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MASTER THESIS

"Intensify Energy Security and State Sovereignty: An investigation into the implementation of Renewable Energy Sources

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Lastly, I could not have undertaken this project without the support of my family.

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Structure of thesis

In general, this thesis is an effort to illustrate and view the renewable energy transition and infrastructure updates from a geopolitical point of view.

Chapter 1 consists of a brief analysis of energy and how this commodity serves to fulfill geopolitical and political objectives, alongside fostering transnational relations through the consistent provision of energy resources. Chapter 2 begins with a literature review regarding the two categories of energy: conventional and non-conventional ones, and the urge for transition into the new era of renewables. More analytically, a review of the historical progress of renewable energy adaptation is demonstrated along with a couple of important geopolitically associated concepts and ideas.

Moreover, as this works proceeds several case studies of concrete instances of countries adopting renewable energy sources are provided, along with the effects of this shift on their energy security and reliance on traditional energy suppliers from other nations. How these nations enhanced their sovereignty in response to their geopolitical surroundings through their energy transition was addressed. Finally, this analysis attempts to concentrate on the case of Greece the existing renewables adoption conditions, and the scope for further applications.

Introduction
Preamble

Energy is an elementary necessity, akin to air, water, and land, and has a major influence on the production and distribution of all goods. Humanity's ability to survive relies on the levels of access to a consistent source of energy, given that is both an economic commodity and susceptible to high costs and political interference.[1] Over time, energy has been prone to price fluctuations and flow disturbances that impact every aspect of human existence. Energy serves as a fundamental power source, holding a pivotal position on a societal scale, bolstering industries, transportation, the military, and traditional weaponry systems. At an individual level, facilitates everyday activities like heating and electricity consumption. An imperative characteristic of energy is also

[1] Sovacool BK, Mukherjee I. Conceptualizing and measuring energy security: A synthesized approach. Energy. 2011;**36**(8): 5343-5355. DOI: 10.1016/j.energy.2011. 06.043

the geopolitical influence of resources as a means of enhancing state sovereignty and the comparative power of neighboring countries by weaponizing the interminable flow of energy-consumer states.[2] In situations of scarcity, military conflicts can be justified as a result, as the need for energy is possible to lead to the application of dominance. Hence, international relations and politics are particularly engaged in energy issues, encompassing objectives and methods for attaining national ambitions.[3]

2. Literature review

Introduction

The global energy crisis currently experienced by the world severely disbands the uninterrupted energy supply. This politico-economic and social distortion results in exceptionally high prices, especially for fossil fuels.[4] In the past couple of years, the sudden COVID-19 pandemic has generated unprecedented disruptions in energy markets when distribution networks were disarranged, demand was constrained, and eventually surpassed supplies.[5] The Russian Invasion of Ukraine and the subsequent conflict in the region worsened further the situation, as the Russian prominent role in energy markets was weaponized to breed geopolitical advantages for its government.[6] The global community, particularly Europe, as a primary importer of oil and natural

[2] Correlje, A., & Van der Linde, C. (2006). Energy supply security and geopolitics: A European perspective. *Energy policy*, *34*(5), 532-543.

[3] Paravantis, J. A., & Kontoulis, N. (2020). Energy security and renewable energy: a geopolitical perspective. In Renewable Energy-Resources, Challenges and Applications. IntechOpen.

[4] Chevalier, J., & Geoffron, P. (2013). The new energy crisis: Climate, economics, and geopolitics. UK: Palgrave Macmillan.

[5] Khan, K., Su, C. W., & Zhu, M. N. (2022a). Examining the behaviour of energy prices to COVID-19 uncertainty: A quantile on quantile approach. *Energy*, 122430.

[6] Stulberg, A.N., 2017. Natural gas and the Russia-Ukraine crisis: strategic restraint and the emerging Europe-Eurasia gas network. Energy Res. Soc. Sci. 24, 71–85.

gas from Russia, aimed to counter the energy manipulation by the Russian government. This was pursued by implementing an embargo on Russian oil imports and progressively reducing dependence on them.[7] Countries sought to achieve this venture by collaborating with other suppliers, or more cost-effectively and autonomously, by transitioning to alternative energy sources. Renewable energy sources were regarded as the optimal remedy given their positive impact on matters of energy security and state sovereignty.[8]

Conventional and non-conventional energy sources

Society has harnessed its available energy sources extensively. The broad era of the years of occupation and use led to their categorization into two classes: At first, non-renewable energy sources which describe the utilization of restricted sources such as fossil fuels, derived from the millions of years of compression living and non-living material in the earth's crust, and renewable energy sources.[9] The latter category is identified as both endless and more smoothly spread across the globe while furnishing increased reliability, promoting democratization, sustaining economic growth, and

[7] Leonard M, Popescu N. A Power Audit of the EU-Russia Relations. Policy Paper. London: European Council on Foreign Relations; 2007. Available from: https://www.ecfr.eu/page/-/ECFR-02_ A_POWER_AUDIT_OF_EU-RUSSIA_ RELATIONS.pdf [Accessed: 12 March 2020

[8] Proskuryakova L. Updating energy security and environmental policy: Energy security theories revisited. Journal of Environmental Management. 2018;223:203-214. DOI: 10.1016/j. jenvman.2018.06.016

[9] Scholten, D., Bazilian, M., Overland, I., & Westphal, K. (2020). The geopolitics of renewables: new board, new game. *Energy Policy*, 138, 111059.

enhancing security.[10] Nonetheless, the availability of energy, particularly from traditional sources is questioned, due to the extensive exploitation of fossils that has led to the augmentation of global distress about the drainage and shortage of materials. This diminishment of available resources has impacted not only the strategy of the economic decision-making centers by escalating fossil fuel costs and intensifying price fluctuations but also other aspects of governmental preoccupation, such as foreign policy and environmental issues.[11] The increasing need for energy, heavy dependence on energy imports by untrustworthy producing and transit nations, the negative impacts of climate change, and environmental degradation stand as some examples.[12]

The urgency of transition into a new energy era

The above pressing provocations in the current intricate global landscape, alongside the rising consciousness of the environmental consequences of industrialized lifestyle, underscore the immediate requirement for transitioning to cleaner energy sources, a swift capable of providing a more secure geopolitical system too.[13] An alteration in the existing energy relations, derived from a progressive transition to renewable sources is supposed to disturb the existing geopolitical balance and trigger shifts in power dynamics, moving the field of competition to the immediate and successful introduction

[10] Scholten D, Bosman R. The geopolitics of renewables; exploring the political implications of renewable energy systems. Technol Forecast Soc 2016;103: 273–83.

[11] Khan, K., Khurshid, A., & Cifuentes-Faura, J. (2023a). Energy security analysis in a geopolitically volatile world: A causal study.*Resources Policy*,*83*, 103673.

[12] Rothkopf, D.J., 2009. Is a green world a safe world? Not necessarily. A Guide to the Coming Green Geopolitical Crises, Foreign Policy, September/October 2009.

