sovacool, B.K. (2011). The Routledge Handbook of Energy Security. Routledge International Handbooks.
[8] Collins, A. (2020). Towards Energy Security for the Twenty-First Century. Energy Policy. doi:10.5772/intechopen.90872.

actually came out of the European Coal and Steel Community arrangement. It is based on the concept of introducing mandatory and comprehensive rules of energy generation and utilization. In practice, the actual energy policy remains at national Member State level. The application of energy policy in the EU level requires voluntary cooperation by the different members states. The countries still have the final word over all energy and environment related changes and enforcement. This is a complex matter how this affects the energy security of the different countries in the EU. Because of the lack of uniformity, the countries have different approaches, with successes and failures of their energy security efforts. In an attempt to mitigate some of the major risks, the EU legislation has been trying to design actions that could help avoiding difficult times with energy supplies. In the meantime, energy exporters have succeeded in causing a number of serious disruptions.

Outside the EU, the United Kingdom (UK) imports some of its net primary energy, being close to the depletion of North Sea gas. The high reliance on gas, makes the UK vulnerable to supply interruptions. Countries like Saudi Arabia, Russia, Canada, and Australia, do not depend on imports, and in fact export more than they use. But the major Asian economies, such as Japan and South Korea, are having problems with their energy supplies. Japan tries to diversify its electricity generation, including a significant share of nuclear power, alongside coal and gas. However, following the Fukushima accident, this balance has been questioned. The United States of America (USA) is also an interesting case, being one of the few countries which imports and exports large quantities of energy resources. But since the fossils are going fast, this situation seems unsustainable[9].

[9]Blazev, A. (2015). Energy security for the 21st century. CRC Press. ISBN 0-88173-739-9.

First Chapter

The four As of energy security

We have seen that through the years, energy security has become a crucial aspect. Numerous articles have been published on the concept of energy security. A lot of them refer to "*the four As of energy security*", which had been introduced by the Asia Pacific Energy Research Centre (APERC)[10]. These As are: availability, affordability, accessibility and acceptability. In 2007, APERC used the As, combining the classic "*availability*" and "*affordability*" with "*accessibility*" and "*acceptability*" developing a report on energy security in Asia. In literature, there are multiple authors that have challenged the use of the As, to rank energy sources according to their contribution to energy security.

L. Hughes and D. Shupe[11] have introduced a method of producing an energy security ranking for the different energy sources used in a jurisdiction, based on the four As of APERC. For this purpose, they have introduced a decision matrix for creating the ranking. The As served as four criteria. The criteria were associated with quantitative metrics. This means that the higher the value, the more secure the energy source. For the analysis, the authors used the Analytic Hierarchy Process (AHP), a well-know and widely used process for a multi-criteria decision analysis, to solve complex decision problems.

Hughes et al. support that energy security is linked to energy sources ranking and can be done qualitatively or quantitatively. "*Although both approaches work, ranking based on quantitative data is typically easier to reproduce and can be more justifiable than using qualitative data*". Hughes et al. conclude on the use of the four As:
"*Availability: It refers to the present levels of supply of a given energy source from a supplier. "The greater the availability, the more secure the source". It deals with current consumption and not future supply.*

[10] APERC. Asia Pacific Energy Research Centre. (2007). A Quest for Energy Security in the 21st Century: Resources and Constraints. Institute of Energy Economics. Japan.
[11] Hughes, L., Shupe, D. (2011). Applying the four A's in security ranking. The Routledge Handbook of Energy Security.

Accessibility: It refers to historical supply trends, indicating whether access to the source is increasing, decreasing, or remaining constant. The use of availability and accessibility, if considered together, can give an indication of the relative energy security for each energy source.
Affordability: It is the actual cost of the energy source to the consumer.
Acceptability: It is the political and economic risks of the supplier and its state as a supplier of an energy source."

The introduction of the As and the method followed by Hughes can be used to examine the state of energy security in a jurisdiction, as a whole or in its energy services (i.e., transportation, heating and cooling, and electricity production). "*It can also include the annual or regular recalculation of the ranking to show the current state of energy security for the jurisdiction or energy service and the testing of "what-if" scenarios. The ranking can be used in combination with other tools to influence energy policy decisions, including energy and infrastructure choices for all energy services.*"

However, in a more recent study by A. Cherp and J. Jewell, they argue that the As themselves cannot serve the purposes of ranking the energy sources according to their contribution to energy security. This is because they cannot clearly answer the questions: Security for whom? Security for which values? Security from what threats?[12] For this reason, J. Jewell proposes a new definition of energy security. Based on this definition, new criteria have been defined to measure and rank energy sources for their contribution to energy security. "*The energy security is defined as "the low vulnerability of vital energy systems". Vital energy systems are those energy systems (energy resources, technologies and uses) that support critical social functions. Vital energy systems can be differentiated according to geographic and sectoral boundaries*[13]. *Vulnerabilities of vital energy systems are combinations of*

[12] Cherp, A., Jewell, J. (2014). The concept of energy security: Beyond the four As. Energy Policy. 75. 415–421.
[13] Cherp, A., Jewell, J. (2013). Energy security assessment framework and three case studies. International Handbook of Energy Security. Edward Elgar. Cheltenham. UK. Northampton. MA. USA. pp.146–173.

their exposure to risks and their resilience"[14]. The risks differ in nature and origin. The main difference is made between short-term disruptions called "*shocks*" and long-term "*stresses*"[15][16]. Another common difference is between physical and economic risks. As for the resilience, it concerns the origin of risks in largely unpredictable social, economic and technological factors. It has its roots in ecology, economics and complex systems analysis.

We realize that we have to seriously consider the social functions with regard "*for whom*" and "*for which values*". In addition, we have to consider risks that threaten accordingly energy security and define energy policies. Apart from having resilient energy systems and communities, we need flexibility, a highly sophisticated balance between energy demand and supply, considering shocks and stresses from climate phenomena, military actions, and cybersecurity, but also recalculating the state of energy security on a regular basis. A multi-criteria decision making approach seems from the bibliography to be suitable for examining the state of energy security of a jurisdiction. For this approach, there are tools to be considered.

[14]Cherp, A., Jewell, J. (2011) .The Three Perspectives on Energy Security: Intellectual History, Disciplinary Roots and the Potential for Integration. Current Opinion in Environmental Sustainability 3(4), 202–212. http://dx.doi.org/ 10.1016/j.cosust.2011.07.001.

[15]Stirling, A. (2014.) From sustainability, through diversity to transformation: towards more reflexive governance of vulnerability. Vulnerability in Technological Cultures. New Directions in Research and Governance. MIT Press,pp.305–332. ISBN:9780262027106.

[16]Winzer, C. (2012). Conceptualizing energy security. Energy Policy. 46. 36–48. http://dx.doi.org/10.1016/j.enpol.2012.02.067.

Second Chapter

The four Rs of energy security

It is clear that energy security is not perceived in the same way worldwide. Moreover, there is no common agreement on its precise interpretation. There are regions that energy security is somehow mistaken and interchanged with energy independence[17]. Moreover, energy security is considered on the basis of energy imports, and with a focus on domestic supplies and infrastructure.

There have been studies trying to clarify issues in energy security, with a holistic approach. One of them, is the study of L. Hughes entitled "*The four Rs of energy security*"[18]. The author from Canada has tried to approach energy security by "*review (understanding the problem), reduction (using less energy), replacement (shifting to secure sources), and restriction (limiting new demand to secure sources).*" These are the four Rs often cited in research and academic studies.

The first R has to do with review. Of course, it is a crucial issue to understand the problem and clarify what we mean when we talk about energy security. We have seen that the IEA's definition is condensed, leaving open issues to be interpreted individually. Hughes proposes three pillars for the review of energy security. The first pillar is comprised of the existing sources with the suppliers, the supplies of energy, and the infrastructure. In order to rank each source, he proposes the introduction of the energy security index, based upon the opinion of energy experts and using Analytic Hierarchy Process (AHP), a Multi-Criteria Decision Making method. The second pillar is comprised of the review of each separate energy services sector (ie heating, cooling, lighting, etc). The third pillar examines the different secure energy supplies, their lifetimes, the infrastructure needed, and the cost of them.

The second R is reduction. Actions have been taken for energy conservation and reducing energy consumed, despite the different outlook for energy demand increase in the following decades. Energy reduction can be achieved not only through energy conservation but also energy efficiency. In energy conservation, less energy is available for a specific energy service. This means that the same service is not

[17] Bryce, R. (2008). Gusher of Lies: The Dangerous Delusions of Energy Independence. Public Affairs, Philadelphia.
[18] Hughes, L. (2009). The four R's of energy security. Energy Policy. 37. 2459–2461.

performed on previous levels. Energy efficiency allows the same level of activities to be done with less energy.

“*Conservation measures can be introduced rapidly and with little cost (ie lowering room temperatures, reducing roadway speeds, and turning off unnecessary lighting). However, conservation is often short-lived, and a non-practical activity)*”[19]. “*Permanent energy reduction through conservation measures will require both psychological and structural strategies linked to education, infrastructure, and pricing*”[20].

Energy reduction through energy efficiency measures demands more time and investments to implement, offering greater reduction potential. Examples are buildings insulation to reduce heat loss, a vehicle purchase with an improved fuel economy, and old bulbs remplacement with lower wattage LED bulbs.

Rising energy prices may induce energy reduction, as individuals and other entities look for ways to lower their energy costs. However, this may lead to societal instability and unforeseen evolutions, affecting negatively the environment and other economic activities. “*Besides, reducing energy consumption does not automatically mean an improvement in energy security. If the reductions target secure sources, there may be an overall reduction in energy consumption, but the reliance on insecure sources may remain unchanged.*”

The third R is replacement. New infrastructure may allow alternative energy sources to be used. These can replace the existing ones (ie applied to electrical generation by switching from lignite to natural gas). The UK was a rather typical example where there was a move from coal to natural gas and nuclear for electrical generation, driven largely by the coal miners’ strike which threatened supply in the 1980s. Another example is the transportation sector. There have been significant replacement programs, established in different economies. “*One can recall the EU biodiesel program (EU, 2006) and the US renewable fuels program (Energy Independence and Security Act, 2007), being examples of replacement policies to improve energy security. Replacement policies were introduced to improve energy security.*”However,

[19]Kettle, M., et al. (2008). Going backwards. Cheney Promises Big US Nuclear Power Expansion. CommonDreams.org News Center. http://www.commondreams.org/headlines01/0502-01.htm.
[20] Steg, L. (2008). Promoting household energy conservation. Energy Policy. 36. 4449–4453.

not all solved the energy security problem. "*This reflects the temporal nature of replacement programs based upon finite supplies.*"

The fourth R is restriction. This is introduced with the scope to limit new demand to secure sources. Restricting energy sources to secure ones may be easier to meet the new demand. But which sources are secure? This aspect has already been solved. Every source has its pros and cons. Choosing one source against another it takes a tradeoff, a compromise.

In Hughes' study for the four Rs of energy security, it is well explained the actions needed to improve and ensure energy security, beginning with the understanding of the problem (review), then moving on with using less energy (reduction), continuing with shifting to secure sources (replacement), and finally limiting new demand to secure sources (restriction).

If we consider the four Rs, we have a methodology that can be used as a tool to initiate the development of improved and modern energy security policies, following the pledges and agreements for clean energy utilization and zero carbon emissions. Hughes has already used the four Rs concept to explain energy security and "*climate issues to members of the general public, and Canadian provincial and federal politicians. He argues that commercial and community organizations have already incorporated the tool into their strategic planning efforts and it has been applied to develop energy policies in several jurisdictions.*" He also believes that the Rs methodology can be more successful by including measurement and visualization tools to assist in identifying current energy security status and indicating pathways to improved energy security. The World Energy Forum has already proposed such work and presented this on October 2021.

Third Chapter

Energy security in statistics

How prices, consumption, population and subsidies play their role in energy security?

What is the current estimated energy demand and power generation mix?

Energy security is playing a crucial role in the well functioning of the society. As already discussed in the previous chapters, one important aspect of security is the reliability and affordability. In order to understand what specific factors and how these determine energy security in short-term and long-term in different regions, I have consulted and extracted relative supporting data from "*Our World In Data*"[21], a project of the Global Change Data Lab[22].

From the figures and the visualization in maps, one very important issue is to tackle the continuous subsidization of fossil fuels. The answer to the shocks in energy sector and especially to unexpectedly extreme increases in energy prices, are subsidies offered by the governments, with the intention to ensure energy security. The disappointing issue is that the governments subsidize the consumption of fossil fuels. In this framework, there are many countries that subsidize more than $100 per person per year (see Figure 2).

[21] Our World in Data. (2021). https://ourworldindata.org/.
[22]https://global-change-data-lab.org/.

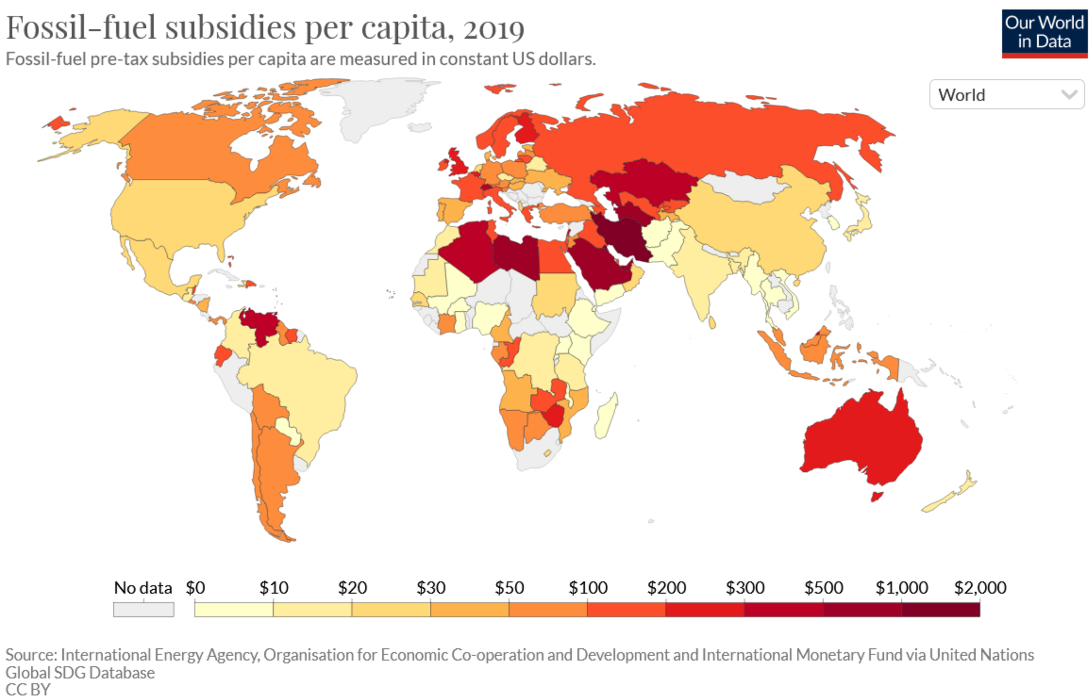


Figure 2. Fossil-fuelsubsidies per capita

These subsidies can be very large compared to other public expenditures. For poorer countries they are often a major expense. For example, this is up to 16% of GDP in Zimbabwe and 21% of GDP in Iran (see Figure 3).

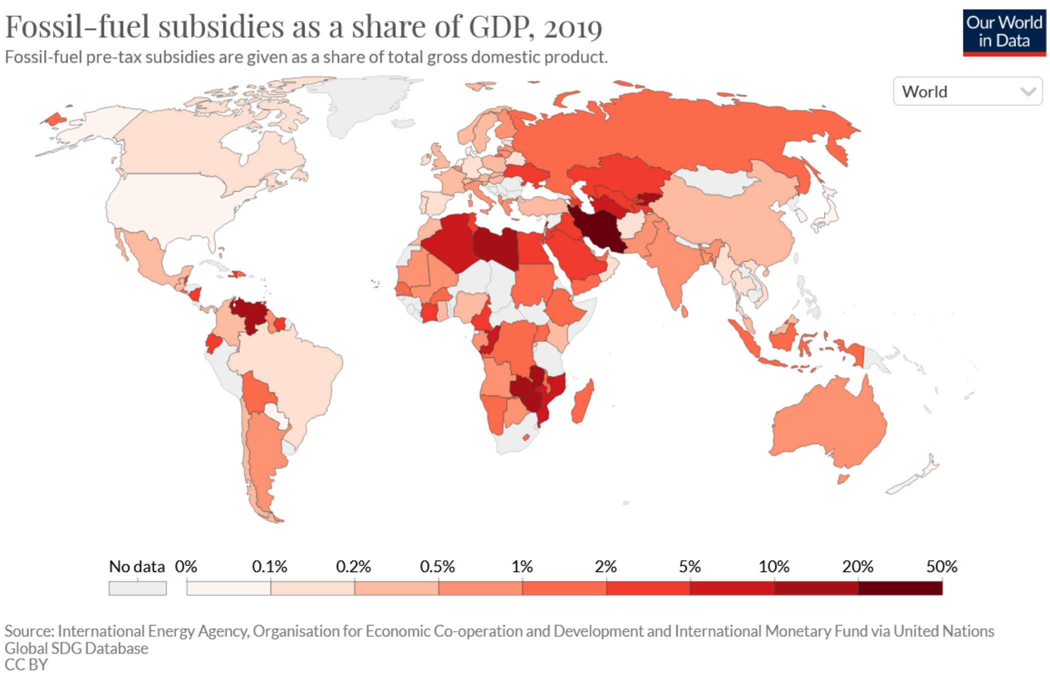


Figure 3. Fossil-fuel subsidies as a share of GDP

"*For political leaders, the attractiveness of fuel subsidies seems obvious. Access to cheap energy is important to people and subsidies are an easy way of support for governments. On top of this, subsidies, once they are established, are very hard to be taken back*"[23][24]. Additionally, fossil fuel subsidies are expensive and of course environmentally disastrous. On the other hand, energy security is so crucial. The solution is not as simple as just repealing these subsidies. If people cannot access fossil fuel energy, they need substitutes. To end the subsidies that keep going the consumption of fossil fuels there must be a change to make energy from clean sources both accessible and affordable.

Industry and individuals choose energy fuels basing largely their decision on their price. To secure energy and move from fossil fuels to clean sources, the second firstly need to be cheaper. The fact that fossil fuels are subsidised makes this much harder. Clean sources don't just have to be cheaper than fossil fuels but they have to be cheaper than fossil fuels with subsidies.