[13] Vakulchuk, R., Overland, I., & Scholten, D. (2020). Renewable energy and geopolitics: a review. *Renewable Sustainable Energy Review*, 122, 109547.

of renewable energy sources into the state's power grid.[14] Currently, renewable energy makes up only a small portion of the world's power and electricity demand, possessing a secondary role in electricity grids, but it has experienced the most rapid growth among all energy sources over the past decade.[15]

Renewable energy encompasses a variety of sources, with the primary categories being briefly:

1. Solar Energy: Generated from sunlight through photovoltaic panels or solar thermal systems.
2. Wind Energy: Produced by capturing the kinetic energy of the wind via wind turbines[16].
3. Hydropower: Derived by the movement of water, typically by impounding rivers or utilizing water turbines.
4. Geothermal Energy: Obtained from the Earth's internal heat through geothermal power plants.
5. Biomass energy: Created from organic materials like wood, agricultural residues, and waste.

Pioneering applications of renewables

The very first recorded implications of renewable energy sources are detected back to thousands of years. Ancient cultures utilized renewables like wind, water, and solar energy for diverse objectives.

[14] Flouros, F., Pistikou, V., & Plakandaras, V. (2022). Geopolitical risk as a determinant of renewable energy investments. *Energies*, *15*(4), 1498.

[15] Paltsev, S., 2016. The complicated geopolitics of renewable energy. Bull. At. Sci. 72 (6), 390–395.

[16] Janssen, R. (2002), *Renewable energy into the mainstream*, OECD/IEA, Paris, 54 pp.

Wind energy: Wind power has been implicated for years, initially for sailing ships and grinding grain. The first acknowledged windmills were constructed in Persia (currently Iran) around 200 BCE for milling grain and pumping water. Windmills afterward have been distributed to China and Europe.

Water energy: Waterwheels were developed by early civilizations to take advantage of the movements of flowing water for activities like irrigation and machinery. Greek, Roman, and Chinese cultures demonstrated samples of such applications.

Solar energy: Heating, cooking, and lighting are a few examples of solar energy implications since ancient times. The Greeks and Romans manufactured houses with extensive south-facing windows to seize the sun's warmth during the day. Furthermore, they utilized curved mirrors to accumulate sunlight to seize sun power for cooking and lightning.

Despite this amateur usage of renewables being elemental compared to contemporary technologies, these fundamental efforts laid the ground for the advancement of more intricate renewable energy systems in recent times.[17]

The current state of renewables adoption

The embracement of renewable energy sources globally has demonstrated an upward trend, with record-breaking facilities' implementations of solar and wind power in a bunch of nations, with various characteristics and requirements. According to the International Energy Agency (IEA), renewable capacity extensions have regularly surpassed those of conventional fossils lately.[18] This evolution has been initiated by

[17] Rothkopf, D.J., 2009. Is a green world a safe world? Not necessarily. A Guide to the Coming Green Geopolitical Crises, Foreign Policy, September/October 2009.

[18] International Renewable Energy Agency. (2019). A New World: The geopolitics of energy transformation

numerous factors such as environmental concerns, technological developments, and governance strategies to promote a "cleaner" energy mix. Not only renewable energy technology regarding wind and solar have been on the rise but also other forms of non-conventional sources like hydroelectric and biomass, have demonstrated a considerable growth in deployment and capacity expansion.[19]

The concept of Geopolitics

The term "geopolitics" has its roots in the unification of two words: "geo", stemmed from the Greek word "ge", meaning "earth" or "land", and "politics", derived from the Greek word "polis" signifying "city" or "state".[20] All in all, as a term, essentially symbolizes the "politics of land" or "the politics of geography". The idea of geopolitics appeared in the late 19th and early 20th centuries, especially with the assignment of scholars such as Sir Halford Mackinder, Friedrich Ratzel, and Alfred Thayer Mahan, who underlined the magnitude of geography in forming international relations and global power dynamics.[21]

Mackinder conceived a pioneering idea, the 'Heartland theory', which emphasized the strategic significance of Eastern Europe and Central Asia, while Ratzel concentrated on developing an organic theory, inspecting nations as living organisms in continuous rivalry for position and sources. Furthermore, Geopolitics obtained prominence in the

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[19] Cergibozan, R. (2021). Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries. Renewable Energy, An International Journal. Retrieved on March 2nd, 2022, from https://www.sciencedirect.com/science/article/abs/pii/S0960148121016384

[20] Hafner, M., Tagliapietra, S. (2020). The Geopolitics of the Global Energy Transition. Lecture Notes in Energy. Retrieved on February 10th, 2023, https://library.oapen.org/bitstream/id/826718b9-f036-4a35-926e- 6f5e32b78162/2020_Book_TheGeopoliticsOfTheGlobalEnerg.pdf

[21] Koliopoulos, K. (2010). The art of strategy from antiquity to the present day [in Greek]. Poiotita. Retrieved on June 30th, 2022.

course of the World Wars and Cold War, affecting the strategies and actions of states and superpowers. Post-Cold War, Geopolitical study broadened to incorporate economic and cultural factors, forming present international relations. All in all, Geopolitics clearly describes the transition from the bipolarity of Cold War powers to the multipolarity that prevails today.[22]

The geopolitical influence of energy poses a direct connection to national interests and relationships, while prominently highlighting the matter of Geopolitics. The foundation of the Geopolitics notion is structured to the distribution of power across regional and international environments and is inherently a dynamic idea.[23] It is commonly understood and demonstrated as the examination of global affairs through a spatial and geographic lens, with a major focus on geographic aspects, such as terrain, location, and resources. Geopolitics delves into how these characteristics can influence a nation's foreign policy, alliances, conflicts, and overall global impact.[24] All in all, it is an academic field that integrates and enhances various disciplines such as sociology, geography, and strategic history, among others.[25]

The association between Geopolitics and Energy Security

Geopolitics and energy security are genuinely intertwined, as geopolitical components like regional rivalries, partnerships, and jurisdiction dynamics are capable of importantly impacting the availability, accessibility, and affordability of energy

[22] Franza, L., Bianchi, M., Bergamaschi, L. (2020). The geopolitics of RES: Global trends. Istituto Affari Internazionali. Retrieved on September 2nd, 2022, from http://bitly.ws/zBWe

[23] Agnew, J. (1998). Geopolitics: Re-visioning world politics. London: Routledge.

[24] Dannreuther, R. (2010). International relations theories: Energy, minerals, and conflict. POLINARES working paper, No. 8.

[25] Criekemans, D. (2007). Geopolitics: 'Geographical consciousness' of foreign policy? Ph.D. thesis. Garant.

sources. (at least 3 out of 4 dimensions of energy).[26] Vice versa, energy security is directly linked to the "construction" of geopolitical strategies and actions. Nations tend to conflict over access and control to key energy reserves, pipelines, and transit routes or arrange alliances for maintaining a peaceful global geopolitical system with specific registration of power.[27] Consequently, comprehending the correlation between Geopolitics and energy security is fundamental for evaluating international affairs and future geopolitical breakthroughs.

The literature on renewable energy and geopolitics is divided on the security implications of renewable energy expansion, with two main viewpoints: the "renewed conflict" camp and the "reduced conflict" camp. The former argues that the energy transition won't decrease energy-related conflict, while the latter believes that increased self-sufficiency will lessen such conflicts among states.