In the years of humanity evolution, the world rarely solves a problem through a single event. This is also happening with the energy sector and repealing subsidies. The good news is that there are several countries that are making progress and others can learn from. Indonesia of 270 million people and with a major oil industry, is one of these countries. Indonesia overcame the political obstacles to gasoline and diesel subsidy reforms and focused on the reforms after the 2014 price hike.

In the 00's, the subsidies started declining, but this progress is slow. It has been made some progress, but energy security is still in the agenda. Many governments are failing to secure energy sector while reducing greenhouse gas emissions. In the meantime, our world needs more a more energy due our consuming behavior. Fossil fuels play a great role in this (see Figure 4) compared to other resources.

[23] Kyle, J. (2018). Local Corruption and Popular Support for Fuel Subsidy Reform in Indonesia. Comparative Political Studies. 1472-1503. doi:10.1177/0010414018758755.

[24] Cheon, A., Urpelainen, J., Lackner, M. (2013). Why do governments subsidize gasoline consumption? An empirical analysis of global gasoline prices. 2002-2009. Energy Policy. 56. 382-390.

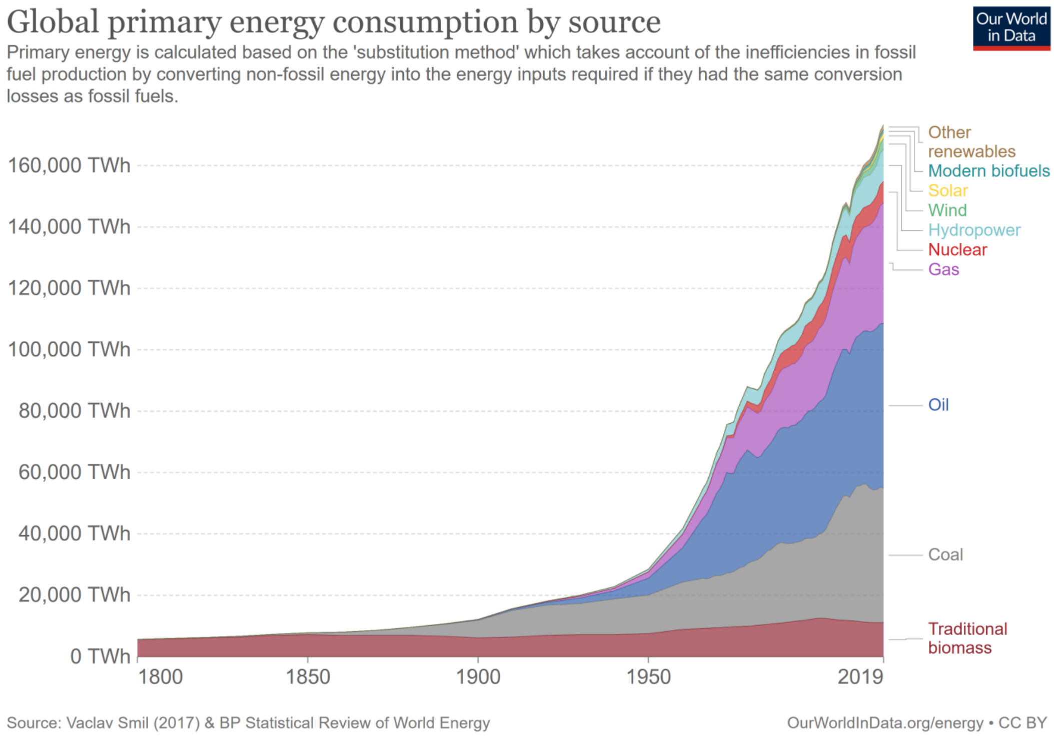


Figure 4. Global primary energy consumption by source

In 2019, almost 85% of the energy consumed came from fossil fuels. It is unclear how we can repeal from fossil fuels while securing energy access and supply in affordable prices. The most of energy is consumed in the big polluters and mostly in the US, China, Russia, India, Canada, and Brazil. These countries have also the biggest share of responsibility.

When we look at total energy consumption, differences across countries often reflect differences in population size. Countries with large population inevitably consume more energy than small countries. But how do countries compare when we look at energy consumption per person? In Figure 5, we see vast differences across the world. The developing countries in the North, consume less per person than the developed ones in the South.

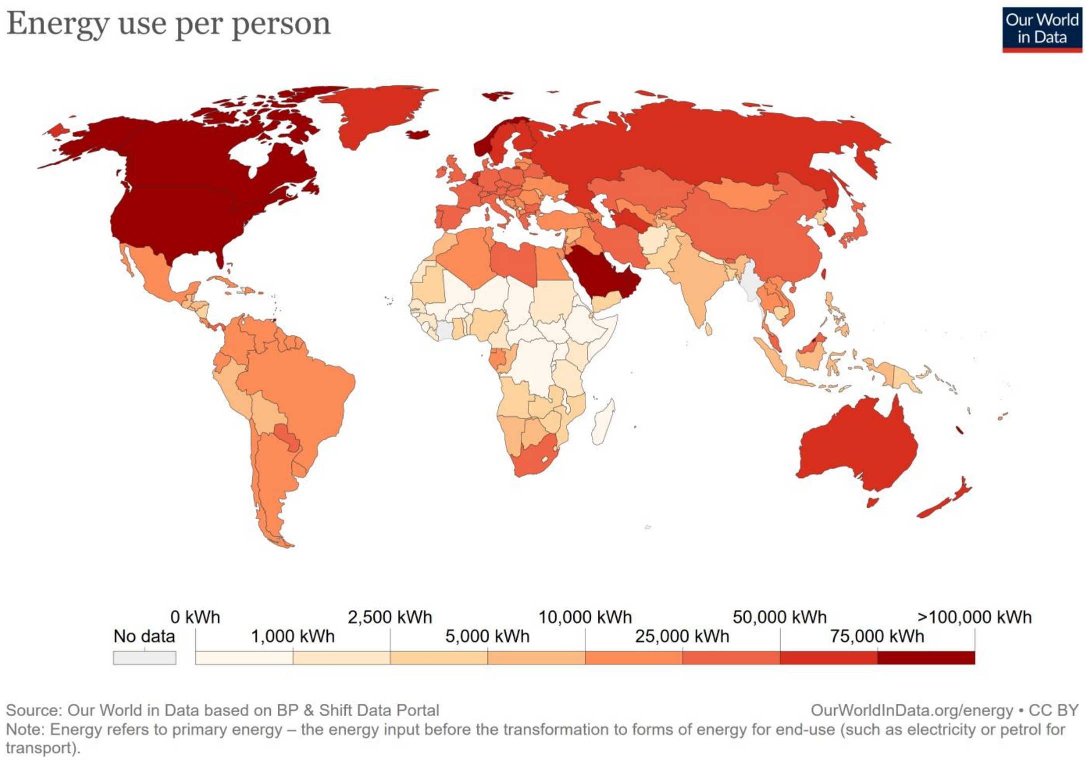


Figure 5. Energy use per person

The largest energy consumers include Iceland, Norway, Canada, the United States, and wealthy nations in the Middle East such as Oman, Saudi Arabia and Qatar. "*The average person in these countries consumes as much as 100 times more than the average person in some of the poorest countries. For example, in Bangladesh, the energy consumption per capita is in the range of 2.000 to 3.000 KWh. In Oman, it's over 200.000 KWh.*" In fact, the true differences between the richest and poorest might be even greater. In bibliography, there is no high quality data on energy consumption for many of the world's poorest countries. "*This is because they often use very little commercially traded energy sources (such as coal, oil, gas, or grid electricity) and instead rely on traditional biomass, crop residues, wood and other organic matter that is difficult to quantify.*" This means there is no good data on energy consumption for the world's poorest. "*Globally, primary energy consumption has increased nearly every year for at least half a century.*"But this is not the case everywhere in the world. Energy consumption is rising in many countries where incomes are rising quickly and the population is growing. However, "*in countries, particularly richer countries, that are trying to improve energy efficiency, the primary* *energy consumption is actually falling*" (see Figure 6). This is characteristic for the European region, that there have been remarkable energy efficiency interventions.

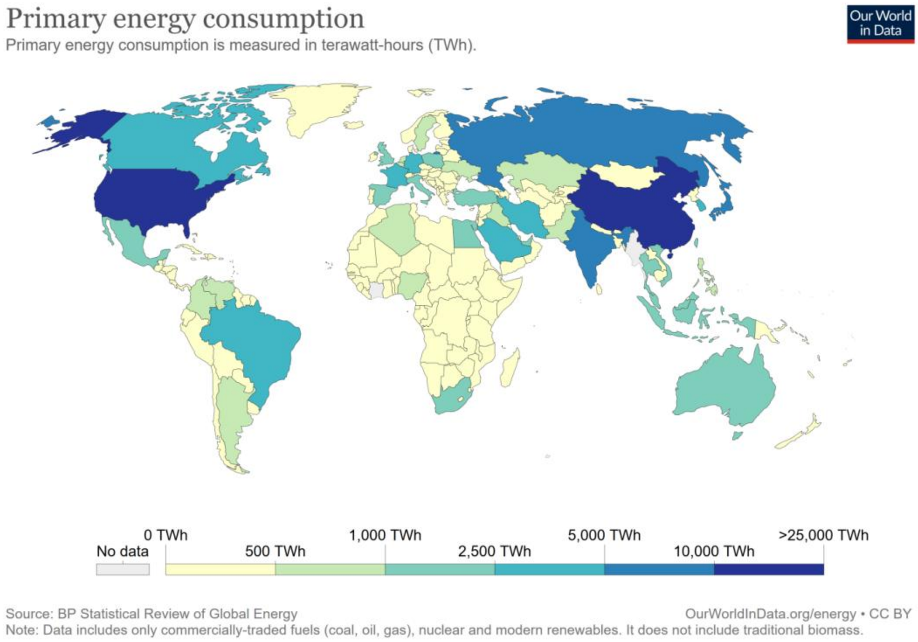


Figure 6. Primary energy consumption

As with total energy, comparisons on levels of electricity generation often reflect population size and whether the country belongs to the developed or developing group (see Figure 7).

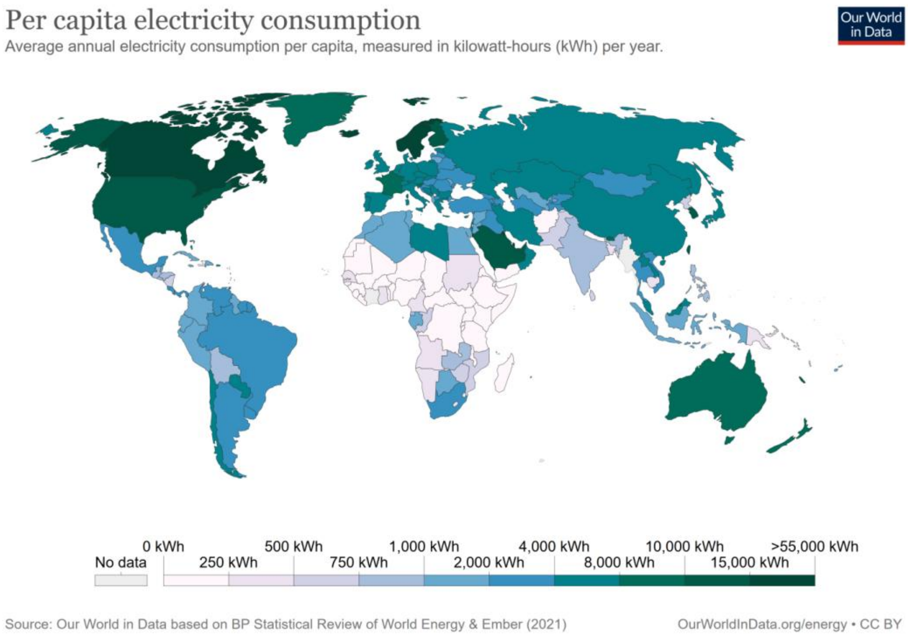


Figure 7. Per capita electricity consumption

Again we see vast differences in electricity consumption per person across the world. The largest producers like Iceland, Norway, Sweden and Canada generate 100 times as much electricity as the smallest. In many of the poorest countries in the world, people consume very little electricity, which estimates lower than 100 KWh per person.

If we go deeper in the analysis and have a look in the current estimated energy demand mix and the current estimated power generation energy mix, we will see differences around the world. For sure, we will note the high reliance on fossil fuels (ie coal) and the struggle that clean sources are making to gain a good share. There are three countries (Canada, Brazil and New Zealand) that rely on hydropower in a big share. At the corner, we will see that some "*big consumers*" use in quite good share the nuclear power (France, Ukraine). On the way to abolish nuclear power, there are some lobbies that try hard to convince this source of energy is carbon free emission (mainly true), safe, reliable, with manageable waste and can be consider as a clean, green power. I have extracted useful figures and information, presented in graphical pies (see Appendix), showing the estimated energy demand mix and estimated power generation energy mix, in different countries in the world. The data comes from the Global Energy Institute, of the US Chamber of Commerce[25]. It is from 2018 and published in 2020. There we can see the huge differences in the energy demand mix and the power generation mix based on country or regional factors. Even for countries that have physical borders and are close to each other, differences in energy mix are more than obvious.

From all the above, we understand that the world cannot approach energy security in the same way. There are huge differences in the planet. The world is divided in rich and poor countries, in developed and developing countries, with clear barriers and opportunities in energy sector. The subsidies of fossil fuels may support short-term energy security but of course undermine long-term energy security and the decarbonisation. Each country has different energy demands and of course different capabilities in exploiting different energy resources, based on the size of population, GDP per capita, economic activities and access to energy resources. These factors

[25] Global Energy Institute. (2020). International Index of Energy Security Risk. Assessing Risk in a Global Energy Market. US Chamber of Commerce.

determine energy security. It is remains on the strategy, design, societal discussion and agreement and of course political decision, as a form of democracy.

Fourth Chapter

State of play for energy security in world

The last years, energy security has been studied thoroughly. There have been studies for different regions and countries around the world. It is very important to quantify, index and rank the state of play in energy security, in different regions and countries, following pledges, agreements and political decisions taken from 2015 in Paris until now. An important and worth-mentioning annual study is being conducted by World Energy Council (WEC)[26]. This year's study covers 127 countries and gives a global overview of different countries and regions. It also offers a comparative ranking that can kick-off a conversation about energy security.

WEC defines energy security not differently as defined by other institutions, organizations and researchers. WEC summarizes energy security definition in Table 1 (as for what it measures and what it covers):

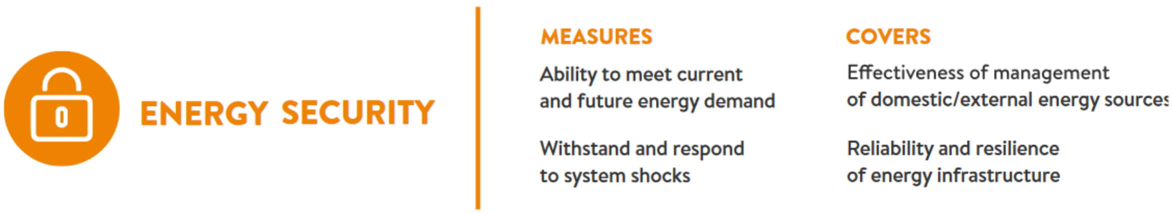


Table 1. Energy Security definition by World Energy Council

WEC has considered a broader definition, taking into account "*energy vectors and resiliency issues that arise from energy systems becoming more decentralised, digitalised, decarbonised and disrupted by demand*".

WEC agrees that energy security definition needs to keep evolving with the new challenges and opportunities followed by energy transition, while diversity remain important. In relation to that, we have to think beyond diversity of supply, stocks and storage levels. Besides, experience from the pandemic is also likely to reshape how countries think about energy security and focus on the importance placed upon resilience. *"The energy sector has proved to be resilient during the pandemic,*

[26]World Energy Council. (2021). https://www.worldenergy.org/.

preserving business continuity and fuel supplies flowing, but there is now a greater recognition of resilience that extends from beyond physical systems to include people, contractors and supply chains." While we have faced electricity system disruptions, we need to explore new measures to assess aspects such as flexibility. Moreover, the trend in increasing digitalization has been accelerated. But it has also increased cyber security, with this topic being on the top critical uncertainties. "*Cyber attacks have highlighted the potential to disrupt energy supply systems and the need to consider how it might be possible to develop suitable and measurable cybersecurity performance indicators.*"

Having all those in mind, a methodology for measuring energy security by WEC was based on specific indicators, and on multiple datasets. The indicators have been assigned with weights and scores have been normalized. The main two indicators are "*A1: Security of Supply and Demand and A2: Resilience of Energy Systems. These are divided into sub-indicators. These are A1a: Diversity of primary energy supply, A1b: Import independence, A2a: Diversity of electricity generation, A2b: Energy storage, A2c: System stability and recovery capacity.*"

Following the WEC study on energy security, we realize that the national context is critical to how countries develop their own energy policies, based upon domestic situation with varying natural resources and socio-economic systems. These differing contexts lead to a systems divergence. Each country tries to determine its own energy policy at its best with respect to the national situation and priorities. It is interesting that interaction among countries and regions can open discussion that may turn the countries learn from each other about what policies work in what circumstances and why. A study on energy security like that can help countries and energy stakeholders to prioritise areas of their energy policy, improve and explore which options might be more appropriate.

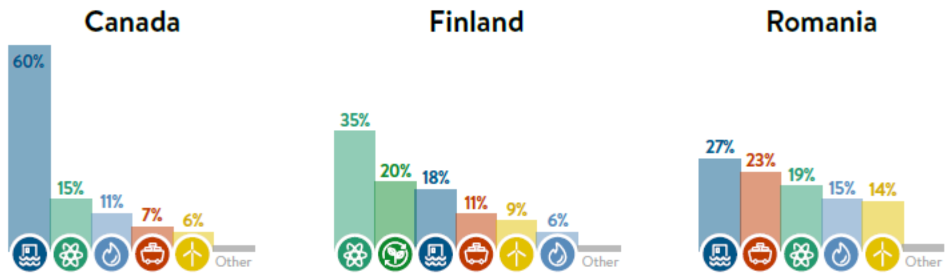
Following WEC report on energy security, it looks that this is the one of the most important dimensions of the energy policies for domestic resources, while diversifying and trying to decarbonise energy systems. Of the countries that are high in energy security, Canada, Finland and Romania are in the top energy security list (see Table 2). "*Brazil is the only non-OECD / European country to feature in the top 10 energy security list, due to its significant hydrocarbon resources and decarbonised* *power system, which provide security through diversity.*"We understand that certain natural resources can show good performance, over-reliance on abundant domestic hydrocarbon resources can also lead to reduced diversity and declining performance for some hydrocarbon-rich countries. Diversifying a country's energy mix improves energy security score and leads to a stronger system resilience.

TOP 10 RANK **PERFORMERS**		
Rank		Score
1	Canada	77.5
2	Finland	75.3
3	Romania	75.1
4	Latvia	74.9
5	Sweden	74.5
6	Brazil	73.5
7	United States	73.3
8	Bulgaria	73.1
9	Czech Republic	72.8
10	Germany	71.9

Source: World Energy Council

Table 2. Top 10 Rank Performers in Energy Security

The top 10 ranking countries for energy security dimension are very similar to last year, with Canada, Finland and Romania leading the list, but each taking different routes. "*Canada and Romania both benefit from being hydrocarbon producers that have focused on diversifying their energy systems and economies.*" Canada has more significant and diverse natural resources, while Romania has benefitted from its EU membership improving its energy policies and interconnections. Finland is perhaps the most interesting of the top 3, given that it benefits less from its natural resources. "*It has focused heavily on decarbonising its energy systems, reducing fossil fuel generation and increasing solar and wind to diversify its generation mix*" (see Figure 8). However, "*nuclear power has a share of 35% and allows Finland to decarbonise energy sector and activities much easier.*"



Source (Electricity generation): Natural Resources Canada (NRCan), Energy Fact Book 2020-2021; EUROSTAT; EIA, August 2021.
Source (Trilemma Balances): World Energy Council.

Figure 8. Canada, Finland, Romania share of energy sources

All three countries "*benefit from close energy market integration with their respective neighbours.*""*Greater interconnectivity with neighbouring grids can improve system resilience and address weather variability, but it creates new dependencies and security challenges where disruptions in adjacent countries can pass cross-border*.""*Brazil has a diverse energy system with a substantially decarbonised power system reliant upon hydropower and a longstanding focus on biofuels for transport.*"However, "*Brazil has poor water management and has always needed to manage drought periods, which affects its hydropower generation*" (see Figure 9). To address increasing concerns about longer periods of water stress, "*Brazil has approved a new gas law, which unbundles the vertically integrated gas market to increase capacity and leverage the country's domestic natural gas resources for power generation.*"Even if this is against decarbonisation, this will increase the diversity of electricity generation capacity and provide greater resilience to power supplies. Brazil takes advantage that natural gas has been globally considered as a transitional energy power for the next two decades.

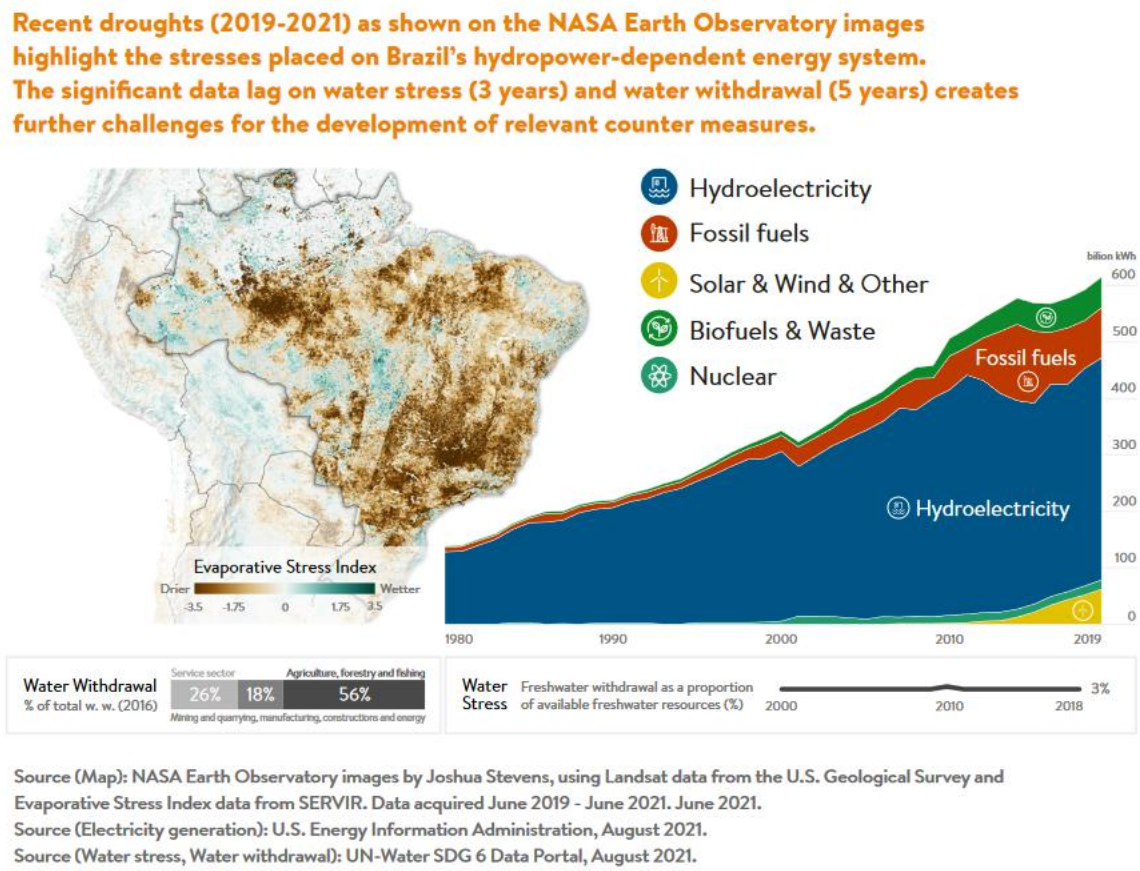
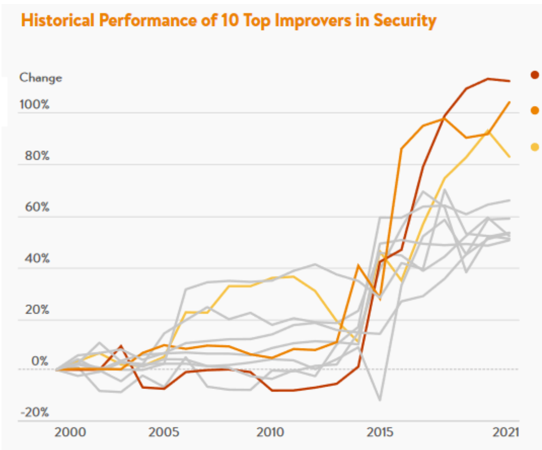


Figure 9. Brazil's hydropower high contribution to power generation and the impact of droughts

At this point, it is worth mentioning that it does not count only the top performers but also the top improvers in energy security worldwide. We have to encourage also countries to make it better in energy security. In the top 10 ranking we find more countries outside the EU and among them two island countries (Malta and Cyprus) of the EU that have no terrestrial connection and land borders with the rest of the EU (see Figure 10 and Table 3).



Rank	TOP 10 RANK IMPROVERS	Improvement since 2000
1	Malta	113%
2	Cambodia	104%
3	Jordan	83%
4	Cyprus	66%
5	Kenya	59%
6	Jamaica	54%
7	Tajikistan	53%
8	Dominican Republic	52%
9	Tanzania	51%
10	Singapore	51%

Source: World Energy Council

Figure 10. Historical Performance of 10 Top Improvers in Security

Table 3. Top 10 Rank Improvers in Energy Security

Countries that have significantly improved their energy security scores have all increased the diversity of their energy systems in power generation and total energy supply (see Figure 11).

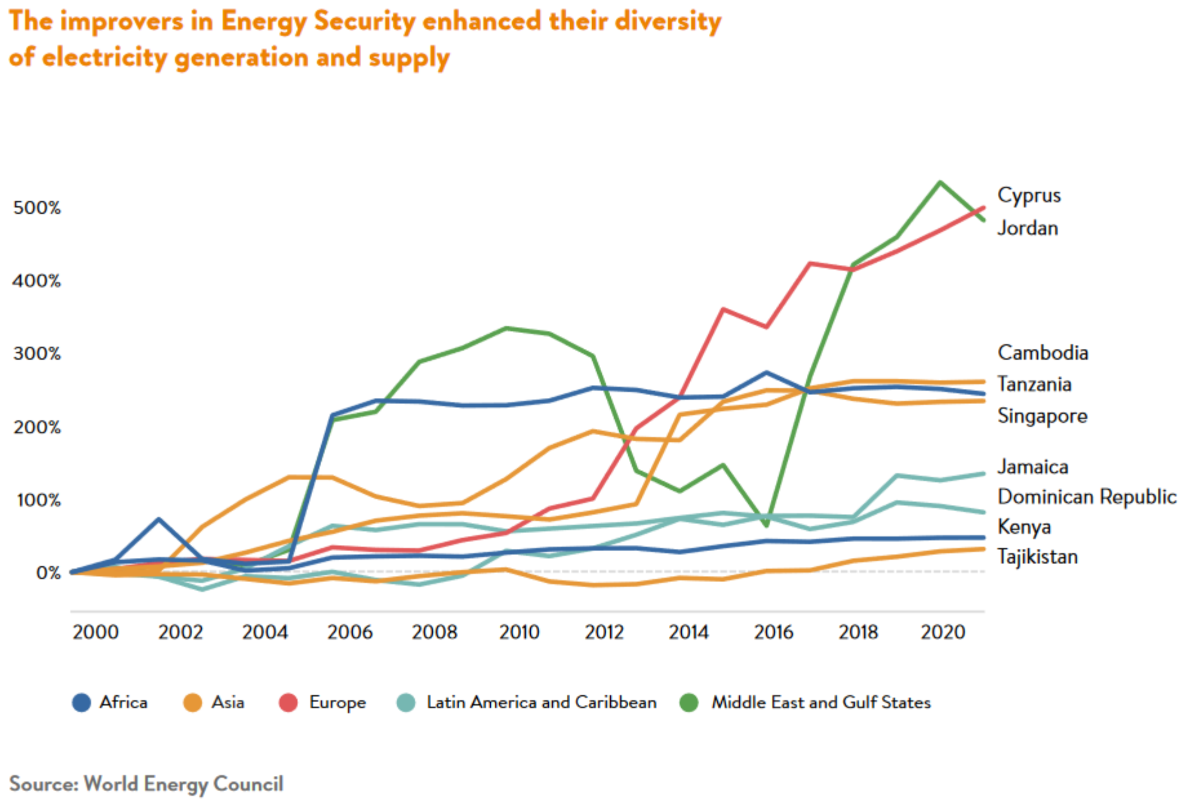


Figure 11. Enhancement in Electricity Generation and Supply Diversity by Improvers in Energy Security

EU membership and the accession process has been a significant catalyst for a number of smaller countries to improve their energy systems and liberalise their energy markets. "*Malta and Cyprus have liberalised their energy markets and increased their energy stocks.*" This is why they have showed substantial "*improvements in the security dimension compared to other new EU countries such as Estonia and Latvia.*" At same time, some of the EU's founding members have also made steps to improve their energy security, with "*Italy and Luxembourg both improving the diversity of their power generation and supply*."Outside the EU, "*the increased generation capacity for Angola, Cambodia and Kenya has increased electricity generation. Angola and Cambodia are both planning to further expand their generation capacity with both RES and carbon-intensive power plants*."

Despite countries like "*Canada, Brazil and US demonstrating that resource-rich countries can score well for energy security, a substantial number of hydrocarbon producers score lower than expected.*" This may result from the fact that those countries focus on making best use of their domestic resources at the expense of over-concentrating their energy systems on typically more carbon-intensive fuels. "*Abundant and domestic energy resources can lessen the economic incentives to explore other energy options that will frequently be substantially more expensive. Many hydrocarbon producers are aware of the risks to their economies and are actively seeking to diversify both their economies and their energy systems from over-relying on hydrocarbons. For example, the United Arab Emirates (UAE) has recently commissioned its first nuclear power plant to diversify its power generation mix while exploring RES. The traditional oil producers can also be well placed financially to afford to diversify their energy systems*".

An important issue for energy security is the interconnectivity and the differences in socio-economic contextes. Such example is "*Austria and Slovakia, with their capitals being less than a hundred kilometers apart. These European neighbours score the same on the energy security dimension, but have followed different approaches. Neither country has particularly strong domestic energy resources. Austria has more hydropower opportunities and has used this to diversify its energy mix. Slovakia is less wealthy and uses more coal. However, it makes substantive use of nuclear power generation, which is unacceptable in Austria. Austria and Slovakia share cross-border connections with all of their neighbours except between each other*" (see

Figure 12). "*Both countries face challenges of decarbonisation of the electricity generation, as coal has a big share of their mix.*"

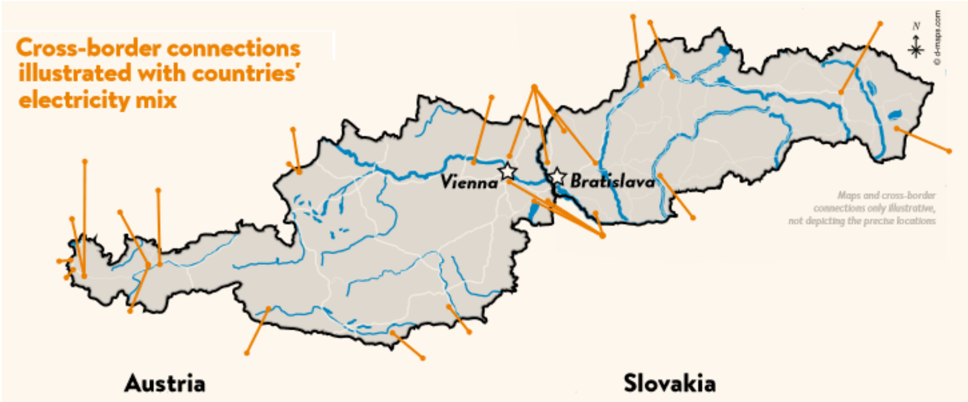


Figure 12. Austria & Slovakia cross-border electricity connections

If we have a look on a regional level and study the energy security profiles, we will find interesting things for discussion.

Africa

Energy security has slightly improved this year with some progress for a few countries. "*Analysis of the regional historical performance for energy security dimension, since 2000, shows substantial increase from 2000 to 2021, achieving 40% growth in the period, while the historical scores indexed to base year 2000 show little progress in this dimension from 2000–2007 and substantial increase since 2016. The past three years (2019 to 2021) have brought a clear consolidation of the growth rates (+16% for each year). Energy security in Africa could be improved substantially by further developing and exploiting the region's abundant energy resources cost-effectively, and by enhancing the energy infrastructure to secure a more reliable energy supply*."

For energy security, "*the top 5 African performers are Angola, Kenya, Gabon, Côte d'Ivoire, and Egypt, with Nigeria dropping out of the list of top performers. Angola has been amongst the top 10 global performers for the past three years and is continuing on its positive trajectory. Angola is a major oil producing and oil-exporting country and a member of OPEC, and oil revenues continue to dominate the* *economy. The country is exploiting its oil reserves, while maintaining a low-carbon generation mix that includes 58% hydro, and has developed an integrated transmission network to improve electricity supply across the country.*"All top 5 performing countries "*have developed their energy resources to meet their domestic energy demands while also establishing energy efficiency programmes and increasing deployment of renewable energies that have improved the reliability of their energy systems.*""*A number of countries in the region have shown substantial progress in their energy security scores since 2000, including Kenya (+59%), Tanzania (+51%), Ghana (+40%), Senegal (37%), Swaziland (+37%) and Cameroon (+35%). However, three countries fell back over the same period. This is Egypt (-5%), Algeria (-4%), and Mauritius (-2%). Many African countries scored low for energy security in 2021. This low performance is generally caused by a lack of capacity to develop a reliable and secure energy supply, but also relates to a number of cumulative factors depending on the countries' specific circumstances. The most relevant factors contributing to a low energy security score include lack of adequate investment, significant energy infrastructure gap, shortage of energy supply and energy services, insufficient power generation capacities, inadequate networks, non-reliability of the power supply with increased power shortages, substantial technical and commercial electricity loses, terror attacks and sabotages of pipelines, political and social instability, etc*." The implementation of centralised and decentralised grids offers a promising opportunity to provide access to electricity in a sustainable way to rural areas. Accordingly, many countries in the region need to promote these technologies (including micro-grids for off-grid and grid-connected), and adopt innovative and distributed generation.

Asia

Energy security has been an issue for many Asian countries. Energy security scores are generally below the global average for most of Asian countries. Many countries in the region rely a lot on energy imports. At the same time demand is growing exponentially, which forms a difficult situation. "*The expansion of renewable energies, driven by the improving economics of RES and the emerging trend of large corporations in Asia starting to procure renewable supply, reduces the Asia-Pacific region's dependency on fossil fuels and promotes the overall decentralisation of energy supplies*", which is widely perceived as enhancing energy security. However, "*the integration cost of RES and the impact of RES on grid system reliability is a major challenge for Asian energy leaders to overcome*".

"*Low levels of power grid interconnection across Asia have been another major challenge, which makes it difficult to improve the level of energy security in the region. Political challenges and national security concerns often reduce the level of trust between neighboring countries in Asia. This leads to more fragmented and nationally adopted solutions.*" Enhanced multilateral cooperation on a regional level will benefit many countries, where learning from and with regional neighbors could help share best practices that ensure uninterrupted energy supply in the cleanest and most efficient and sustainable manner.

Europe

European region historically performs worst in energy security. The overall trend in energy security is however upwards, mainly due to an increase in the use of energy storage and diversification of electricity generation. The main energy security indicator where Europe continues to score below global median is import dependence. "*Since 2013, all 27 Member States of the EU are net importers of energy, with Luxembourg, Malta and Belgium being the largest net importers relative to population size in 2019. The EU's dependency rate on energy imports has increased from 56% in 2000 to 61% in 2019, with the EU's dependency on non-member countries for supplies of natural gas growing significantly faster compared to solid fossil fuels and crude oil during the same period. Almost 55% of the EU's imports of natural gas in 2018 came from only three non-EU suppliers, meaning Russia, Norway and Qatar, while four suppliers, meaning Russia, Iraq, Nigeria and Saudi Arabia, accounted for half of imports of crude oil.*"

The increased penetration of renewable energies will likely lessen the import dependence in many countries. "*Italy, for example, reported that the growth in use of RES has enabled the country both to lower CO2 emissions per capita and, at the same time, diversify its final energy mix, thereby managing to reduce its energy imports dependence more than 30% in the past decade.*"

A number of countries that traditionally rely on domestic fossil fuel production, notably coal, expect challenges in the short to medium term. "*While large-scale* *renewable energy production takes time to be developed and coal production to be phased out to meet CO2 reduction targets, concerns about energy security and the potentially increasing dependence on energy imports (notably for natural gas) from non-EU countries are being created. An example is Serbia, where two-thirds of electricity is generated by burning domestic lignite resources. With most hydro potential already being used and large-scale wind and solar still under development, Serbia expects to become increasingly dependent on natural gas imports from abroad in the short- to medium term.*" The same goes for Greece.