The notion of energy security

Energy security relates to the bond between the reachability of energy resources and a nation's security. It is gradually employed to emphasize the delicate interdependence

[26] Ang BW, Choong WL, Ng TS. Energy security: Definitions, dimensions and indexes. Renewable and Sustainable Energy Reviews. 2015;**42**: 1077-1093. DOI: 10.1016/j.rser.2014. 10.064

[27] Matsumoto K, Doumpos M, Andriosopoulos K. Historical energy security performance in EU countries. Renewable and Sustainable Energy Reviews. 2018;**82**: 1737-1748. DOI: 10.1016/j.rser.2017. 06.058

between Western countries and erratic regions that provide most of the globe's oil.[28] Multiple obstacles endanger the security of developed nations and their interconnection with their developing trade partners, all linked to energy concerns. Inherently, these encompass rivalry and handling over energy supplies, volatile political characteristics in supplying countries, terrorism actions, natural catastrophes, and an overabundant reliance on petroleum.[29] The outrageous dependence on fossils generates security vulnerabilities, as energy-milestone countries thriving in geopolitically fragile areas pose multiple issues regarding the sovereignty and well-being of regional countries.

Consequently, the assurance of energy supply is a constant concern for the total states and constitutes the core of energy government policy.[30] In brief, the unceasing access to credible energy sources and the certainty of energy flows with relatively few margins of vulnerability and unaffordability compose the main elements of energy security of supply definition.[31] Nevertheless, the massive dependence on exhaustible energy sources entails hazards for the rest of the national interests as the undisputable correlation between conventional energy sources and economic growth, and the environmental impact of the ongoing use of fossils. At times, geopolitical upheavals inextricably linked to energy routes and flow interruptions, have risen energy security

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[28] Rodríguez-Fern ́andez, L., Carvajal, A.B.F., Ruiz-G ́omez, L.M. (2020). Evolution of European Union's 'energy security in gas supply during Russia–
Ukraine gas crises (2006–2009). *Energy Strategy Review*, 30, 100518.

[29] Sovacool BK, Brown MA. Competing Dimensions of Energy Security: An International Perspective. Working Paper #45, Working Paper Series. Atlanta, GA: Ivan Allen College, School of Public Policy, Georgia Tech; 2009. Available from: https://people.iac. gatech.edu/files/publication/394_wp45. pdf [Accessed: 21 October 2019]

[30] Chester, L., 2010. Conceptualising energy security and making explicit its polysemic nature. Energy Policy 38, 887–895.

[31] Criqui, P., Mima, S., 2012. European climate—energy security nexus: a model-based scenario analysis. Energy Policy 4, 827–841.

of supply as the most crucial element of energy security.[32] States to protect their national interests and maintain their national sovereignty in a changing geopolitical environment seek alternative energy sources to diversify their energy mix, focusing mainly on investments related to Renewable Energy Sources.[33] Due to the massive shift of nations to renewable energy sources, international competition seems to be repositioning itself in a new field of conflict, a struggle to safeguard the compatible infrastructure, and the prerequisites to welcome evenly the state-of-the-art forms of energy.[34]

All in all, energy security and renewables share a strong connection, with the integration of renewable energy sources bolstering a country's resilience and diminishing reliance on external and vulnerable sources.[35] The acceptance of renewables, a matter stemming from the swift effort to incorporate them rapidly, is not a trivial concern from a societal perspective.[36] However, their contribution to fostering a secure and sustainable energy future and advancing self-sufficiency in fulfilling a nation's energy requirements is indisputable.

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[32] Jewell, J., Cherp, A., Riahi, K., 2014. Energy security under de-carbonization scenarios: an assessment framework and evaluation under different technology and policy choices. Energy Policy 65, 743–760.

[33] Hache, E., 2018. Do renewable energies improve energy security in the long run? Int. Econ. 156, 127–135.

[34] Flouros, F., Pistikou, V., & Plakandaras, V. (2022). Geopolitical risk as a determinant of renewable energy investments. *Energies*, *15*(4), 1498.

[35] Hache, E. (2018). Do renewable energies improve energy security in the long run? *International Economics*, *156*, 127-135.

[36] Stigka E, Paravantis JA, Mihalakakou GK. Social acceptance of renewable energy sources: A review of contingent valuation applications. Renewable and Sustainable Energy Reviews. 2014;**32**:100-106. DOI: 10.1016/j.rser.2013.12.026

The notion of state's sovereignty

State sovereignty is a fundamental principle of international law and constitutes the most comprehensive type of jurisdiction under the above legislation. This term is widely used to signify the entitlement of an actor to unchallengeable power over a territory and the people living in it throughout the time.[37] The exact meaning of sovereignty varies as it undergoes evolution to suit and express each prevailing circumstance.

Its etymological origins reflect its elementary connection with supreme authority and domination. The term "sovereignty" possesses its roots in Latin and is specifically derived from the word "superanus", meaning "chief" or "highest". From there, it inserted Old French as "soverainete" before being adjusted into Middle English as "sovereignty".[38]

[37] Royster, J.V., 2008. Practical sovereignty, political sovereignty, and the Indian Tribal Energy Development and Self Determination Act. Lewis Clark Law Rev. 12, 1065.

[38] Laldjebaev, M., Sovacool, B.K., 2015. Energy security, poverty, and sovereignty: complex interlinkages and compelling implications. In: International Energy and Poverty. Routledge, pp. 121–136

Historical review of the sovereignty term

The concept of sovereignty has been expanded over time, influenced by historical, political, and philosophical breakthroughs. Its origins are traced back to Medieval Europe, while it was raised as a principle of political prestige and rule in feudal civilizations. During this era, sovereignty was especially related with the divine jurisdiction of kings, which asserted that monarchs acquired their authority to command directly from God.[39]

The notion started to undergo important revision during the Renaissance and Enlightenment periods, while scholars like Jean Bodin and Thomas Hobbes contemplated the nature of political authority and the correlation between rulers and the masses. Bodin, in his assignment "Six Books of the Commonwealth" (1576), presented sovereignty as the principal power to rule and impose obedience in a certain province, depositing the preliminaries for contemporary conceptions over a nation's sovereignty[40].

The Treaty of Westphalia in 1648 is usually quoted as a watershed time in the expansion of the current idea of sovereignty. This Treaty concluded the Thirty Years' War in the Old Continent and introduced the fundamental of territorial sovereignty, asserting the right of states to dominate over their internal affairs without external interference. The Westphalian system spotted a variation away from the medieval feudal directive and

[39] Laldjebaev, M., Sovacool, B.K., 2015. Energy security, poverty, and sovereignty: complex interlinkages and compelling implications. In: International Energy and Poverty. Routledge, pp. 121–136

[40] Hatipoglu, E., Al Muhanna, S., Efird, B., 2020. Renewables and the future of geopolitics: revisiting main concepts of international relations from the lens of renewables. Russian J. Econ. 6, 358–373.

constructed the foundation for the present nation's system originating from the principles of regional integrity and non-intervention.[41]

The above-mentioned notion continued to mature in the centuries that came afterward, influenced by numerous historical incidents like the incipience of nationalism, the spread of colonialism, and the rise of international organizations and law. The 20th century was characterized by additional debates and contestations over supremacy, notably in the context of decolonization, globalization, and the increasing magnetism of supranational authorities.[42]

In this day and age, sovereignty remains a dominant idea of international studies and political theory, albeit with upcoming arguments and clarifications concerning its scope, restrictions, and applicability in a progressively interconnected international environment.[43] While the Westphalian idea of state supremacy is still appreciated and approved, modern determinations often analyze issues such as human rights, international governance, and the equilibrium between nation autonomy and global coordination.