It is well known that the EU Energy Union is to enhance interconnection capacity to facilitate cross-border energy flows. By connecting demand, supply and storage capacities over large geographical areas, interconnectors will facilitate the uptake of renewable energy sources while, at the same time, contributing to security of supply. There are also growing concerns about balance between electricity demand and supply in the EU. There is a need for a wholesale market design evolution. This will provide "*long-term prices and remuneration mechanisms necessary for new decarbonized production capacity and will reinforce electricity security of supply in Europe.*"

Energy source diversification, another indicator under energy security, has improved in the European region. "*The growth in the use of RES has contributed to this, but it should also be noted that nuclear energy remains an important part of a low-carbon energy mix in multiple countries, including Bulgaria, Finland, France, Hungary, Romania, Russia, and Slovenia, with nuclear generation capacity being or planned (ie France) to be increased in some places.*"

Middle East

There are a lot of Middle Eastern countries which have set ambitious renewable energy targets to be reached by 2030 and 2050, while also are committed to reducing emissions from the hydrocarbon industry. "*In 2021, Saudi Arabia announced the Saudi and Middle East Green Initiatives. The scope of this covers climate and energy-related plans aimed at addressing both development and environment. Furthermore, the concept of creating a circular carbon economy is moving forward, though cost is still preventing large-scale implementation of technologies to extract, store and utilise carbon dioxide in the effort to decarbonise the energy and industrial sectors. Saudi*

Arabia and the UAE have some of the largest carbon capture storage and utilisation projects in the world, with facilities in Saudi Arabia and in the UAE capturing each around 800,000 mt/year of CO2, used mainly for enhanced oil recovery, and potentially to produce blue hydrogen".

The UAE remains the leader in diversifying its energy mix and has the highest percentage of installed renewable energy capacity. "*The UAE's large-scale solar projects have seen record bids. The latest is a 2GW solar plant that may become the world's largest solar installation. In 2020, the UAE became the first Arab country to operate a nuclear power plant when it started commissioning the Barakah nuclear power station. At full capacity, the plant will meet 25% of the UAE's electricity.*"

Meanwhile, Saudi Arabia has stepped up its renewable energy programme and launched several tenders for solar and wind projects. "*The country's first wind project with 99 turbines, is halfway complete, with expected commercial operation by 2022. Saudi Arabia has recently set targets to increase the share of RES in the energy mix to approximately 50% by 2030.*"

In Bahrain, an important goal is affordable clean energy. "*A renewable energy target of 5% by 2025 and 10% by 2035 has been set, with major projects in solar power initiatives being underway.*"

In Kuwait, the renewable energy sector is in early stages. "*The targets set are ambitious and look to meet 15% of energy requirements from renewable resources by 2030.*" The major motivation behind Kuwait's RES program is energy security and diversification of the energy mix. The transition to a low-carbon economy brings many additional benefits to the country, including the opportunity to reduce carbon and ecological footprints, economic growth, and societal development.

In Lebanon, "*the ambitious target of 30% of its energy consumption from RES by 2030 has been severely hit by the economic crisis since late 2019.*" A depreciating currency, coupled with a default on foreign debt payments, the pandemic, and last year's Beirut port incident, have all stopped major solar and wind projects in the country. Moreover, Lebanon has been recently exposed to a fuel shortage that impacted even further its power sector and economy.

Saudi Arabia and the UAE have also started to explore the potential for hydrogen production. "*Saudi Arabia dispatched the world's first shipment of blue ammonia to Japan in September 2020. In parallel, the world's largest green hydrogen project, in under construction. This will produce 650 mt/day of green hydrogen and will be exported through green ammonia to global markets. The first green hydrogen production in the UAE is in the commissioning stage at Dubai's solar park.*" The project aims to test and showcase an integrated megawatt-scale plant to produce green hydrogen using renewable energy, but also store the gas, then deliver it for use in electricity generation, transportation, and other industrial uses.

North America

Energy security in North America is widely seen as a positive continental strength, based on a long track record of developing abundant and diverse energy resources. The large energy trade flows between the three countries further enhances energy security. This is because of supply diversity and the redundancy in the continental transmission networks, with mutual aid cooperative arrangements. This can restore supply in times of regional outages or supply interruptions. "*Canada has been joined by the US as a net exporter of energy, due to the US becoming the biggest global oil producer during 2020, and fifth in natural gas production, while Mexico is a net energy importer to meet its energy demand.*""*The falling costs for RES has led to continued growth within the North American energy systems.*"But the situation is not universal, with Mexico moving in a different direction by using more of its domestically produced oil in its power system while reducing RES. Furthermore, "*Mexico has increased its dependency on imported natural gas coming from a single field in the US, and the country has recently experienced risks associated to this dependency*", which affects the country's energy security. In addition, "*the country has not only seen declining oil production but also well declining reserves, affecting Mexico's position in the global oil market and posing a challenge for the country in the medium term*". Reinforcing cooperation within the North American region remains crucial to improving energy security for the three countries.

Latin America

In recent years, the renewable energy market in Latin America has undergone unprecedented changes. Political risk factors, investment trends, technological progress and external shocks have affected the energy industry in many ways. As the covid-19 pandemic has created huge damage to the worlds' economy, trends in the Latin American market have shifted and so has the future of the industry. Nevertheless, the power industry is showing resilience amid slowing infrastructure.

The region's dependence on oil exports continues to be a major issue, particularly in countries such as Colombia, Bolivia, Argentina and Brazil that are highly dependent on oil revenues. In the demand side, while governments seek to overcome the impacts of the pandemic, ongoing infrastructure projects have been delayed and project pipelines canceled. "*Restrictions and regulations are still in force in several countries and economic uncertainty is holding back the private sector from investing.*"However, with economic activity, being dependent on the use of electricity and energy access, the power sector has become a priority for the region. RES demand keeps increasing side-by-side with energy demand, in contrast to oil and gas demand, which has submerged due to falling demand. It is unclear whether RES will shape the future of energy in the region while technological advances will drive the costs down.

"*Brazil, Chile, Colombia and Mexico have issued regulations that facilitate bilateral Power Purchase Agreements and spot markets, offering an economic advantage for investors, including long-term price forecasts*." These investment and energy policies support the transition.

The region still has a high percentage of electricity from hydropower. This has led to lower greenhouse gas emissions, as a consequence of the abundance of the natural resource. In addition, there are many policies and regulations to work on the energy efficiency sector. "*There are also opportunities for establishing hydrogen production, which is currently included on the government agendas of Brazil, Chile, Argentina and Uruguay.*" All roadmaps mention interest in producing hydrogen from low cost renewable electricity for export.

The main challenge for most countries in the region continues to be "*the lack of clear regulatory frameworks, economic certainty and political stability.*" When it comes to policies, "*the region should consider transparent regulations, promoting sustainable targets that could help decarbonise the region's energy mix.*" This also includes considering new opportunities for distributed generation and energy storage, where again "*there are several opportunities for decentralising hydrogen production through renewable electricity.*"Clear collaboration with the private sector may permit the development of a robust and secure energy infrastructure.

Until now, we study energy security alone. However, WEC examines energy security as part of a three-dimensional index, including energy equity and environmental sustainability. However, the scope of this thesis is to examine energy security in a unique dimension. Focusing on a comparative study and ranking countries may not be that helpful in providing guidance on how to improve a country's energy security. If we look at the top 10 ranking countries, it is not easy to understand whether or not their policies are relevant to other countries. The main issue of comparative rankings is the fact that improving performance by one country does not mean that other countries have improved more. A time-series analysis can be more useful.

Nowadays, the global energy sector is facing a remarkable change, as a lot of countries try hard to decarbonise and form a decisive energy transition, while trying to recover from the economic shocks and the pandemic. "*Energy policies and regulations tend to hold the market changes, but occasionally move forward reframing energy markets and enabling new technologies and business models.*" It looks that the challenges and opportunities presented by post-pandemic recovery will reshape energy policies and the agenda for energy security. Energy security will reflect a country's capability to reliably meet current and future energy demand, be resilient and recover as soon as possible from system shocks with minimal disruption to supplies.

An increasing number of countries have already set net zero targets either following binding international pledges or having incorporated them in their national legislation. Details of how countries intend to meet the target are limited in many cases. However, various policies are emerging and will probably change energy security. It is important to point out that the percentage of countries with no net zero target is almost 30%. Worldwide the net zero targets cover the 73% of global emissions (see Figure 13). It is understood that a big step has been made but there is still road to go.

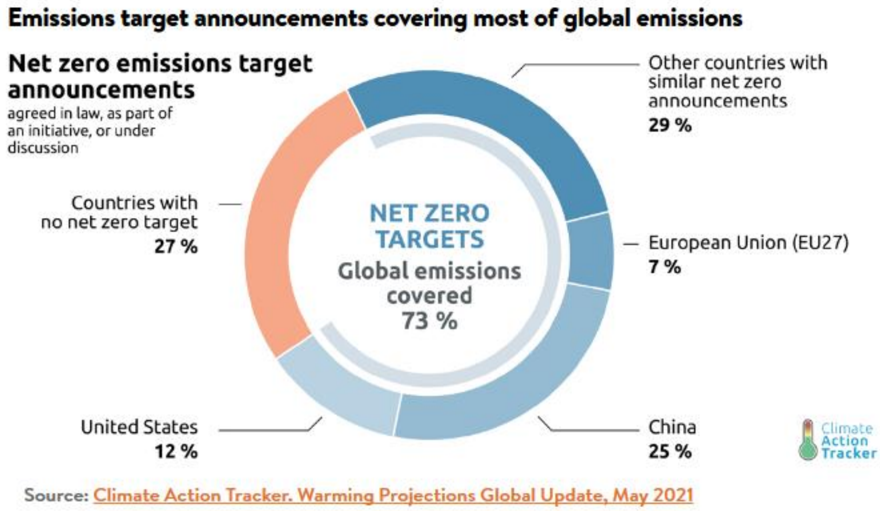


Figure 13. Emissions target announcements covering most of global emissions

In order to achieve the net zero targets, there are many countries (ie Greece, UK) which plan to end the sale of new internal combustion engine vehicles in the next 10 years. This policy will reform not only energy consumption patterns but also the whole economy.

In the following map of WEC (see Figure 14), we can have an overview of energy security performance per country with a scale from A to D (best to worst). It is interesting to point out that Africa and part of Asia, having the developing countries, still stand behind the developed countries in terms of energy security. As COP26 didn't manage to specifically support the developing countries, we expect that the next decade will be crucial for those countries. There is still much to talk about energy security regarding world as a whole and not only for fragmented regions and sole countries.

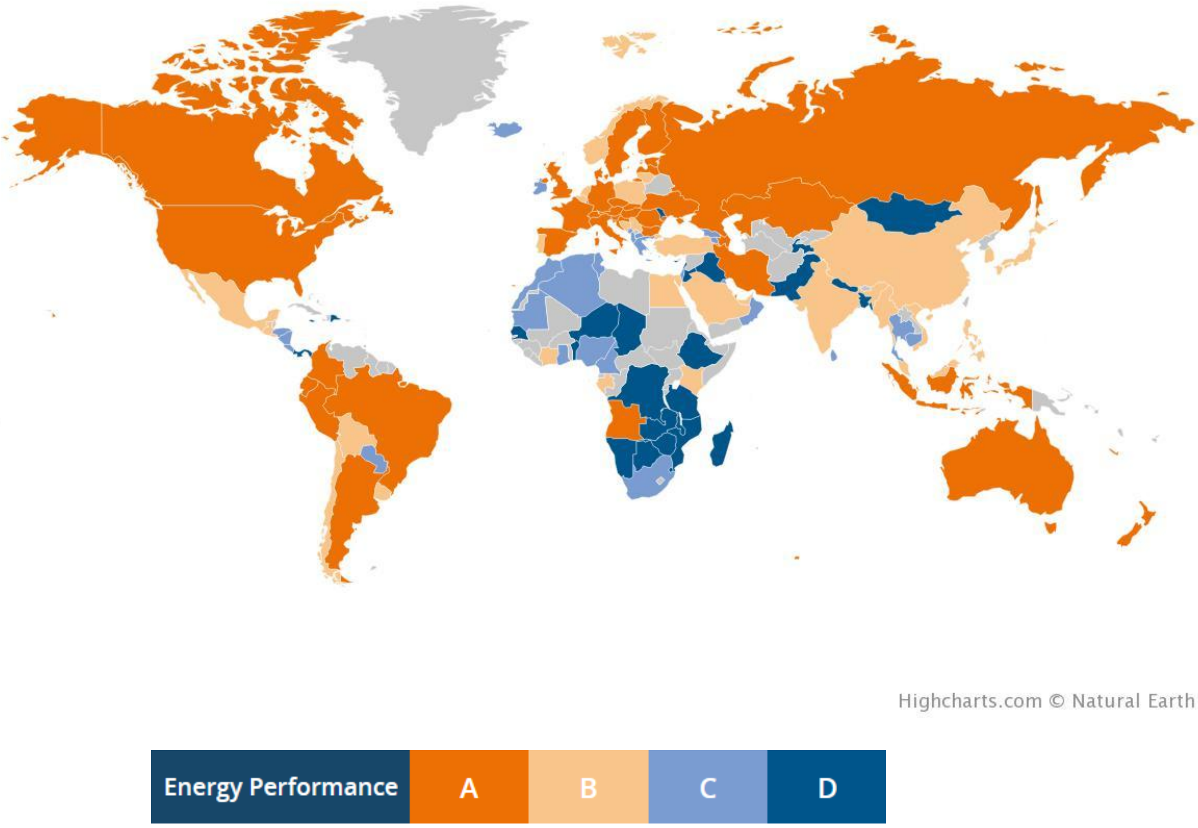


Figure 14. Energy security performance of countries in world

Fifth Chapter

Decision making in energy security

Designing the energy policy and solving the puzzle of energy security is not a trivial issue. Different countries and regions in the world try to manage this in different ways, with different means, depending on domestic resources, external relationships and other aspects. Energy security is a dynamic aspect and characterises the general security and progress of a society. Focusing on the roadmap to decarbonisation and green energy transition, many countries try to abandon the fossil fuels and reduce or achieve zero carbon emissions, with different steps. Most of world's countries have pledged up to 2050 to decarbonise their economies and activities. The dependency on the traditional energy sources causes rather negative effects on human health and also on environment due to global deforestation and greenhouse emissions[27]. In order to address the environmental issues in the framework of sustainable development, the "*clean or green*" energy resources can play a crucial role. This means that the societies have to move and roll without carbon emissions. In addition to the renewable energy resources availability, the efficient use of energy is also highly necessary. In many countries, "*there are governmental policies for transforming the current energy systems to highly efficient and sustainable energy systems.*"

Up to here, everything seems fine and promising. But what about energy security while we decarbonise the economy and the way we live? How can we ensure energy security for the societies while we move to net zero carbon emissions? Policymakers, scientists, and many others who get involved in designing and modeling energy policy do not find this task so easy. In the meantime, switching from fossil fuels to renewable resources, is not "*one button push*". Switching in stages and step-by-step seems more feasible in order to have energy security. But what can be the optimal share of which kind of sustainable energy resources, keeping the promises for a decarbonised world? How can we decide whether this or that is the best energy resources mix? The main aim of some countries is to maximize the energy resources utilization by enhancing the infrastructure capacity. This is very challenging and needs a clear answer how these countries can ensure energy security with a horizon of

[27]Sovacool, B.K. (2012). Design principles for renewable energy programs in developing countries. Energy Environ. Sci.5:9157–62.

net zero carbon emissions. For this reason, the energy planning methodology has been transformed from a simple single dimensional to more complex due to the inclusion of multiple dimensions and of course benchmarks, stakeholders and disagreeing aims.“*Traditional decision making is basically concerned with either maximization or minimization of a particular element. However, this remains beneficial only in a study of a small system.*”[28].

A modern energy planning scenario has multiple criteria making it more difficult with a perception of sustainability. Studies based only on technological market trends seem to fail. Or at least, they cannot fulfill the societal needs and inevitably cannot ensure energy security for people. Some studies rely on performance indexes, based on quantified indicators, applying also normalisation. Other studies use cost-benefit methods. These seem not to serve the needs for designing the energy policy committed to energy security and with net zero carbon emissions. Thus, a planning methodology which considers the necessary political, social, economic and environmental factors is essential to address the rising demand of energy, with a perspective of sustainable development, with the aim to energy security and net zero carbon emissions. In order to solve such complex problems concerning energy planning, Multi-Criteria Decision Making or Multiple Criteria Decision Making (MCDM) has been proved to be one of the best tools for efficient energy planning.

The last years, policymakers and scientists, working on different models, rely on multi-criteria analysis. There have been a lot of research studies based on multi-criteria analysis that have conclude the proper energy policy for securing energy, while moving away from carbon emissions. The energy security coupled with the net zero carbon emissions is an issue of designing the energy policy, while protecting the environment. However, environmental protection includes many factors apart from economic ones, guiding decision makers to use MCDM methods to solve energy problems. In the recent decade, MCDM has found wide application in energy system design. “*Various technical methodologies and algorithms exist to evaluate and design energy systems based on optimization of either single or multiple criteria. MCDM is considered as an evaluation methodology to solve environmental, socio-economic,*

[28] JRSC, Mateo. (2012). Multi Criteria Analysis in the Renewable Energy Industry. London. Springer.

technical, and institutional puzzles involved in energy planning"[29]. Having in mind the Paris Agreement and the introduction of Sustainable Development Goals (SDGs) and particularly SDG 7, the choice of the right and proper share of resources to form the adequate mixture of energy is a complex task. The scientists have proposed an optimal solution based on multiple criteria[30]. MCDM techniques can bring considerable advantages to complex problems with conflicting criteria and uncertainty. MCDM has become popular in energy planning as it enables the decision maker to give attention to all the criteria available and take the appropriate decision. Since a perfect design is governed by multiple dimensions, a good decision maker looks for parameters like technical or economical that can be compromised. MCDM helps a decision maker who quantifies particular criteria based on their importance. The MCDM techniques can be used to find out an apt solution to the energy system design problems involving multiple and conflicting factors[31].

P.D. Rigo et al, have improved MCDM process in the direction that can help energy decision makers, entrepreneurs, investors, and policymakers to improve their ability to choose the proper MCDM method to solve energy problems[32]. There are many methods available in the literature, which may confuse the researcher when deciding which one would give a better result according to the problem situation. Moreover, each MCDM method has its advantages and disadvantages, and neither method is superior to other methods[33].