[41] Kirsten Westphal, Strategic Sovereignty in Energy Affairs: Reflections on Germany and the EU's Ability to Act, 2021, http://dx.doi.org/10.18449/
2021C07.

[42] Royster, J.V., 2008. Practical sovereignty, political sovereignty, and the Indian Tribal Energy Development and Self Determination Act. Lewis Clark Law Rev. 12, 1065.

[43] Leonard M, Popescu N. A Power Audit of the EU-Russia Relations. Policy Paper. London: European Council on Foreign Relations; 2007. Available from: https://www.ecfr.eu/page/-/ECFR-02_ A_POWER_AUDIT_OF_EU-RUSSIA_ RELATIONS.pdf (Accessed: 12 March 2023)

In the energy context, sovereignty pertains to a country's capacity to autonomously manage and determine its energy resources, policies, and infrastructure.[44] This state incorporates retaining authority over energy-related affairs within national borders, lessening reliance on external sources, and assuring a stable and sustainable energy provision. By reducing dependence on foreign imported sources, national resilience is enhanced while achieving a level of independence in the energy arena by covering energy needs mainly from internal goods.[45]

The constantly evolving renewable energy technology contributes significantly to the mentioned situation by enabling an increasing number of countries to develop internal sources for their energy supply. Apart from a major part of achievement as a form of energy sustainability and autonomy, countries by implementing renewables in their energy mix, play a pivotal role in global efforts to address environmental challenges.[46]

The Link between energy security and state sovereignty

The bond between energy security and state sovereignty is intricate and multifaceted. Energy security is a necessary element of state's sovereignty, as in case of absence of reliable and accessible energy supply alternatives, the state's capability to govern productively may be jeopardized.[47]

[44] C. Schelly, V. Gagnon, K. Arola, A. Fiss, M. Schaefer, K.E. Halvorsen, Cultural imaginaries or incommensurable ontologies? Relationality and sovereignty as worldviews in socio-technological system transitions, Energy Res. Soc. Sci. 80 (2021) 102242, https://doi.org/10.1016/j.erss.2021.102242

[45] Greene D. Measuring energy security: Can the United States achieve oil independence? Energy Policy. 2010; **38**:1614-1621. DOI: 10.1016/j.enpol. 2009.01.041

[46] Proskuryakova L. Updating energy security and environmental policy: Energy security theories revisited. Journal of Environmental Management. 2018;**223**:203-214. DOI: 10.1016/j. jenvman.2018.06.016

[47] Hatipoglu, E., Al Muhanna, S., Efird, B., 2020. Renewables and the future of geopolitics: revisiting main concepts of international relations from the lens of renewables. Russian J. Econ. 6, 358–373.

Attempts to accentuate energy security often implicate strategies striving to safeguard or strengthen state sovereignty. The diversification of energy sources and supply routes, investments in domestic energy production, and achieving beneficial energy trade deals are a few of the national strategies to enhance energy, and consequently state's security. Energy and national security are exceptionally linked as interruptions in supply are interpreted as economic, social, and political ramifications, endangering the state's survival and presence in a multipole political system.[48]

Case studies

Case studies fulfill pivotal roles across diverse disciplines for several compelling reasons. Firstly, they vividly demonstrate the operation of theories and concepts in real-life scenarios, granting insights into actual issues. Additionally, they serve as potent problem-solving tools, facilitating researchers, students, and professionals to analyze complex situations and devise efficient solutions in certain frameworks. In the context of education, they captivate learners by clarifying critical thinking and decision-making tools, while within the realm of academic inquiry, they offer a nuanced approach to investigating phenomena by yielding extensive data to notify a wide-ranging theoretical structure.[49]

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[48] Chester, L., 2010. Conceptualising energy security and making explicit its polysemic nature. Energy Policy 38, 887–895.

[49] Gnansounou E. Assessing the energy vulnerability: Case of industrialized countries. Energy Policy. 2008;**36**: 3734-3744. DOI: 10.1016/j.enpol.2008. 07.004

On the other hand, case studies contribute to the verification or trial of existing theories through experiential evidence, intensifying our comprehension of distinct subjects. In pragmatic spheres, including business policymaking, and healthcare, they provide significant insights for knowledgeable decision formation by drawing from previous encounters.[50] Furthermore, case studies tend to accelerate effective interactions, enabling communicators to distribute clues and supreme practices with peers and stakeholders.

Overall, this form of examination serves as a precious bridge between theory and action, improving our apprehension of evident complexities and mentoring informed activity.

Case studies in countries

Case studies on countries are conducted to investigate the complicated dynamics of challenging systems, providing insights into the interaction of social, economic, political, and cultural agents within certain national conditions. The examination of individual countries assists researchers in assessing the effectiveness of policies and interferences, distinguishing standards, and trends through comparative analysis, and plotting the right course by assessing failures and successes.[51] These examinations contribute to academic research by developing empirical data and forging ahead knowledge in disciplines like political science, economics, and international affairs.[52] Moreover, case studies notify policy-making procedures, form international

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[50] Castán Broto, V. (2017). Energy sovereignty and development planning: The case of Maputo. *Mozam- bique. International Development Planning Review, 39*(3), 229–248. https://doi.org/10.3828/idpr. 2017.9

[51] Castán Broto, V. (2017). Energy sovereignty and development planning: The case of Maputo. *Mozam- bique. International Development Planning Review, 39*(3), 229–248. https://doi.org/10.3828/idpr. 2017.9

[52] Gnansounou, E., 2008. Assessing the energy vulnerability: case of industrialised countries. Energy Policy 36, 3734–3744.

connections and relations, and serve as advantageous instructional resources for students pursuing to comprehend existing paradigms of socio-political phenomena.

As far as “national energy case studies” are concerned, these surveys refer to in-depth examinations or analyses of particular specimens or instances correlated to energy policies, practices, technology breakthroughs, or struggles in a certain country or nation. Indeed, they offer to provide glances into the nation’s approach to matters such as energy production and consumption, regulation system, sustainability methods, and technology application, while ‘supplying’ with valuable lessons, effective practices, and possible solutions for confronting energy-related issues in a national environment.[53]

Case studies and renewable energy

Certain nations’ experiences regarding the sustainable energy model transition contribute to offering precious insights for every country that seeks to enhance the renewable energy portion of their electricity grid and embrace the standard capacities needed to achieve functionality.[54] Case studies on renewable energy can supply researchers with precious insights into the correlation among diverse elements like technology implementation, policy jurisdiction, environmental consequences, and

[53] Kopp SD. Politics, Markets and EU Gas Supply Security. Case Studies of the UK and Germany. Berlin, Germany: Springer; 2014

[54] Proskuryakova L. Updating energy security and environmental policy: Energy security theories revisited. Journal of Environmental Management. 2018; **223:203**-214. DOI: 10.1016/j. jenvman.2018.06.016

economic impacts. They aim to analyze scenarios regarding the effectiveness of renewable energy projects in accomplishing sustainability goals, diminishing carbon emissions, and advancing economic development. The inspection of various cases allows researchers to distinguish common trends, effective practices, and potential challenges regarding renewable energy adoption and implementation in various fields.[55] Additionally, this form of study could highlight the significance of supplementary policies, public-private sector correlation and alliance, and community commitment in intensifying the transition to an extra-renewable energy future.

For the advancement of this particular research endeavor, it is imperative to analyze each renewable energy source individually, categorizing examples by geographical area. It is acknowledged that every nation exhibits a distinct blend of energy sources within its energy portfolio[56]. This progressive breakthrough in the context of nations' energy mix has demonstrated a couple of significant characteristics and factors that accelerated this power grid evolution.

Solar power

Solar energy is considered a renewable and sustainable form of energy, as it depends on a bountiful and inexhaustible resource, the Sun. The usage of this energy source has a very slight environmental impact compared to conventional energy sources,

[55] Janssen, R. (2002), *Renewable energy into the mainstream*, OECD/IEA, Paris, 54 pp

[56] Bitsa, D. (2019). The challenge of renewable energy sources as a leader to the New Energy Order. University of Piraeus. Retrieved on September 2nd, 2023, from https://dione.lib.unipi.gr/xmlui/handle/unipi/12517

produces approximately zero emissions during operations, and contributes to decreasing the global dependence on fossil fuels for power grid and heating.[57]

Historical progress of solar energy implications

Since the 19th century, the energy harnessed from the Sun's radiation has demonstrated remarkable progress as far as implemented infrastructure is concerned. The photovoltaic repercussion was detected in 1839 by French physicist Alexandre-Edmond Becquerel. In 1876, William Grylls Adams and his colleague Richard Evans Day discovered that selenium creates electricity if it is exhibited in light.[58]
In the fullness of time, Albert Einstein described the photoelectric impact, laying the substructure for contemporary solar cell technology applications. Later on, in the 1950s, Bell Labs conceived the idea for the initial silicon photovoltaic cell. These inventions were high-priced and inefficacious, predominantly utilized in niche applications like satellites.

The oil crisis of the 1970s accelerated renewed interest in renewable energy sources and state-of-the-art techniques for implementation. Solar power was one of the main

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[57] International Energy Agency (IEA). (2015). A fundamental look at supply side energy reserves for the planet. SHC Solar update. https://www.iea-shc.org/data/sites/1/publications/2015-11-A-Fundamental-Look-at-Supply-Side-Energy-Reserves-for-the-Planet.pdf. Accessed May 2017.

[58] Duan, H.B., Zhu, L., Fan, Y., 2014. A cross-country study on the relationship between diffusion of wind and photovoltaic solar technology. Technol. Forecast. Soc. Chang. 83, 156–169.

choices, as governments invested in research in this field, arising in advancing technology accessibility.

Between the decades of the 1980s and the 1990s, advances were witnessed regarding the efficiency of materials and the cost of solar cells, but it wasn't until the 2000s that more considerable breakthroughs were generated. In the 21st century, important progress was effectuated in solar power adoption mainly because of declining costs, government motivation, and environmental concerns.

Nowadays, solar energy has experienced exceptional upgrades in photovoltaic (PV) and concentrated solar power (CSP) technologies, leading to sizable diminutions in costs and enhanced efficiency. Allocated solar emplacements on rooftops and utility-scale solar farms are more frequently witnessed, granting the decentralization of power production. In the context of technological advancement in solar infrastructure, several countries have established ambitious targets for renewable energy transition.[59]

Case studies of solar energy adoption

The following examination is concentrated in three countries elected mainly because of the high scale of solar energy implementation on their electricity grid and their commitment to expand the existing technology and acceptance.[60]

Germany

[59] Perez, et al., 2009. A Fundamental Look at Reserves for the Planet. Draft for publication in the IEA/SHC Solar update.

[60] Rothkopf, D.J., 2009. Is a green world a safe world? Not necessarily. A Guide to the Coming Green Geopolitical Crises, Foreign Policy, September/October 2009.

Germany has been a pioneer in solar energy embracement and is considered to be a leading figure in shaping the international solar industry.

Germany's achievement could be attributed partly to its bracing policy system. The country implemented feed-in tariffs in its constitutional framework in the early 2000s, ensuring fixed prices for solar electricity provided into the grid.[61] Long-term revenue assurance and incentivized rapid expansion of solar panel implementation gave investors the stimulus to proceed.

All in all, Germany's commitment to transitioning away from fossils and nuclear power is acknowledged as the "Energiewende". The nation's government introduced challenging renewable energy ambitions, incorporating escalating the share of renewables in electricity generation to 80% by 2050. Solar energy plays a pivotal role in this target. Along with public incentives, there is an outstanding public preference and support in solar energy projects, driven by environmental issues, energy security awareness, and the ambition for decentralized energy production. Community solar schemes and citizen involvement in cooperatives are common, cultivating a sense of ownership and commitment to energy transition.

Technology innovation in the German territories contributes to accomplishing the energy shift claims and the expansion of commercial enterprise. The country has been viewed as a hub for technological innovation in the solar industry. Research institutions, universities, and private companies are in constant collaboration to develop the

[61] Go˙kgo˙z F, Güvercin MT. Energy security and renewable energy efficiency in EU. Renew Sustain Energy Rev 2018;96:226–39.

efficiency of infrastructure and advanced manufacturing solutions.[62] This research background fostered the growth of an impressive solar industry ecosystem with significant solar panel manufacturers, installers, developers, and service providers.

Despite its accomplishments, Germany's solar energy sector confronts challenges like grid integration, intermittency, and the necessity for storage space. Fluctuations in policies have also caused disturbances, leading to boom-and-bust cycles in the market.[63]

China

China leads internationally in both solar energy production and facilities. It is claimed to possess the most considerable capacity of solar power in the world and is an important fabricator of solar panels and elements.[64]

The country's central executive power has enacted aspiring renewable energy projects and proffered consequential support to the sector. Financial inducements are a major part of this patronage, including policies such as feed-in tariffs, tax advantages, and subsidies for producers and project planners. The government has also developed

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[62] Martha Maria Frysztacki, Jonas Hörsch, Veit Hagenmeyer, Tom Brown, The strong effect of network resolution on electricity system models with high shares of wind and solar, Appl. Energy (ISSN: 03062619) 291 (2021) 116726, http://dx.doi.org/10.1016/j.apenergy.2021.116726.

[63] Schelly, C., Bessette, D., Brosemer, K., Gagnon, V., Arola, K. L., Fiss, A., Pearce, J. M., & Halvorsen, K. E. (2020). Energy policy for energy sovereignty: Can policy tools enhance energy sovereignty? *Solar Energy, 205*, 109–112. https://doi.org/10.1016/j.solener.2020.05.056

[64] Eisen, J. B. (2011). New energy geopolitics?: China, renewable energy, and the greentech race. Chicago-Kent Law Review, 9(86).

initiatives such as the “Golden Sun” program and the “Top Runner” program to accelerate the implementation of solar infrastructure in the territory.[65]

Golden Sun and Top Runner programs

The Chinese government established The Golden Sun project in 2009 to precipitate the development of solar power generation. The main objective was to hasten the manufacturing of grid-connected photovoltaic (PV) and concentrated solar power technologies. Long-term aims included the enlargement of the share of solar energy in the Chinese electricity grid, nurturing technological innovation, and addressing environmental apprehension by promoting the utilization of renewable energy. The program also offered financial and policy support on large-scale utility projects and distributed generation investments.[66]

The Top Runner Program, formally acknowledged as the National Energy Administration’s (NEA) “Front Runner and Benchmarking Base for Photovoltaic and Wind Power Demonstration Projects” was introduced in 2015. This incentive aimed to firm up efficiency standards and performance points to promote the assimilation of high-efficiency and superior solar PV technologies.[67] The application of innovative

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[65] Pouran, H. M. (2018). From collapsed coal mines to floating solar farms, why China’s new power stations matter. *Energy Policy, 123,* 414–420. https://doi.org/10.1016/j.enpol.2018.09.010

[66] Li K, Yuan W. The nexus between industrial growth and electricity consumption in China–New evidence from a quantile-on-quantile approach. Energy 2021;231: 120991.