In the meantime, countries and economies are becoming increasingly concerned and interested in planning projects related to clean energy sources ie solar, wind, hydro, and geothermal, while securing the energy supply. However, these sources are exposed to problems related to multiple conflicting criteria. As a result, there is a need for a methodology that makes it possible to incorporate these different criteria in

[29]Tsoutsos, T., Drandaki, M., Frantzeskaki, N., Iosifidis, E., Kiosses, I. (2009). Sustainable energy planning by using multi-criteria analysis application in the island of Crete. Energy Policy. 37. 1587–600.
[30]Buyukozkan, G., Karabulut,Y., Mukul, E. (2018). A novel renewable energy selection model for United Nations' sustainable development goals. Energy. 165. 290–302.
[31] Kumar, A., et al. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable and Sustainable Energy Reviews. 69. 596–609.
[32]Rigo, P.D., et al. (2020). Renewable Energy Problems: Exploring the Methods to Support the Decision-Making Process. Sustainability. 12. 10195. doi:10.3390/su122310195.
[33] Lee, H.C., Chang, C.T. (2018). Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan. Renew. Sustain. Energy Rev. 92. 883–896.

mathematical models. MCDM methods have become a popular tool in the area of energy planning, applied to the most varied types of problems. "*Due to the flexibility, MCDM methods provide decision makers a scientific support, which on several cases, involves conflicting criteria, inaccurate data, and a challenge to quantify. The complexity of the problems and the characteristics of uncertain and imprecise collected data, demands an approach that looks for addressing these factors.*"With this information, when the decision maker has a problem with many criteria to be analyzed in energy, he/she can choose MCDM methods"[34].

From the literature, we recognize two regions that highly apply MCDM methods in energy management towards low or zero carbon emissions. These are Eastern European and Asian regions. Take the example of Turkey. Turkey is an accelerated economy and demands more electricity[35]. This is met by less carbon emitting technologies[36]. Therefore, "*the Turkish government policy aims to increase the percentage of renewable energy resources by approximately 30% in total installed capacity by 2023*"[37]. This scenario motivates researchers about the choice of renewable energy sources. Another example is China. China's intense economy has led to numerous issues relating to energy production and environmental impact[38]. The country does not have the adequate resources and the reserves of traditional energy are not enough for the increasing and demanding needs. Thus, it is urgent to establish a strategy for the sustainable development of electricity generation.

For the successful application of the MCDM methods, there is a need for properly selecting the criteria. This is done by consulting experts in the field. In the area of renewable and sustainable energy, experts are professionals involved in the power process, like electricity generation techniques professionals, engineers, economists,

[34]Buyukozkan, G., Karabulut, Y., Mukul, E. (2018). A novel renewable energy selection model for United Nations' sustainable development goals. Energy. 165. 290–302.
[35]Topcu, I., Ulengin, F., Kabak, O., Isik, M., Unver, B., Ekici, S.O. (2019). The evaluation of electricity generation resources: The case of Turkey. Energy. 167. 417–427.
[36]Buyukozkan, G., Karabulut, Y., Mukul, E. (2018). A novel renewable energy selection model for United Nations' sustainable development goals. Energy. 165. 290–302.
[37]Erdin, C., Ozkaya, G. (2019). Turkey's 2023 Energy Strategies and Investment Opportunities for Renewable Energy Sources: Site Selection Based on ELECTRE. Sustainability. 11. 2136.
[38] Peng, H., Shen, K., He, S., Zhang, H., Wang, J. (2019). Investment risk evaluation for new energy resources: An integrated decision support model based on regret theory and ELECTRE III. Energy Convers. Manag. 183. 332–348.

environmentalists, and politicians[39]. The criteria are extended to behavioral society, economy, and environment. In addition, "*the MCDM methods work when there is also a choice between non-renewable and renewable sources*." In this case, the environmental sustainability factor enters into discussing the impacts arising from the countries' choices to maintain their energy sources based on fossil fuels. The environmental criteria, when applied in the MCDM techniques, help in the rationalization of the decision[40]."*The MCDM methods had been widely employed in sustainable energy decision making, considering multi-criteria*."For this reason, there is a need for a methodology that makes it possible to include different criteria in mathematical models. "*MCDM has become a popular tool due to the flexibility it provides decision makers, providing scientific support*"[41].

There are plenty of studies and research articles focusing on the application MCDM methods in energy sector. These studies mainly focus on Eastern European and Asian countries and regions. Some of them are Kazakhstan, Taiwan, Lithuania and Creta, the Greek island.

In Kazakhstan's case, the electricity generation depends on fossil fuels. While RES and other non-fossil resources provide potential alternatives to diversify the electricity generation system, an MCDM approach, based on expert opinion, was utilized, using four main criteria: technical, economic, social and environmental, and thirteen sub-criteria. It has been proved that Kazakhstan has the potential to develop a non-fossil fuel based electricity system. Furthermore, the model showed hydro to be the most favorable resource while biomass was found to be the least attractive option. These findings can assist decision makers to articulate long-term energy security policy.[42].

In Taiwan's case, the MCDM methods were also used, solving energy selection problems because these problems involve multiple and often conflicting criteria.

[39]Supriyasilp, T., Pongput, K., Boonyasirikul, T. (2009). Hydropower development priority using MCDM method. Energy Policy. 37. 1866–1875.
[40]Rigo, P.D., et al. (2020). Renewable Energy Problems: Exploring the Methods to Support the Decision-Making Process. Sustainability. 12. 10195. doi:10.3390/su122310195.
[41]Rigo, P.D., et al. (2020). Renewable Energy Problems: Exploring the Methods to Support the Decision-Making Process. Sustainability. 12. 10195. doi:10.3390/su122310195.
[42] Ahmad, S., et al. (2017). Multi-criteria evaluation of renewable and nuclear resources for electricity generation in Kazakhstan. Energy. 141. 1880-1891.

Taiwan has understood that high consumption of fossil fuels leads to serious environmental problems, with increasing GHG emissions. Four MCDM methods were used for quantitative evaluation and ranking of all available renewable alternatives. The first priority was efficiency in all evaluation criteria, followed by job creation, operation, and maintenance cost. The ranking results showed that hydro is the best alternative in Taiwan, followed by solar, wind, biomass and geothermal. When talking for financial or technical aspects, hydropower is the best renewable because its technology is the most mature and the cost is the lowest in Taiwan. In addition, from an environmental perspective, wind energy is the best choice, and from the social perspective, solar PV is the best choice. These findings can provide useful information to energy decision makers and serve as a reference for Taiwan's energy security policy[43].

In Lithuania's case, the process of choice of electricity generation technologies, has been solved using MCDM methods. Having considered the impact of environment, a set of evaluation criteria was compiled for electricity generation technologies. Analysis of qualitative and quantitative criteria helped to rate the electricity generation technologies, considering their economic, technological, environmental, social and political factors. The results showed that in the case of Lithuania it is useful to consider further development of the nuclear power generation capacity. Among the electricity generation technologies related to renewable energy sources, a clear priority is assigned to biomass technologies[44]. However, there is continuous try to consider nuclear power as a green power and be in the same box with the conventional renewable sources.

In Creta's case, the energy planning and the decision making was directly related to the processes of analysis and management of different types of factors (technological, environmental, economic and social). Very often, the traditional evaluation methods, such as the cost- benefit analysis and macro-economic indicators, are not sufficient to incorporate all the elements included in a zero carbon emissions energy plan. However, the MCDM methods provide a tool, which is more appropriate for a wide

[43] Lee, H.C., Chang, C.T. (2018). Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan. Renew. Sustain. Energy Rev. 92. 883–896.
[44]Streimikiene, D. (2016). Multi-criteria analysis of electricity generation technologies in Lithuania. Renewable Energy. 85. 148-156.

range of variables that are evaluated in different ways and thus offer valid decision support. A set of energy planning alternatives were determined upon the implementation of installations of renewable energy sources on the island and were assessed against economic, technical, social and environmental criteria identified by the experts involved. The study is an exploratory analysis with the potential to assist decision makers responsible for regional energy planning, providing them the possibility of creating classifications of alternative sustainable energy alternatives. The results showed that we have neither optimal nor absolute energy resource. What energy resource would be chosen against another is related to a variety of criteria and opinions of multiple experts, who are involved in formulating and analysing the issue with the MCDM methods[45].

From the Kyoto Protocol in 1997 to the Paris Agreement in 2015, many countries have strongly redefined their strategy to carbon reduction and green economy development. Therefore, the transition from fossil sources to clean energy is an important issue for many countries. Additionally, there are countries which have almost no energy sources of their own, with high percentage of their energy consumption depending on imports, and almost the majority of fossil fuels coming from unstable politically areas. In order to overcome the challenges of energy security and reduction of GHG emissions, they have developed energy policies supporting the supply and utilization of RES and accelerating the development of the industry of RES. The goal of these energy policies have focused on improving energy efficiency and developing clean energy, as well as a secure energy sector. It is a challenge for policymakers to determine which energy policy should be promoted and what resources should be utilized. According to geographical advantages, natural resources, economic development, and the international situation, the energy policy that suits one country is formulated. The application of various MCDM methods and analysis prove that different situations lead to corresponding resources. In the meantime, MCDM is becoming popular in the field of energy planning due to the flexibility it provides to the decision makers to take decisions while considering all the criteria and objectives simultaneously[46]. This enables policymakers to recognize the suitable

[45]Tsoutsos, T. (2009). Sustainable energy planning by using multi-criteria analysis application in the island of Crete. Energy Policy. 37. 1587–1600.
[46] Kumar, A., et al. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable and Sustainable Energy Reviews. 69. 596–609.

resources under different policy. The decision maker usually decides which method to be used by taking the nature of the problem into consideration. Luckily, there are enough multi-criteria methods. For the selection, the important factors to be considered are suitability, validity and user-friendliness of the methods.[47][48].

Energy projects with sophisticated technologies and promised affordable electricity tend to fail many times, due to ignorance or underestimation of social factors. In order to have an efficient and successful energy project, a synergy has to be found considering different scenarios with multiple indicators. Different scenarios must be created by prioritizing criteria and indices considering different constraints. Unfortunately, most of the times, the evaluation has been done based on single scenario and an energy system design fails to take into consideration the social factor by giving it equal importance as other factors. Besides, no single MCDM model can be ranked as best or worst. Every model has its own strength and weakness depending upon its application. Hybrid techniques are used among MCDM models or even with other tools. Most of MCDM methods are implemented in the areas where we have national, regional or a particular geographical location. Last but not least, energy planning with the aim of decarbonisation should not only consider a single scenario based on multiple criteria but consider multiple scenarios based on multiple criteria[49].

[47] Sliogeriene, J., et al. (2009). Environment factors of energy companies and their effect on value: analysis model and applied methods. Technol. Econ. Dev. Econ. 15. 3. 490-521.

[48] Ulucan, A., Atici, K.B. (2010). Efficiency evaluations with context-dependent and measure-specific data envelopment approaches: an application in a World supported project. Omega. 38. 68-83.

[49] Kumar, A., et al. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable and Sustainable Energy Reviews. 69. 596–609.

Discussion

The discussion for energy security on our planet is more relevant than ever before. The study, design, and decision of what can be the energy mix form a dynamic procedure. It is related to different factors and the answer for a proper solution that fits to a country can be given by introducing a multiple criteria analysis. We can account for energy security in different countries of the world and we can identify the sectors that each country can improve or sustain in order to ensure energy security. We can identify each country's dependencies and what can make them more independent or at least move to cooperations and partnerships with other countries and stakeholders, legally binding. In any case, the policymakers and decision makers can facilitate their work with the multiple criteria tools. Of course these are not the only suitable tool. Sometimes, there must be a study including more tools other than a single multiple criteria tool.

In the meantime, with the pledges for net zero carbon emissions, the future remains unpredictable. The "*big polluters*" rely their economy on coal and other fossil fuels and are not willing to make generous steps to abandon and finally repeal of the pollutant energy sources. Even if the smaller countries are much more willing to convert their economies and make a transfer from fossil fuels to cleaner sources, this does not make the difference worldwide. The "*big restart*" after the first big shock of the covid-19 pandemia, was based on the "*business as usual*" method. Again, the fossil fuels played their "*big role*". On top of this, the prices of energy skyrocketed, being justified by the acute high demand for energy to boost the economies, volatilities in supply chains, and also the governmental taxes.

So, what can be done to have energy security in a country or in a region, with the pledge that we move to decarbonisation? For sure, this question cannot be answered with a few words or phrases. But of course, there must be a framework that a policymaker or a decision maker can step in and have a helpful guide in her/his work.

The first and foremost is a clear definition of what energy security means to a country. The country has to conceptualize energy security in a universal and applicable way. This means planning and prevention of any interruptions in the energy sector, regardless of their source, magnitude, or intentions. For a country, it is a clear task of ensuring an uninterrupted and sufficient energy supply, by employing efficient and safe internal and external risk prevention measures. Then, the country has to distinguish between short-term and long-term energy security. It has to make a risk assessment study and identify the internal and external risks and list all the possible threats. On this, it has to quantify how dangerous is a certain risk and what is the impact of it. This means it has to make an impact assessment by quantifying the possibility of risk existence and the impact that might have. Likert scale is used most of the times. For the moment, the countries find it difficult to move away of fossil fuels and especially gas. They are trying to decarbonise gas with different means. However, the taxes for energy are high and this leads to energy insecurity, meaning more difficulties in electrification and heating and high prices in transportation and production.

Financing and Investment Innovation

The transition to more resilient and flexible energy systems, while decarbonising the economies and societies, needs a new financing and investment model. There is a need for an innovative financing and investment management. While enormous pressure exists to continue reducing capital project costs, operating costs, energy consumption, meeting environmental sustainability targets, with less resources, we need to redefine how we approach capital and operational investments for securing energy.

One solution found in bibliography is to follow a total expenditure (TOTEX) approach, spending money to achieve outcomes regardless of its capital expenditure (CAPEX) or operational expenditure (OPEX) (see Figure 15 in the example of a power plant).

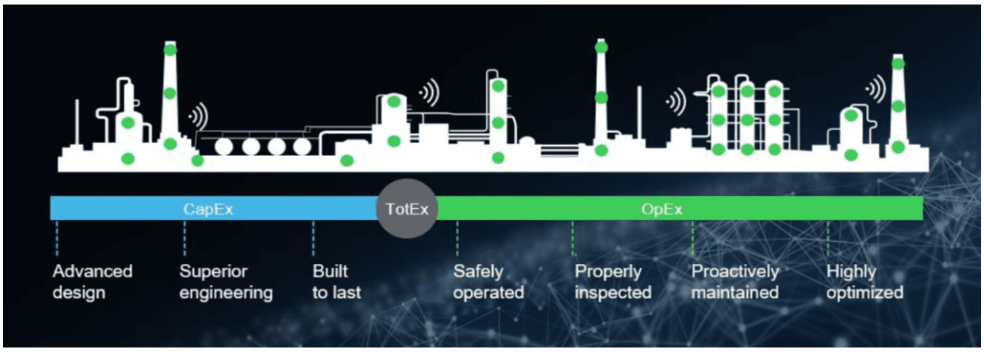


Figure 15. Total expenditure approach in power plant

A simplistic approach is to think of CAPEX and OPEX as separate blocks, without necessarily tying these together in a whole life total expenditure (TOTEX) view. However, the TOTEX approach, meaning the capital expenditure plus the operational expenditure, includes the total cost of expenditure, over the long-term operating life of a project. For example, an energy project may appear relatively expensive in terms of CAPEX, but under the TOTEX approach, appears to offer economic benefits with attractive payback period.

A fundamental requirement of managing TOTEX is that "*decisions must be made based on quantitative measures in order to make the optimization. A pre-requisite of any TOTEX reduction initiative must be the acquisition of data that is reliable, accurate and current*." In a TOTEX approach, it is important to "*establish an accurate baseline which is why accurate design information from the CAPEX phase is important*" as it allows us to move away from "*experience and intuition*" to "*data and analysis*". Data-driven decision making is defined not only by collecting data, but also by how and if it is used in making crucial decisions. A TOTEX approach "*increases the flexibility of decision making and provides greater freedom to pursue innovation with better collaboration of finance, engineering, operations, and maintenance teams*" to bring total lifecycle value[50].

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[50]Panasuik, E. (2020). CAPEX or OPEX? How about TOTEX? Time for a fundamental rethink. https://blog.se.com.

A modern example of TOTEX approach in energy sector comes from regulating electricity distribution networks. It has been realised that the regulatory framework should not constitute a barrier for the efficient development of the grid or the implementation of new market and technical solutions. For this reason, a TOTEX approach seems highly appropriate, in particular when considering that decarbonisation targets are likely to continue generating challenges and increasing expenditures at the distribution level[51].

Smart Grids

The digitalization of energy sector will facilitate the wide utilization of renewable resources and will decarbonize the economies. As long as the energy storage from RES are in infant stage, the digital transform of energy sector is a realistic answer to a more efficient energy management and the repeal of fossil fuels. The digital energy sector will be composed of smart power grids. Since electricity plays a crucial role in energy sector and in societies, the improvement and development of more sustainable energy systems is of high importance. The smart grids as electricity networks enable a two-way flow of electricity and data with digital communications technology enabling to detect, react and proact to changes in utilization and multiple issues. Smart grids have "*self-healing*" capabilities and enable electricity customers to become active participants. This will increase the end-users participation in energy production, transforming them to prosumers. Then the energy systems will be resilient to stresses and shocks from energy demand and supply, price fluctuations and climate extreme phenomena. A smart grid will serve several purposes and the movement from traditional electric grids to smart grids is driven by multiple factors. These include the better regulation of the energy market, evolutions in metering (smart meters), decentralization, renewable energy pledges, the rise of microgeneration and microgrids at citizen or energy community level.

In a smart grid we have different wiring and cabling systems compared to a traditional power grid. The purpose of an electrical grid is to make sure that electricity is always

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[51]Boneva, F., Delfanti, M., Fumagalli, E. (2020). TOTEX approach for regulating electricity distribution networks: a comparison of UK and Italy initiatives. doi:10.13140/RG.2.2.17988.78729**.**

provided when and where needed, without interruption. Given the complexity and the multiple challenges that can arise such as the consequences of severe weather conditions, damage by wildlife, human sabotage and other external factors and internal factors, managing a grid is very complex and a dedicated field for experts who also need to consider the choices regarding energy regulations and initiatives by countries. "*The two-way flow of electricity and data that is the essential characteristic of a smart grid enables to feed information and data to the various stakeholders in the electricity market which can be analyzed to optimize the grid, foresee potential issues, react faster when challenges arise and build new capacities and services*." Smart grids include highly sensor intensive operations, use of big data and advanced analytics with artificial intelligence and machine learning on top, complex communication standards to send data from one point to another (i.e. from smart meters to utility companies). In a nutshell, the evolution from a traditional smart grid of yesterday to smart grid of tomorrow impact the sectors of production, market, transmission, distribution and consumption (see Figure 16[52]).