[67] Zhang D, Wang J, Lin Y, Si Y, Huang C, Yang J, et al. Present situation, and future prospect of renewable energy in China. Renewable and Sustainable Energy Reviews. 2017; **76**:865-871. DOI: 10.1016/j. rser.2017.03.023

solar infrastructure like bifacial solar panels, PERC (Passivated Emitter Rear Cell) cells, and other state-of-the-art manufacturing techniques was also inspired.

These initiatives promoted the Chinese vision to expand its solar power capacity, by driving down the expense of solar energy infrastructure and production and reducing its reliance on fossil fuels for electricity generation and in the manufacturing sector.[68] China also demonstrated its commitment to renewable energy acceptance and its leadership in the international efforts for energy transition.

Apart from the implementation of certain programs to accelerate energy transition, China also invests in its manufacturing dominance. Its mastery in solar power fabrication in combination with economies of scale and technological progress has set the standards for cost diminution in solar power infrastructure. This momentum has grown solar power into a gradually competitive form of power, capable of replenishing or even replacing conventional energy sources, causing an increasingly adopted paradigm for other countries.[69] After all, it is not haphazard that China boasts the internationally grander installed capacity of solar power, combined with both utility-scale projects and distributed generation installations.

Chinese solar installations

[68] Liu J. China's renewable energy law and policy: A critical review. Renewable and Sustainable Energy Reviews. 2019; **99**:212-219. DOI: 10.1016/j.rser.2018. 10.007

[69] Wang B, Wang Q , Wei Y-M, Li Z-P. Role of renewable energy in China’s energy security and climate change mitigation: An index decomposition analysis. Renewable and Sustainable Energy Reviews. 2018;**90**:187-194. DOI: 10.1016/j.rser.2018.03.012

China has implemented multiple solar power projects in the country's territories, proving its dedication to renewable energy and especially the perpetual power of the sun.

Longyangxia Dam Solar Park

The previously mentioned project is based in Qinghai Province and is one of the most enormous solar power plants globally. It expands in an area of approximately 27 square kilometers and has an amplitude of around 850 MW.[70] This solar park harnesses both photovoltaic and concentrated solar power technologies to produce clean electricity.

Dunhuang Solar Park

This project is situated in Gansu Province and is a Chinese solar power plan of great importance. It extends across over 6 square kilometers and possesses an installed magnitude of around 550 MW. The solar park consists of spacious layouts of solar panels, taking advantage of the region's ample sunlight to generate renewable energy.[71]

Datong Solar Power Top Runner Base

The Datong Solar Power Top Runner Base is located in Shanxi Province and is considered to be one of the most innovative solar energy schemes, aimed at embracing state-of-the-art solar power technologies and enhancing energy efficiency. It demonstrates high-efficiency panels, energy storage spaces, and smart grid assimilation, aiming at existing as a role model for sustainable energy progress.[72]

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[70] Liu J. China's renewable energy law and policy: A critical review. Renewable and Sustainable Energy Reviews. 2019; **99**:212-219. DOI: 10.1016/j.rser.2018. 10.007

[71] , Hu H, Tan T, Li J. China's renewable energy goals by 2050. Environmental Development. 2016;**20**: 83-90. DOI: 10.1016/j.envdev.2016. 10.001

[72] Zhang L, Sovacool BK, Ren J, Ely A. The dragon awakens: Innovation, competition, and transition in the energy strategy of the People's Republic of China, 1949–2017. Energy Policy.

Floating Solar Farms

China has also empowered floating solar farms, especially invested in reservoirs and lakes, to maximize land utilization effectiveness and mitigate environmental repercussions. For instance, The Huainan Solar Farm in Anhui Province is one of the most sizeable floating solar projects at a global level, accompanied by an installed capacity of 150 MW.[73]

Rooftop solar installations

In addition to high-scale projects and considerable investments, China has urged the emplacement of rooftop solar panels on domestic, commercial, and manufacturing structures.

Despite its breakthroughs, China's solar power sector confronts issues associated with grid integration, condensation, and sustainability. The accelerated enlargement of solar infrastructure has tightened the nation's grid installations and magnified distress about land treatment, resource depletion, and contamination identified with solar panel manufacturing.[74]

United States

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[73] , Hu H, Tan T, Li J. China's renewable energy goals by 2050. Environmental Development. 2016;**20**: 83-90. DOI: 10.1016/j.envdev.2016. 10.001

[74] Wang B, Wang Q , Wei Y-M, Li Z-P. Role of renewable energy in China's energy security and climate change mitigation: An index decomposition analysis. Renewable and Sustainable Energy Reviews. 2018;**90**:187-194. DOI: 10.1016/j.rser.2018.03.012

The United States is considered to be a locus for solar energy advancements, with meaningful breakthroughs across miscellaneous sides of solar technology and emplacement. The country displays substantial broadening in solar energy incorporation, especially in sun-rich states like California, Arizona, and Texas. The territories of these States witnessed a rapid expansion of utility-scale solar farms, with dimensions ranging from tens to hundreds of megawatts.[75] The previously quoted projects contribute to the diversification of the nation's energy portfolio and serve to meet the government's renewable energy standards.

United States solar power initiatives

The augmentation of the utilization of Thin-Film Solar Technology has paved the way for the nation's government to become a pioneer in technologies that use lightweight, flexible materials to construct solar panels. Corporations such as First Solar and Solar Frontier have made meaningful steps to alleviate the competence and cost-effectiveness of thin-film solar cells, assembling them competitively compared to regular silicon-based panels.[76]

A significant paradigm of the implementation of thin-film solar cell technology is the Perovskite solar cells, a promising innovation due to their elevated suitability and low manufacturing expense.[77] Researchers at guiding American institutions, like the

[75] 63] Greene D. Measuring energy security: Can the United States achieve oil independence? Energy Policy. 2010; **38**:1614-1621. DOI: 10.1016/j.enpol. 2009.01.041

[76] Sivaram V, Saha S. The geopolitical implications of a clean energy future from the perspective of the United States. In: The geopolitics of renewables. Cham: Springer; 2018. p. 125–62.

[77] U.S. Chamber of Commerce. Index of U.S. Energy Security Risk: Assessing America's Vulnerabilities in a Global Energy Market. Washington D.C., USA: U.S. Chamber of Commerce; 2013. Available from: https://www.globalene rgyinstitute.org/sites/default/files/Idex %20of%20US%20Energy%20Security% 20Risk.pdf

National Renewable Energy Laboratory (NREL) and the Massachusetts Institute of Technology (MIT), have progressed significantly in enhancing the steadiness and scalability of this invention, leading the path for its commercialization.

Energy storage has been a major issue in all countries engaged in renewable energy applications and in The United States the unification of energy storage resolutions with solar power systems has remained a considerable matter. Advances in battery technology, like lithium-ion batteries and flow batteries, are examined to become the means to store excess solar energy for exploitation during times of deficient sunlight or high demand.[78] Enterprises like Tesla, with its Powerwall and Powerpack techniques, have accelerated the deployment of solar-plus-storage solutions for domestic, commercial, and utility-scale functions.[79]

Another type of invention to enhance the American application of solar energy infrastructures is the improvement of Solar Tracking Systems, an increasingly widespread contrivance that adjusts the orientation of solar panels to maximize sunlight display for the day. Novelties in solar tracking technology, encompassing dual-axis and azimuth tracking procedures, have developed the productiveness and operation of solar power plants, leading to more elevated energy surrenders and minor fees per kilowatt-hour.

[78] Sivaram V, Saha S. The geopolitical implications of a clean energy future from the perspective of the United States. In: The geopolitics of renewables. Cham: Springer; 2018. p. 125–62.

[79] Bazilian, M., Sovacool, B., Moss, T., 2017. Rethinking energy statecraft: United States foreign policy and the changing geopolitics of energy. Glob Policy 8, 422–425.

The United States, aiming to enhance the accessibility and affordability of solar power deployment for homeowners, businesses, and communities, has been a pioneer in magnifying innovative financing forms. Schemes like third-party ownership, community solar, and property-assessed clean energy (PACE) financing have aimed to incite comprehensive acceptance of solar power throughout the country's territories.[80]

A widely known financing incentive is the implementation of the federal Solar Investment Tax Credit (ITC), which has been regarded as a crucial policy tool in intensifying solar energy exploitation in the States.[81] The ITC supplies a tax credit to owners of solar energy infrastructures and was incipiently enacted in 2006 yet outspread multiple times because of its positive influence on solar vigor. In association with ITC, several States provide their exclusive incentives and financing programs, incorporating rebates, tax credits, low-interest loans, and net-metering strategies. These policies authorize solar energy installation owners to retail overstock solar electricity back to the grid.[82]

American governmental targets on solar energy applications vary from spacious utility-scale projects to more regular low-scale schemes. Formerly mentioned the community solar programs are a substantial American initiative that permits the distribution of

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[80] Sivaram, V., Saha, S., 2018. The geopolitical implications of a clean energy future from the perspective of the United States. In: The Geopolitics of Renewables. Springer, Cham, pp. 125–162.

[81] Rose McDermott, Risk-Taking in International Politics: Prospect Theory in American Foreign Policy, University of Michigan Press, Ann Arbor, MI, 1998.

[82] McLaren Duncan, Olaf Corry, The Politics and Governance of Research into Solar Geoengineering, Wiley Interdisciplinary Reviews Climate Change, 2021, p. e707.

benefits of a single solar energy system to multiple participants. By implying this project, solar energy assets are reachable to renters, low-income households, and several more individuals who may not possess appropriate rooftops for solar settlements. Even well-known federal buildings and facilities have been enriched with solar energy systems, proving the U.S. authorities' loyalty to sustainability and energy competence. Projects such as the Federal Energy Management Program and the Department of Defense's Renewable Energy Program have expedited the installation of solar panels on military bases, offices, and other national properties.[83]

Benefits from the enhancement of solar energy application on the countries' energy security and sovereignty

The expansion of solar energy applications offers countries the opportunity to diversify their energy sources, downscaling reliance on foreign-originated fossil fuels and lessen the menace related to geopolitical distress, supply discontinuation, and fluctuating fuel prices. Solar energy is a form of abundant energy source that is generated domestically and reduces dependence on external forms. In particular, the previously mentioned countries to differing extents, rely on nations with traditional energy reservoirs for their energy supply.[84]

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[83] U.S. Chamber of Commerce. Index of U.S. Energy Security Risk: Assessing America's Vulnerabilities in a Global Energy Market. Washington D.C., USA: U.S. Chamber of Commerce; 2013. Available from: https://www.globalene rgyinstitute.org/sites/default/files/Idex %20of%20US%20Energy%20Security% 20Risk.pdf

[84] Freeman, D., 2018. China and renewables: the priority of economics over geopolitics. In: Scholten, D. (Ed.), The Geopolitics of Renewables. Springer Nature, Cham, pp. 187–201

Initially, Germany as a West European nation did not have energy wealth in the conventional sense and used to import large quantities of fossils both for electricity generation and the patronage of its blossoming industry. A main oil and gas importer used to be Russia, not only for Germany but for a significant majority of European nations. However, this country's government frequently exploits its dominance in oil and natural gas exports to exert geopolitical influence, particularly over countries heavily reliant on Russian energy imports.[85] This leverage is commonly wielded as a geopolitical tool by Russian authorities, serving political agendas and satisfying political stakeholders. Following recent developments in Ukraine and ongoing energy tensions with Russia, the European Union and its member states have enacted a new energy policy favoring renewable energy sources.[86] Thanks to Repower EU, Europeans safeguarding citizens and businesses from energy supply disruptions while also aiding Ukraine by undermining Russia's military capabilities and hastening the shift toward renewable energy.[87] On the other hand, the integration of renewable energy particularly solar in the electricity grid has resulted in economic gains, as the need for costly LNG imports from northern nations like Norway has diminished, as well as imported oil reserves via pipelines from neighboring countries such as the Netherlands. In periods of high electricity demand, if renewable energy sources are incapable of fulfilling the

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[85] Rodríguez-Fern´andez L, Carvajal ABF, Ruiz-Go´mez LM. Evolution of European Union's 'energy security in gas supply during Russia–Ukraine gas crises (2006–2009). Energy Strategy Rev 2020;30:100518.

[86] Wei YM, Liang QM, Wu G, Liao H. Effects of clean and renewable energy on national energy security. In: Energy economics. Emerald Publishing Limited; 2019. p. 253–70.

[87] Rodríguez-Fern´andez L, Carvajal ABF, Ruiz-Go´mez LM. Evolution of European Union's 'energy security in gas supply during Russia–Ukraine gas crises (2006–2009). Energy Strategy Rev 2020;30:100518.

energy grid requirements, Germany imports electricity from adjacent nations like France or the Czech Republic.