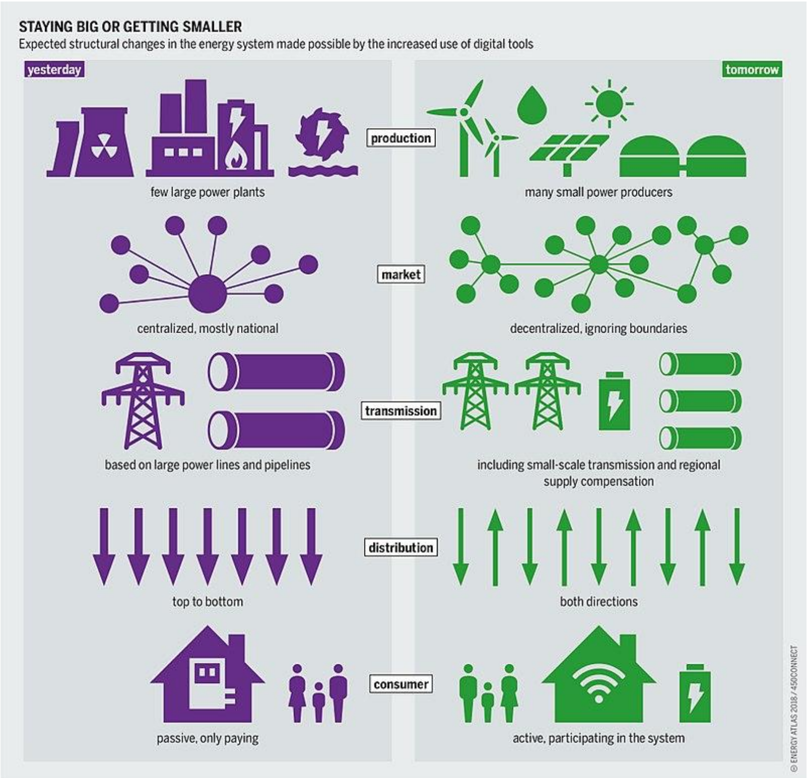

Figure 16. Characteristics of smart grid compared to traditional electric grid

[52]Bartz, Stockmar. (2018). Energy Atlas. Figures and Facts about RES in Europe. https://energytransition.org/2018/04/europe-must-choose-a-green-future/.

By 2023, two thirds of electricity companies will have invested in digital technologies and platforms to support flexibility services. Besides, challenges of smart girds will need to be addressed. These are private data protection, Internet of Things (IoT) and the wide coverage of new generation of Internet. Additional challenges in smart grids include "*regulatory changes, the complexity in integrating sources, systems and partnerships between various players, the local situation whereby a selected number of large companies often still dominate and changing attitudes among prosumers*"[53]. Of course, more research and study need to be developed on smart grids and specific investments need to be organized and introduced.

Multicriteria Decision Making Tools

Policymakers and decision makers need specific tools in their hands in order to decide. As for other sectors, also in energy sector, the use of Multicriteria Decision Making (MCDM) tools is widespread. This is because the decisions in energy sector and especially in energy security with decarbonisation have multiple dimensions and incorporate different factors. This means multiple criteria. Thus, MCDM tools like analytic hierarchy process (AHP) is widely found in the bibliography used for decision making in energy sector, moving to renewable resources utilization, decarbonising the economies and societies, and ensuring energy security. For the successful application of the MCDM methods, there is a need for properly selecting the criteria. This is done by consulting experts in the field. In the area of renewable and sustainable energy, experts are professionals involved in the power process, like electricity generation techniques professionals, engineers, economists, environmentalists, and politicians. MCDM is becoming popular in the field of energy planning due to the flexibility it provides to the decision makers to take decisions while considering all criteria and objectives simultaneously[54]. This enables policymakers to recognize the suitable resources under different policy. A variety of multi-criteria methods exists in the literature. The decision maker usually decides which method to be used by taking the nature of the problem into consideration. In

[53] I-scoop publication. (2021). Smart grids: electricity networks and the grid in evolution. https://www.i-scoop.eu/industry-4-0/smart-grids-electrical-grid/.

[54] Kumar, A., et al. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable and Sustainable Energy Reviews. 69. 596–609.

method selection, the suitability, validity and user-friendliness of the methods are the factors that have to be considered. But no single MCDM model can be ranked as best or worst. "*Every method has its own strength and weakness depending upon its application*." Most of MCDM are "*implemented in the areas where we have national, regional or a particular geographical location*."

Energy Efficiency – Energy Storage – H2 – CO2

In the road to decarbonisation, the energy efficiency will play a crucial role. We have to target at using less energy for the same activities. This has to do of course with our habits and behaviour. But, we can objectively move towards better isolated and greener buildings, and also transform other sectors such as transportation and agriculture. Better energy systems and power generation systems, resilient and flexible will contribute to this a lot. Energy efficiency must go on with the same pace as the RES. This is because we must first start reducing energy consumption for the same activities, while we go greener. The problem with the RES is that we cannot store the electricity they produce. And we all know that modern world is mainly dependent on electricity. Advancements are recorded in research for energy storage, using high capacity of battery systems. Batteries need rare materials found in a few parts of the world and their quantities seem that are not enough. Countries like Chile or China that have endowments of these rare materials can switch from fossil fuels to RES and free their economies from imports dependencies of crude oil. But for the rest of the countries, imports of rare materials are an important issue. Also, the technology of high storage is for the moment premature. We need to investment more in research for high storage capacities and examine new roads for energy storage. In the meantime, the RES can play a major role in the production of hydrogen using electricity produced by them. However, the question of storage, distribution and supply remains the same. Even if hydrogen is promising for long-distance transportation and intense industry, the distribution pipeline system and of course the storage infrastructures seem far from the production phase and reality. At least, for the households, hydrogen does not seem cost-efficient. Hydrogen will play its role for areas that cannot be electrified. Also here we need more research and investments and coordinated actions with clear strategy and well-described action programmes. Many countries around the world have understood this and they have included in their policy agenda their strategies for the new era of energy storage and hydrogen production from electricity. It is more than important that we can store the electrical energy produced from the renewable resources because these are volatile and subsequently means energy insecurity. Besides, the message sent from the subsidies of using the remaining quantities of fossil fuels and the high variation in energy prices is totally disastrous for energy security while trying to decarbonise our activities. The message should be clear where we are heading to. In terms of storage, another important issue is the CO2 and other GHG storage. This aims at reducing the amounts of carbon emissions circulated in the atmosphere. These gases can also be used further (ie in agriculture). The cases of CO2 and methane are characteristic. It is not easy to stop every single carbon emission from each human activity. But, we can balance this by using highly sophisticated systems, filters and storage facilities. In addition, reforestation and better forestry management will help a lot in the CO2 capture from the sources emitted.

Smart Modular Nuclear Reactors

In the view of the energy transition to greener technologies that will emit no carbon, one promising solution might be the nuclear power. The disadvantage of the already existing power plants that use nuclear technology and materials are two: The nuclear waste management and the management of a nuclear accident. From the Chernobyl to Fukushima accidents, scientists and policymakers have learnt a lot. Technology has evolved and waste management has been improved. Nowadays, nuclear power seems the most stable power that emits zero carbon. France is trying to establish this as a green power. The countries that acquire nuclear technology but also do not phase extreme environmental phenomena (ie earthquakes, tsunamis) are focusing on smaller and interconnected nuclear plants. These include the smart modular nuclear reactors.

Small modular reactors (SMRs) are advanced nuclear reactors that "*have a power capacity of up to 300 MW per unit*", which is about "*one-third of the generating capacity of traditional nuclear power reactors. SMRs can produce a large amount of low-carbon electricity*"[55]. Many of the benefits of SMRs are linked to the nature of

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[55] IAEA. (2021). What are Small Modular Reactors (SMRs)? https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs.

their design. Given their smaller footprint, SMRs can be sited on locations not suitable for larger nuclear power plants. "*Prefabricated units of SMRs can be manufactured and then shipped and installed on site*", making them more affordable to build than large power reactors. "*SMRs offer savings in cost and construction time.*" In areas lacking sufficient lines of transmission and grid capacity, "*SMRs can be installed into an existing grid or remotely off-grid, providing low-carbon power.*" In comparison to existing reactors, proposed "*SMR designs are generally simpler, and the safety concept for SMRs often relies more on passive systems and inherent safety characteristics of the reactor, such as low power and operating pressure*." This means that in such cases "*no human intervention or external power or force is required to shut down systems, because passive systems rely on physical phenomena, such as natural circulation, convection, gravity and self-pressurization*." These increased safety margins, in some cases, eliminate or significantly lower the potential for unsafe releases of radioactivity to the environment and the public in case of an accident. SMRs have reduced fuel requirements. "*Power plants based on SMRs may require less frequent refueling, meaning every 3 to 7 years, in comparison to between 1 and 2 years for conventional plants*." Some SMRs are designed "*to operate for up to 30 years without refueling.*" Russia's Akademik Lomonosov, "*the world's first floating nuclear power plant began commercial operation in May 2020*", producing energy from SMRs. In Argentina, Canada, China, South Korea and the United States of America there are SMRs under construction or in the licensing stage.

What makes energy security?

Energy security is a dynamic concept and people understand and realize this differently from region to region depending on multiple factors. The biggest challenge is the transition to greener and zero carbon emissions resources while changing the production and consumption behavior. The policymakers have already defined strategies in different countries, from their own perceptive, depending on the fact whether they have adequate energy resources or not. These strategies are heavily dependent on imports of energy, and less on the perception of democracy and the active role of citizens. For policymakers, there are tools to help them make a decision taking into consideration multiple criteria. Besides, there are technological advances and of course financing tools. It is a matter of a good design, proper governance, societal approval, right policies, followed by investments, and effective partnerships with other countries and associations, including legal bindings. No action for energy security means national insecurity. This will also cost all sectors in society.

Short-term and long-term plans are highly needed. Besides, risk assessment and risk management are needed due to shocks and stresses while ensuring business continuity. If we want to move further, digitalization of the energy sector is needed. Digitalisation goes through the regional and local level of energy sector. Besides, digitalization goes with cybersecurity. Digitalisation will provide better scaling, lower and less demanding power plants and infrastructure. New and better interconnected grids will be needed. Introducing and interlinking smart meters, promoting high energy efficiency, with modern, high capacity storage facilities and grid management can mitigate risks. Transmission System Operators (TSOs) and companies must be innovative. Lower grid losses with new power lines will improve the usage of grids. However, RES are not the main driver to develop new grids. Variability can be forecast but not uncertainty. What is needed? Evolution of regulations, innovative transmission grids, incentives for investments and long-term contracts with low risks. Bulk storage, large-scale storage and long-term storage can lower prices, offer electrification by RES, increase flexibility, and resilience of energy systems. This means energy security.

Decisions with citizens and a bottom-up approach will be needed. Better regulations and market transparency is needed in order to talk about energy security. Otherwise, we risk falling in top-bottom decisions excluding active citizens. The acute fluctuations and mainly the increase in prices of energy highly affect security. The answer to this is energy storage. Solutions at local level can secure energy sector. This can be achieved with active energy citizen. These are the prosumers (producers and consumers in local level), while storing and sharing energy through the use of smart grids and IT platforms. The countries can subsidize small scale photovoltaics (PVs) on roofs, or small wind turbines and citizens with energy communities can take advantage of this. However, this can be managed if we have energy literate people. Empowered people in local level, not resellers, with information and experience on energy project scan tell their story (positive impacts), which in turn they can market, influence and create momentum in community level. We cannot mandate people but we can create incentives. People want to understand the benefit, make something that has also fun, and create incentives. We need to engage households, understand bills, new technological solutions on the table; new financing schemes, secure funding. We also need people's involvement: technologists, and people who will explain to others. There is a need for local energy mentors that will make people understand and answer other people's questions (ie how to insulate my home?). No need for project contractors. We need to get people on board and a new start that people will not be enforced to do this or that. We must understand that technology is not the Holy Grail and we finally have to humanize energy. Otherwise we cannot talk about energy security. We have to tackle the problem with energy insecurity instead of subsidizing people. We need to subsidize people's participation into community energy parks. There is a need for policy shift and a need for societal transition, since this is the energy transition. Energy is a social good. We need to concentrate on four Ds and Is apart from As and Rs: Decarbonization, Decentralisation, Digitalisation, Democratisation and Is: Innovation, Infrastructure, Implementation, Integration.

Finally, if we don't work towards energy security and decarbonisation, we will fall into insecure situations, with environmentally negative impact that will affect lives and world as a whole. It is not an easy task. It is dynamic and needs a frequent revision, not only on a single country level but also on a regional and global level. The challenge is here. It is our prerogative whether we want a better and healthier place with environmentally friendly, secure energy resources.

Conclusions

There is no doubt that we live in a time period where energy plays a major role. The amounts of fossils (coal, natural gas, and crude oil) will not be forever, but still exist in usable quantities. This reality cannot provide energy security itself. On top of this, and with the zero carbon emissions pledges, we have to redirect our efforts and policies. On the other hand, we have equally large amounts of RES (i.e. solar, wind, hydropower, biofuels). As people need energy abundance and cheap prices, there are always hidden costs that sometimes are not calculated. Besides, technologies come with problems and risks. The short-term energy security is supported by the availability and low cost of the fossil technologies and fuels subsidies. EU countries are an example of stepping back to use fossil fuels and subsidize them in order to have short-term security due to the shock of high prices in gas and taxes. However, in the long-term, this policy has a negative impact on the environment, human health and possibly lives. This negative impact is not yet fully calculated and I doubt if it has been considered in the energy security equation. If we summarize what are the main energy resources in this planet we can say that:

Coal is not clean, but we still need its energy for the power generation and the industry. The lobbies and industries are not willing to abandon so easily. This leads to the conclusion that we must be aware of the problems and take the necessary precautions. Advanced artificial filters may be used in order to capture the emitted carbon and store this.

Crude oil is the biggest polluter, but we need it for our transportation means. The lobbies and industry are willing to move to other resources, if they get the reassurances they want. Technology is mature and people are convinced to change their consumption behavior. The disadvantage to move to fully electrified transportation is the abundance of rare materials for the batteries manufacture. However, hydrogen is another perspective but we are still behind in engines technology and hydrogen distribution and supply grid.

Natural gas is cleaner, it pollutes less, but still pollutes. Its production and use has been marketed as the transition fuel to the decarbonised world. However, it will be treated as the major fuel for the next years.

Solar and wind means variability. If there is no sun nor wind, it means no power. No materials for batteries and no energy storage means power production that goes unused. Big farms of solar panels or industrial wind turbines on the top of high mountains are not the answer. Bottom-up solutions with targeted funding addressed to energy communities of civilians and building roofs utilization is a must.

Nuclear power has a major drawback due to nuclear accidents. Bad luck or lack of maturity? However, nuclear emits no GHG and France is working on recognizing this power as a green power. Everybody wants cheap electrical energy, with cheap nuclear materials from the developing countries and postponing the risks of nuclear waste to the next generations.

Hydropower is a clean technology if citizens of the project to be implemented are not forced to displace. A chronic and disappointing example is Mesochora region and Acheloos river in Greece.

Biofuels are nice but we need rather large quantities. However, damages done to humans and lands by their production, use, and expansion into the food production are possible. Agriculture needs to play its role there.

Geo-power and ocean-power are promising but have a long way to go. We are still behind in technological maturity and financing instruments.

With the pledges of decarbonisation since carbon emissions by human activity are not easily stopped, these emissions can be partially and artificially filtered and captured, stored and then reused. For this issue, there can also be implementations of large-scale programmes for reforestation and improvements in forestry. In this direction, agriculture and transportation, as big carbon emitters, can play a crucial role in the future contributing to decarbonisation.

Finding the right and proper energy resources mix for the future will play a critical role in economic growth and human wellbeing. This will continue to be an important concern for policymakers in whole world. The way energy is produced and used will also be of national and global concern because of carbon emissions pledges. The rapid demand for energy after the first lockdown due to pandemia and afterwards robust economic expansion, and of course the large global population is a major challenge that requires policy actions to ensure that energy users have access to reliable, affordable, and secure energy supplies. It is a rather uncomfortable situation for countries that are not endowed with abundant energy resources and must rely on energy imports. However, there are several strategies that countries can implement individually or jointly to improve their energy security. Countries can improve their energy security by renewable energy such as wind, solar, and geothermal energy and integrate them into the energy system. This alternative is promising particularly in regions such as North Africa and the Middle East. This should be coupled by production of green hydrogen using electricity produced by RES. In addition, large-scale and for long-term storage facilities should be promoted. Besides, through investments in energy efficiency, countries can reduce their demand for energy, educate and change behaviours. This can be accomplished through more stringent building codes, targeting building isolation and self-producing energy, and real-time pricing of electricity. Moreover, energy security can be greatly supported by improving the performance of energy markets through intervening reforms and institutional changes. In case there are properly designed and implemented, the reforms can reduce wastage, trigger private sector investment in energy generation, and increase competition in energy markets, while reducing the prices to consumer. In the same direction, global energy security can be enhanced through international cooperation on energy issues and the promotion of regional energy trade. Such trade will be a win-win outcome for both exporters and importers of energy[56].

As decarbonisation is regarded to be one of the cornerstones of the global priorities in energy security. Meeting the growing energy requirements without damaging the environment is one of the biggest challenges the world faces today. Developing countries in regions like Southeast Asia, South Asia, Sub-Saharan Africa, and some countries in Latin America face a wide range of energy and environmental challenges. South Asia and Sub-Saharan Africa, jointly have almost 40% of the global population and they face serious energy challenges in the form of lack of access to electricity and refined cooking fuels, fragility of grid, and high energy prices. In these two regions alone, nearly 2 billion people lack access to electricity and clean cooking fuels respectively. Energy issues need to be addressed to improve the socio-economic prosperity in developing countries and as a consequence their energy security.

[56] Collins, A. (2020). Towards Energy Security for the Twenty-First Century. Energy Policy. doi:10.5772/intechopen.90872.

Anthropogenic emissions and pollution is arguably the most important threat facing mankind. Ironically, the poor and developing countries, despite having a marginal contribution towards the GHG emissions, are mainly suffering from the environmental pollution. Extreme weather disasters, water scarcity, and seasonal disorder are exacerbating the food and water security situations in these countries. Low-lying small islands and developing states are particularly facing serious challenges from the rising sea level[57]. Thus, energy security combined with decarbonising the activities is a major issue for the small and developing countries of the world.

The situation is getting more complicated by the fact that energy security can be viewed from different points of view, which are often contradictory and sometimes with no consensus on what energy security is and how it is measured, monitored or foreseen. Many factors affect energy security in different ways. Energy infrastructure (grids, storage facilities, powerful computers, etc), is one of the major preconditions that will along with political changes have the greatest impact on energy security. Large energy producers are developing their own energy strategies in order to use their resources effectively, without jeopardizing the future. Stable energy production, together with economic development and international policy, are major drivers, which will define and shape future energy security. Improved cooperation between countries in the field of energy security would probably enhance energy security worldwide, increasing security generally and boosting the economies at the same time. However, foreign investments in some countries and regions are subject to strict regulations. The development and interconnection of smart grids is an important component for energy security. Insufficient capacity can result in a bottleneck congestion and inability to react on extreme situations like natural disasters. It can also generate crises. Moving to stable and without carbon emissions energy supply in future, requires higher penetration of renewable energy. But this energy is very uncertain and the supply of it is spatially heterogeneous. This requires balancing with the other energy sources. High renewable penetration is problematic for the moment unless is partly balanced with itself. This requires regional integration by high voltage lines at substantial distances. If development of RES is faster than the grid, a large

[57] Asif, A. (2021). Energy and Environmental Security in Developing Countries. Springer. ISSN 2363-9466. https://doi.org/10.1007/978-3-030-63654-8.

fraction of them will be unused. Unfortunately, there are regions that have many bottlenecks across countries and do not plan to expand grid substantially even at national levels. Due to high and usually volatile energy prices, as well as concerns about overall environmental issues, people are concerned about energy security. The countries need to ensure that energy supplies are available, sufficient, affordable and sustainable in order to pursue energy security. This consists of a wide range of measures: conserving and raising energy efficiency, rationalizing pricing and taxation systems, improving governance in the energy sector and diversifying energy supplies, particularly making better use of alternative and renewable resources. In order to improve energy security, the countries should promote renewable energy sources at scale and magnitude suitable to each country. In other words the significant potentials of hydropower, wind energy, photovoltaic, biomass, solar and geothermal energy production must be explored and utilized wisely. Many of these can be commercially developed and used in a decentralized manner. Techno-economic scenarios concerning the decarbonization of the energy sector in the future can be generated through policy decision-making tools, such as Multi-criteria Decision Making. Several different pathways can be investigated by using MCDM method. However, the necessary path which needs to be taken in order to meet energy targets while decarbonizing the power sector is particular for each country and region. Discussions of international organizations are concerned for the importance of energy security, while energy poverty is becoming worse. The largest number of countries in the world is dependent on energy imports and it is not realistic to expect this fact to change in the future[58]. However, there are countries that have no fossil fuels resources but they have endowments of rare elements to promote renewable energy resources. The countries need to consider the current status of energy security and measure the actions needed to ensure high level of energy security, taking into consideration the preferences of the society.

We have seen that energy security has a dynamic character that evolves over time. The meaning of energy security is dependent on the socio-economic and political situation and existing conditions such as local, regional, national and international circumstances and a range of risks, their levels and potential impact. Furthermore,

[58]Radovanovic, M. (2018). Energy Security. Perspectives, Improvement Strategies and Challenges. Nova Science Publishers. Inc. ISBN:978-1-53613-509-1.

energy security is multidimensional, and influenced by various issues, such as "*resource availability and accessibility, technological capacity, policy direction, design and development, policy implementation, economic sustainability, and environmental impact*." Finally, energy security has multiple meanings. For example, its meaning is different for energy importers and energy exporters, developed and developing countries. Therefore, there is no globally accepted definition of energy security, but rather a continuously evolving concept.

Energy generation from RES should be gradually increasing, and replacing energy from fossil fuels. Continuous benefits to the energy system and society at large can be achieved by "*setting gradually increasing targets for improved utilisation of energy resources*." The issue regarding RES and efficiency is not going to help unless "*government policy objectives are supported by a set of governance structures, investment schemes, incentives, subsidies, attractive tariffs, well-designed procedures and effective processes for energy producers and consumers*." By enhancing RES utilisation and resource efficiency via consistent governance, a country becomes less vulnerable to domestic, as well as international, risks. A threat in relation to RES and energy efficiency is a lack of attention paid to making governance effective. While RES and resource efficiency might remain common goals for many countries, the governance and targets of resource poor and resource rich, will be highly different. It is likely that resource rich countries will adopt a slow approach to the increasing energy generation from RES and might be not very active in pursuing energy efficiency programmes. The policy direction, supported by proper governance, is important, although one might realise that implementation might take decades. As energy security has "*both national and international dimensions*", "*coordinated governance is required both domestically and internationally, with variation in governance tools used by different countries*". Looking into the future, for a decarbonised world, the long-term perspective of energy security leads us to a model of a gradual reduction of fossil fuels and an accelerated increase of renewable resources, energy storage and smart management of energy with sophisticated digital tools. It is likely that internal incentives, such as powerful oil sector lobby, with existing contracts and formed supply chains, will continue to put pressure on countries for lengthy periods, forming their opinions and actions regarding energy security. This brings up the questions about values. Energy security is a value to society. With its dynamic profile, there is an open field for research in assessing the trade-offs a government faces in selecting governance instruments and the role of society in strengthening energy security. The active engagement of citizens, interest groups, associations, organizations, and entrepreneurs is an opportunity not to be missed in both research and governance[59].

This thesis can be of interest for energy services either used by individuals or organizations and can also serve as a method for developing energy policies and improving energy security.

[59]Mouraviev, N., Koulouri, A. (2019). Energy Security. Policy Challenges and Solutions for Resource Efficiency. Palgrave Macmillan. ISBN 978-3-030-01033-1. https://doi.org/10.1007/978-3-030-01033-1.

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Lee, H.C., Chang, C.T. (2018). Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan. Renew. Sustain. Energy Rev. 92. 883–896.

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Appendix

Global Energy Institute. (2020). International Index of Energy Security Risk. Assessing Risk in a Global Energy Market. US Chamber of Commerce

Pie charts showing the current estimated energy demand mix.
Pie charts showing the current estimated power generation energy mix.

Data Sources

The Energy Institute relied primarily on government data from the Energy Information Administration and the International Energy and other widely-used and respected sources were employed. The following provides a list of the main sources of the data used.

International Index of Energy Security Risk. Assessing Risk in a Global Energy Market:
https://www.globalenergyinstitute.org/sites/default/files/IESRI-Report_2020_4_20_20.pdf

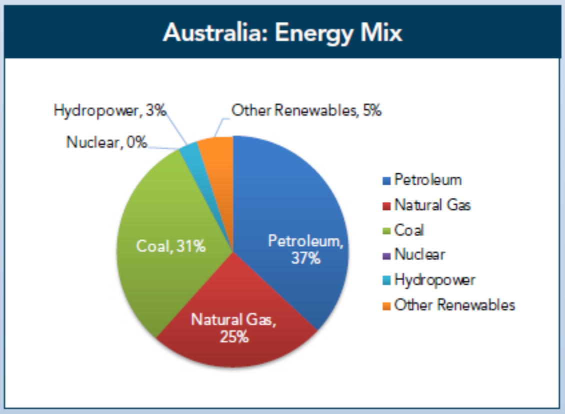
International Energy Agency:
IEA Statistics, Energy Prices and Taxes. Available at: https://www.iea.org/data-and-statistics.

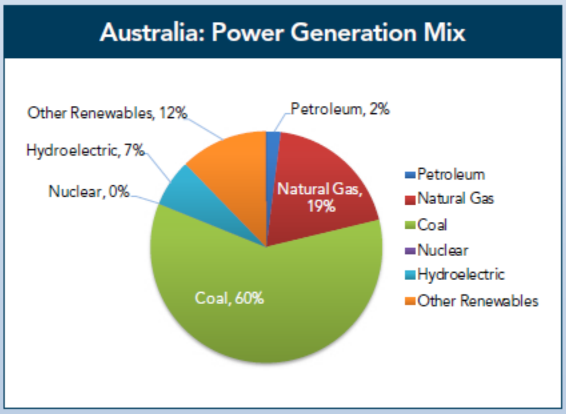
World Bank:
Development Indicators. Available at: https://data.worldbank.org/indicator?tab=all.

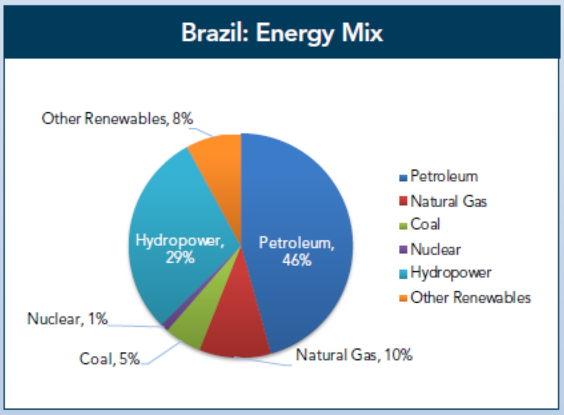
BP:
BP Statistical Review of World Energy.
Available at: https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

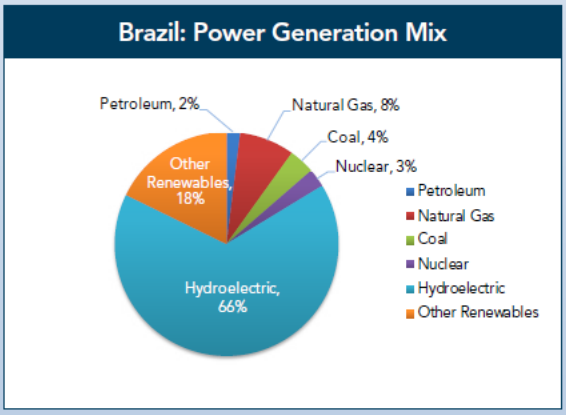
Energy Information Administration:
International Energy Statistics. Available at:
http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm.
http://www.eia.doe.gov/emeu/aer/contents.html.

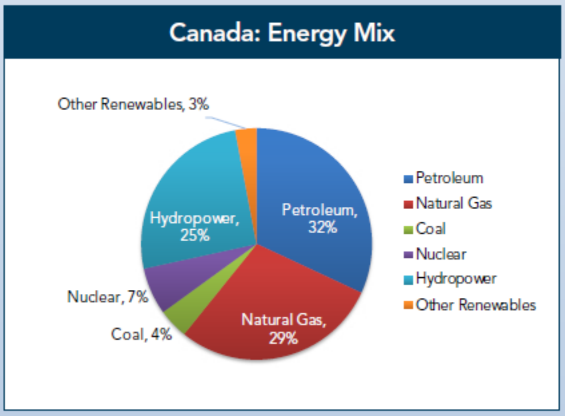
Freedom House:
Freedom in the World: Comparative and Historical Data. Available at:
http://www.freedomhouse.org/report-types/freedom-world.

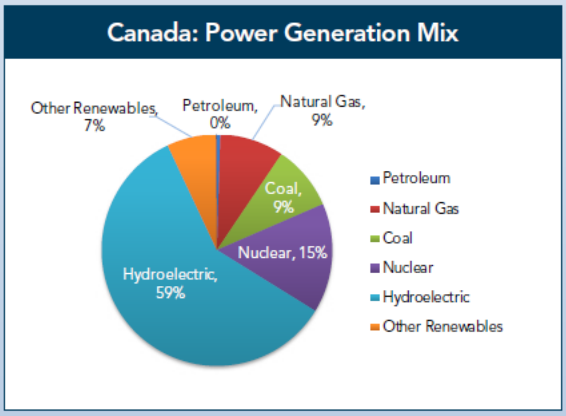

Australia: Energy Mix
Hydropower, 3%
Other Renewables, 5%
Nuclear, 0%
Coal, 31%
Petroleum, 37%
Natural Gas, 25%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables


Australia: Power Generation Mix
Other Renewables, 12%
Petroleum, 2%
Hydroelectric, 7%
Nuclear, 0%
Natural Gas, 19%
Coal, 60%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables

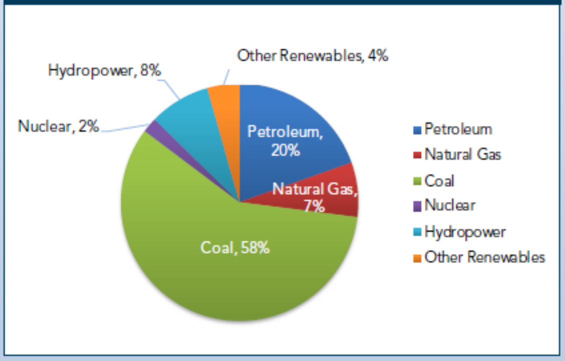

Brazil: Energy Mix
Other Renewables, 8%
Hydropower, 29%
Petroleum, 46%
Nuclear, 1%
Coal, 5%
Natural Gas, 10%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables


Brazil: Power Generation Mix
Petroleum, 2%
Natural Gas, 8%
Coal, 4%
Nuclear, 3%
Other Renewables, 18%
Hydroelectric, 66%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables

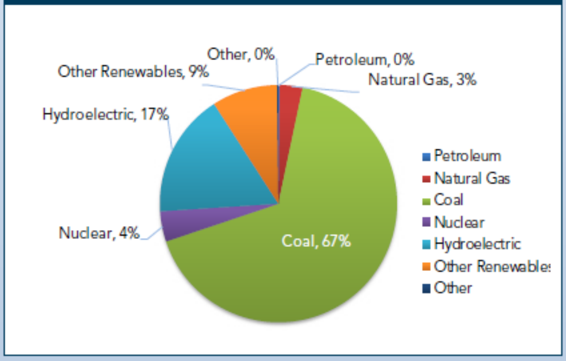

Canada: Energy Mix
Other Renewables, 3%
Hydropower, 25%
Petroleum, 32%
Nuclear, 7%
Coal, 4%
Natural Gas, 29%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables


Canada: Power Generation Mix
Other Renewables, 7%
Petroleum, 0%
Natural Gas, 9%
Coal, 9%
Nuclear, 15%
Hydroelectric, 59%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables

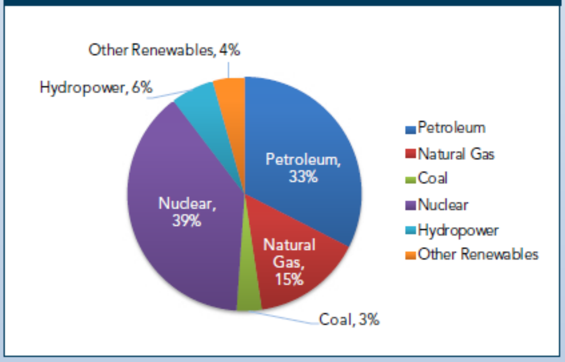
China: Energy Mix



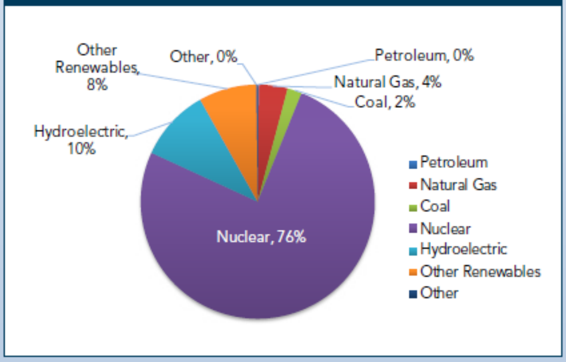
China: Power Generation Mix



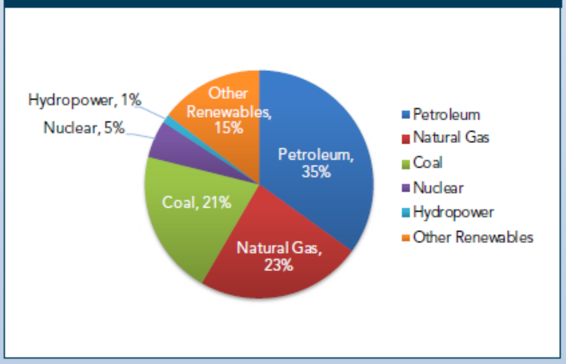
France: Energy Mix



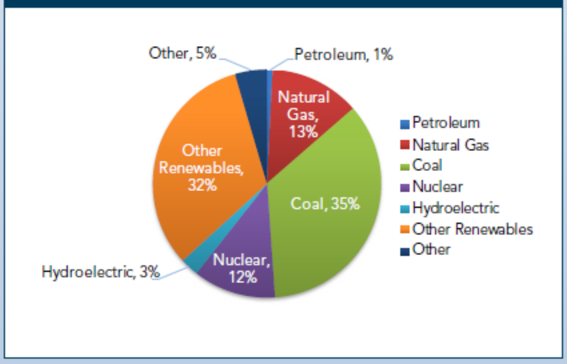
France: Power Generation Mix



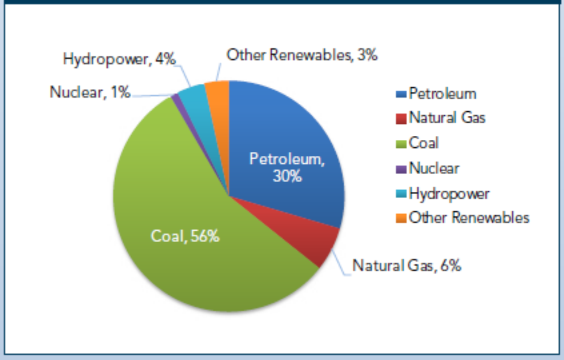
Germany: Energy Mix



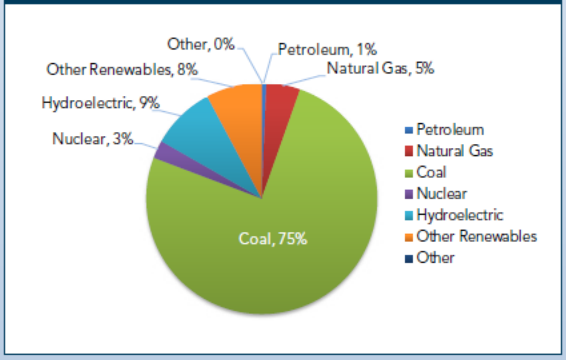
Germany: Power Generation Mix



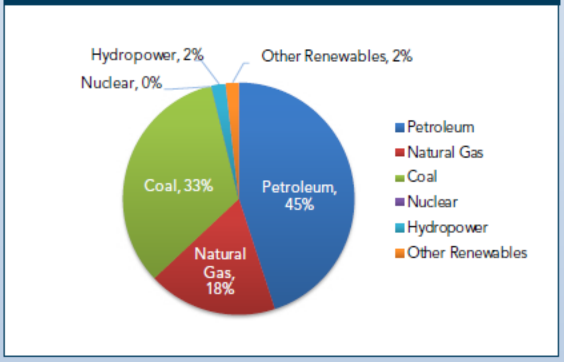
India: Energy Mix



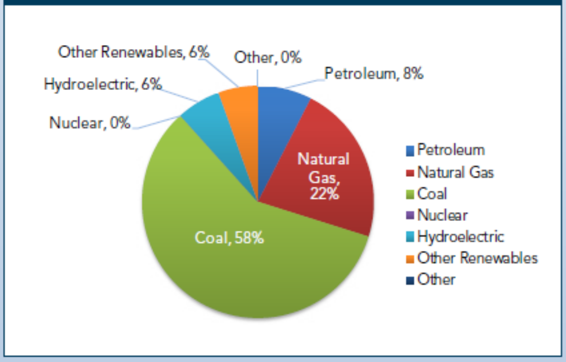
India: Power Generation Mix



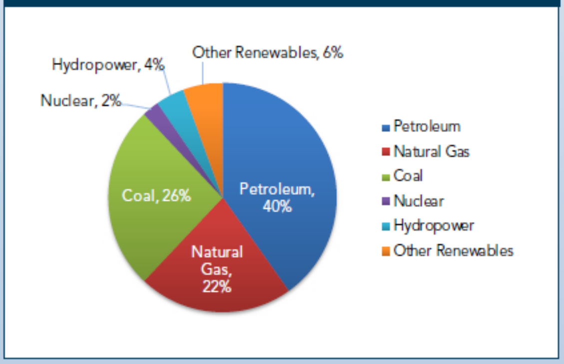
Indonesia: Energy Mix



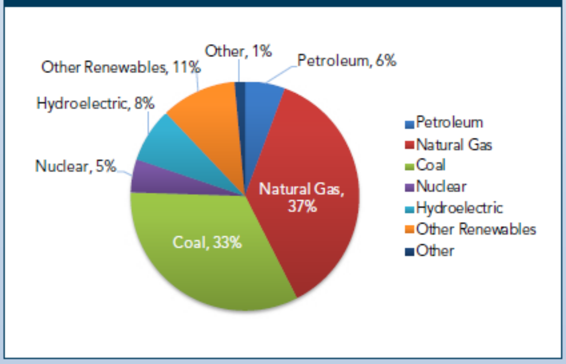
Indonesia: Power Generation Mix

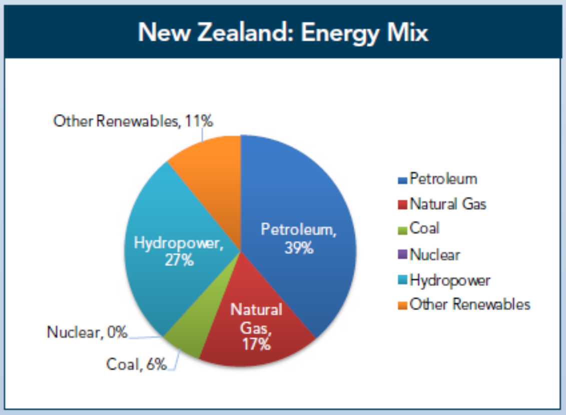


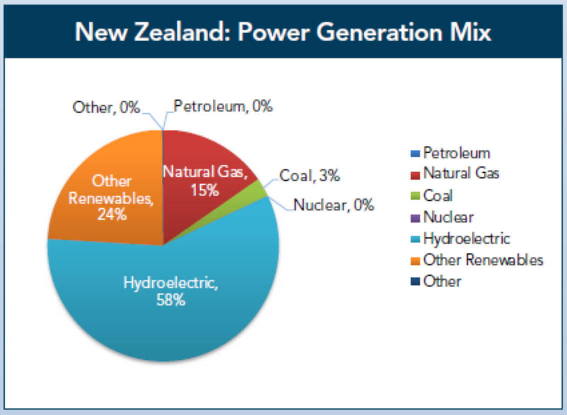
Japan: Energy Mix

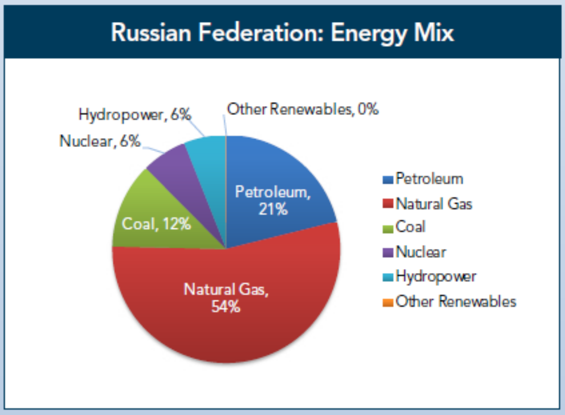


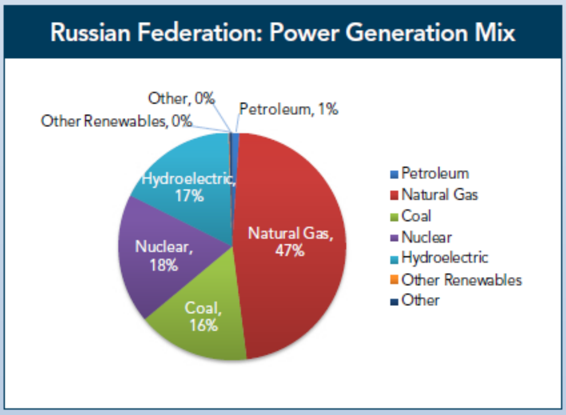
Japan: Power Generation Mix

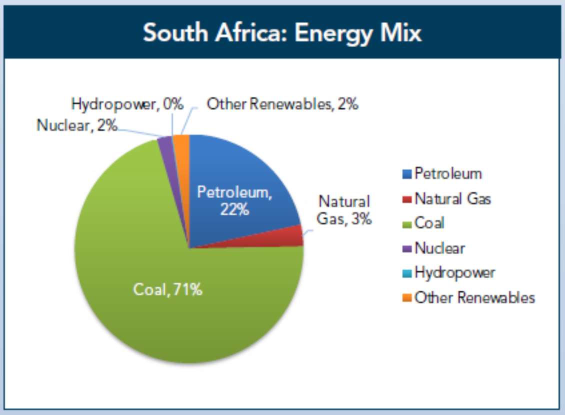


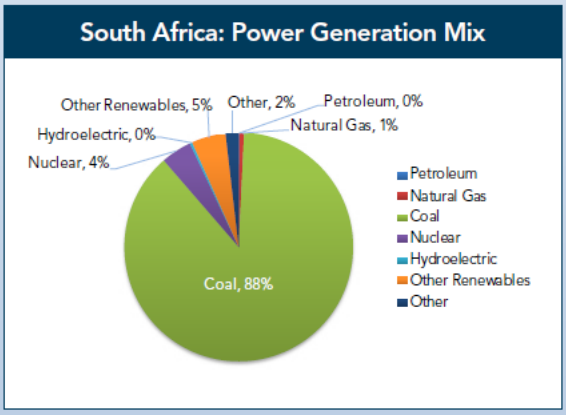

New Zealand: Energy Mix
Other Renewables, 11%
Petroleum, 39%
Hydropower, 27%
Natural Gas, 17%
Nuclear, 0%
Coal, 6%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables

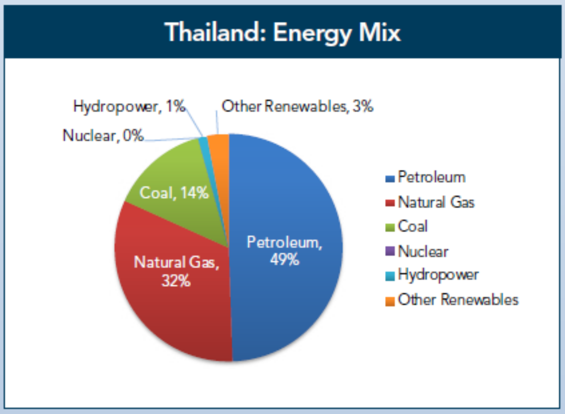

New Zealand: Power Generation Mix
Other, 0%
Petroleum, 0%
Other Renewables, 24%
Natural Gas, 15%
Coal, 3%
Nuclear, 0%
Hydroelectric, 58%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables
Other

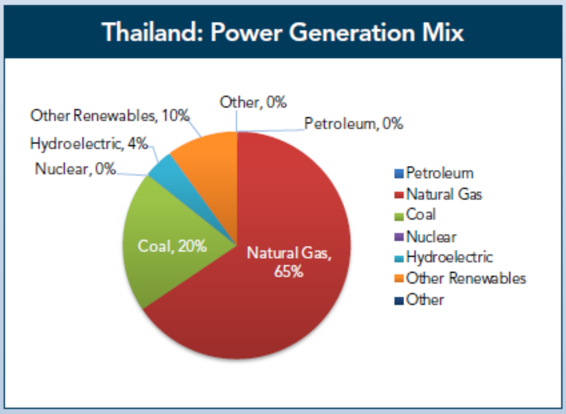

Russian Federation: Energy Mix
Hydropower, 6%
Other Renewables, 0%
Nuclear, 6%
Petroleum, 21%
Coal, 12%
Natural Gas, 54%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables

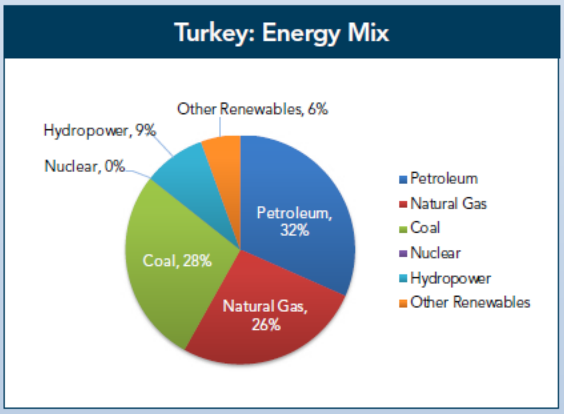

Russian Federation: Power Generation Mix
Other, 0%
Other Renewables, 0%
Petroleum, 1%
Hydroelectric, 17%
Natural Gas, 47%
Nuclear, 18%
Coal, 16%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables
Other

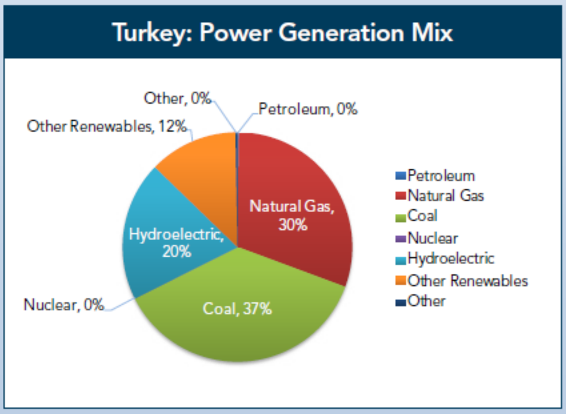

South Africa: Energy Mix
Hydropower, 0%
Other Renewables, 2%
Nuclear, 2%
Petroleum, 22%
Natural Gas, 3%
Coal, 71%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables

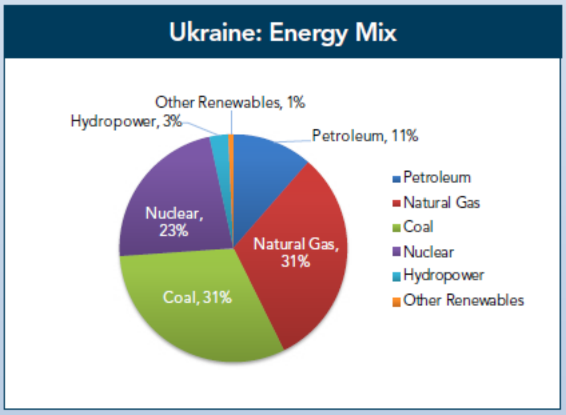

South Africa: Power Generation Mix
Other Renewables, 5%
Other, 2%
Petroleum, 0%
Natural Gas, 1%
Hydroelectric, 0%
Nuclear, 4%
Coal, 88%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables
Other

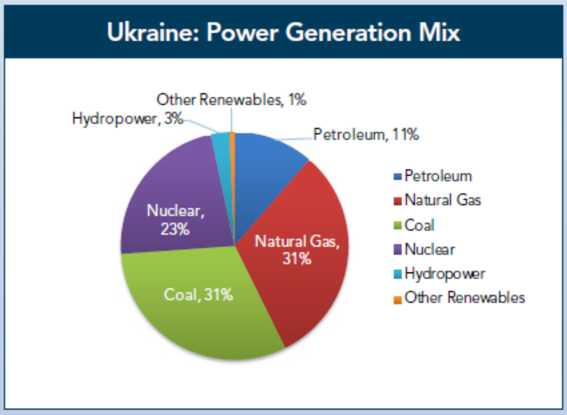

Thailand: Energy Mix
Hydropower, 1%
Other Renewables, 3%
Nuclear, 0%
Coal, 14%
Natural Gas, 32%
Petroleum, 49%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables

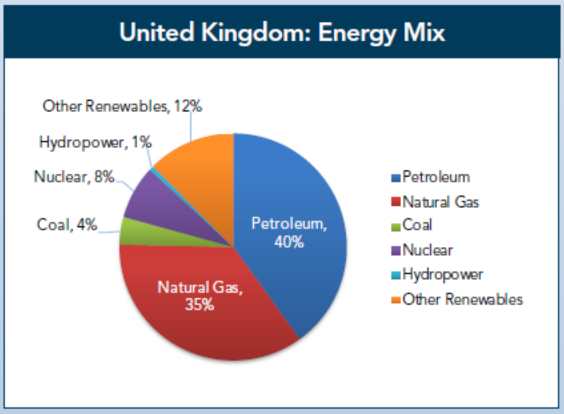

Thailand: Power Generation Mix
Other, 0%
Other Renewables, 10%
Petroleum, 0%
Hydroelectric, 4%
Nuclear, 0%
Coal, 20%
Natural Gas, 65%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables
Other

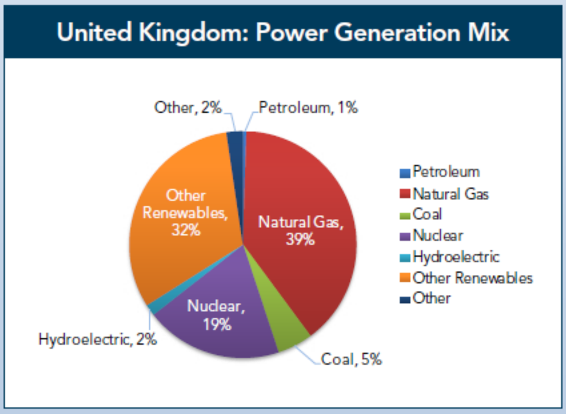

Turkey: Energy Mix
Other Renewables, 6%
Hydropower, 9%
Nuclear, 0%
Petroleum, 32%
Coal, 28%
Natural Gas, 26%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables

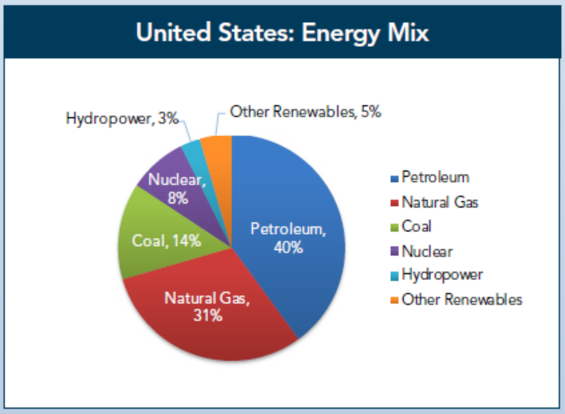

Turkey: Power Generation Mix
Other, 0%
Petroleum, 0%
Other Renewables, 12%
Natural Gas, 30%
Hydroelectric, 20%
Nuclear, 0%
Coal, 37%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables
Other

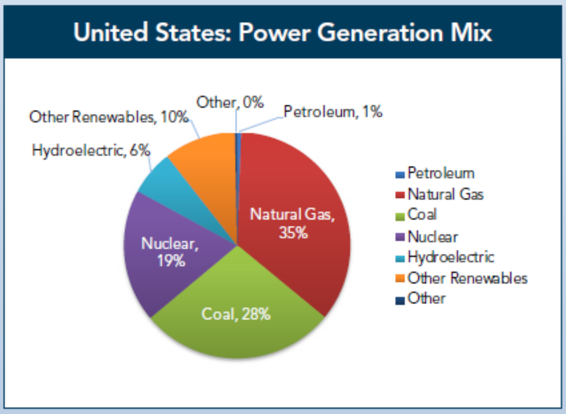

Ukraine: Energy Mix
Other Renewables, 1%
Hydropower, 3%
Petroleum, 11%
Nuclear, 23%
Natural Gas, 31%
Coal, 31%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables


Ukraine: Power Generation Mix
Other Renewables, 1%
Hydropower, 3%
Petroleum, 11%
Nuclear, 23%
Natural Gas, 31%
Coal, 31%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables


United Kingdom: Energy Mix
Other Renewables, 12%
Hydropower, 1%
Nuclear, 8%
Coal, 4%
Petroleum, 40%
Natural Gas, 35%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables


United Kingdom: Power Generation Mix
Other, 2%
Petroleum, 1%
Other Renewables, 32%
Natural Gas, 39%
Nuclear, 19%
Hydroelectric, 2%
Coal, 5%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables
Other


United States: Energy Mix
Hydropower, 3%
Other Renewables, 5%
Nuclear, 8%
Coal, 14%
Petroleum, 40%
Natural Gas, 31%
Petroleum
Natural Gas
Coal
Nuclear
Hydropower
Other Renewables


United States: Power Generation Mix
Other Renewables, 10%
Other, 0%
Petroleum, 1%
Hydroelectric, 6%
Natural Gas, 35%
Nuclear, 19%
Coal, 28%
Petroleum
Natural Gas
Coal
Nuclear
Hydroelectric
Other Renewables
Other