On the other hand, China because of its expansive land area and large population, has significant energy requirements for administrative purposes and to support its industrial sector, which ranks among the world's largest export industries. Consequently, this country imports substantial amounts of oil and gas and relies heavily on nations experiencing internal instability, such as Saudi Arabia, Iraq, Oman, and Iran. Additionally, it collaborates with Russia on oil imports, leveraging alliances like the one with China to exert pressure on European partners and the United States.[88] The growth of solar energy applications in China has also led to a decrease in the country's carbon emissions, establishing a foundation for achieving environmental goals outlined by the UN and other nations. This advancement suggests a transition into a new era, with a greater inclination towards governance and collaboration with Western nations as equal partners.[89]

Correspondingly, the effect of solar energy on environmental and climate objectives in the United States is significant. The country after the shale gas and oil revolution is witnessed as one of the most crucial producers of fossil fuels, incapable yet to meet the broad internal demand for energy. Therefore, advancements in exploiting domestic conventional energy sources and the increased utilization of renewable energy resources have bolstered the country's geopolitical standing concerning both its

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[88] Freeman, D., 2018. China and renewables: the priority of economics over geopolitics. In: Scholten, D. (Ed.), The Geopolitics of Renewables. Springer Nature, Cham, pp. 187–201

[89] Goldthau, A., Westphal, K., Bazilian, M., Bradshaw, M., 2019. Why the energy transformation will reshape geopolitics. Paths to a low-carbon economy will create rivalries, winners and losers. Nature 569, 2–5.

surroundings and former energy suppliers.[90] While it has historically been a global leader, the country found itself in a challenging position due to its reliance on third-party nations like Iraq, Iran, and Saudi Arabia for energy.[91] This reliance led to significant oil crises in the 1970s, resulting in domestic issues and necessitating responsive policy measures. The enhanced energy independence of the United States has led to increased dominance for both the country itself and its European allies.[92]

Wind power

Wind power describes the alteration of wind energy into a meaningful type of energy, especially electricity, utilizing wind turbines. These contraptions capture the kinetic energy of the wind and convert it into mechanical power, which is afterward transformed into electricity via a generator. This useful form of energy is characterized as renewable and sustainable, as provokes no greenhouse gas emissions in the course of operations. Moreover, its growth in applicability and acceptance is escalating globally on an admirable level.[93]

[90] Wei YM, Liang QM, Wu G, Liao H. Effects of clean and renewable energy on national energy security. In: Energy economics. Emerald Publishing Limited; 2019. p. 253–70.

[91] U.S. Chamber of Commerce. Index of U.S. Energy Security Risk: Assessing America's Vulnerabilities in a Global Energy Market. Washington D.C., USA: U.S. Chamber of Commerce; 2013. Available from: https://www.globalene rgyinstitute.org/sites/default/files/Idex %20of%20US%20Energy%20Security% 20Risk.pdf

[92] Sivaram, V., Saha, S., 2018. The geopolitical implications of a clean energy future from the perspective of the United States. In: The Geopolitics of Renewables. Springer, Cham, pp. 125–162.

[93] Scholten D. The geopolitics of renewables—an introduction and expectations. In: The geopolitics of renewables. Cham: Springer; 2018. p. 1–33.

Historical progress of wind power applications

The historical progression of wind power originates in thousands of years, with primary utilizations including sailing ships and windmills, useful inventions for grinding grain and pumping water. However, the modern phase of wind power is applied to be the late 19th century, after the evolution of electricity generation.

As previously mentioned, the association of wind power installations and electricity production has commenced in the late 19th Century. During this time, the introductory electricity-generating wind turbine was constructed in Scotland in 1887 by Professor James Blyth. For more than a century, wind turbines were fundamentally operated in rural areas for electricity production, as they were extremely dominated by fossil fuels, a source characterized as remarkably cost-beneficial in comparison to other power sources at that time.

In the 1970s, the majority of the nations experienced the atrocious consequences of the global oil crises, an incident that spurred revived interest in alternative energy sources, and to a high extent renewed the attraction of wind power applications. Under this advancement, technological innovations and government initiatives effectuated significant prosperity in the wind power industry by the 1980s, and during the 1990s global expansion was retained financed by increasing turbine sizes and ameliorated efficiency.[94]

Since the start of the new millennium, several nations have shown substantial investment in wind power and widespread use of wind energy. This effort for energy sources shift is highly accelerated by the advanced competitiveness of renewables in

[94] Eyraud, L., Wane, A.A., Zhang, C., Clements, B., 2011. Who's going green and why? Trends and determinants of green investment. IMF working paper. WP/11/296.

comparison to conventional fossil fuels and a groundbreaking era of global environmental awareness and incentives. After the 2010s, significant investments to harness the power of the wind were also witnessed in offshore wind farms, accompanied by pertinent technological advancements.[95]

Offshore wind power

Wind power emplacements have gone through remarkable expansions too, as new technology breakthroughs provide new areas for exploitation. The era of offshore wind power has emerged and illustrates significant growth, especially in Europe and progressively in other nations like the United States and Asian regions. This evolution could not be possible without certain factors such as technological state-of-the-art equipment, larger and more powerful turbines, and advantageous offshore wind conditions. In general, offshore wind power relates to the electricity generation from wind turbines situated in bodies of water, mainly in oceans and seas.[96] These innovative forms of wind turbines are specifically manufactured and installed to exploit the strong and steady winds located over water bodies. Offshore wind farms are composed of numerous turbines interconnected in an onshore electrical network, while electricity is dispatched to continental regions via underwater cables.[97] Wind power generated by

[95] Khan K, Su CW, Rehman AU, Ullah R. Is technological innovation a driver of renewable energy? Technol Soc 2022;70:102044.

[96] CambridgeIP, 2014. The Acceleration of Climate Change and Mitigation Technologies: Intellectual Property Trends in the Renewable Energy Landscape. Global Challenges Brief. WIPO, Geneva [Online]. www.wipo.int/globalchallenges.

[97] Sovacool BK, Tambo T. Comparing consumer perceptions of energy security, policy, and low-carbon technology: Insights from Denmark. Energy Research and Social Science. 2016;**11**:79-91. DOI: 10.1016/j.erss.2015. 08.010

offshore turbines is capable of generating considerable amounts of renewable energy and is progressively being enhanced as a major component of the “cleaner” energy transition.

Case studies of wind energy adoption

The following examination is concentrated in countries elected mainly because of the high scale of solar energy implementation on their electricity grid, their commitment to expanding the existing technology and acceptance, and especially the usage of wind power as a means to enter a new era in their conviction about energy usage.

Denmark

Denmark, situated in Northern Europe, is a Nordic country with Copenhagen as its capital. Notable for its high quality of life, sturdy social welfare system, and progressive environmental policies, Denmark comprises the Jutland Peninsula and various islands, equaling approximately 42,951 square kilometers.[98] Danish has been recognized as the official language while the currency is still the Danish krone, as the Danish governments have opted to retain the national currency and averted the adaptation of the euro unlike the majority of European Union countries that have implemented the joint currency in their internal markets. This deviation grants Denmark the potential to

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[98] CambridgeIP, 2014. The Acceleration of Climate Change and Mitigation Technologies: Intellectual Property Trends in the Renewable Energy Landscape. Global Challenges Brief. WIPO, Geneva [Online]. www.wipo.int/globalchallenges.

manage its monetary policy better, while simultaneously, the country benefits from the common economic policies of the European Union.

Denmark stands out as an outstanding example of embracing and implementing successfully renewable energy. Comprehensively recognized for its efficient utilization of wind power, Denmark has proceeded significantly into implementing a sustainable energy model.[99] Denmark as a European Union member has adopted various environmental policies, notably the Energy Agreement. In general, the latter term refers to a formal understanding between parties, that shapes the conditions of production, distribution, or energy consumption. The conditions covered varied from trade and investment to technology-related issues and environmental considerations concerning the generation and utilization of energy.[100]

Denmark has been the pioneer of wind power among its European colleagues, as has incentivized significant investments in this form of power, in a context where renewables possess a notable proportion of the state's overall electricity generation.

This breakthrough is an aftermath of coordinated initiatives between the public and the private sectors, in association with robust public policies and support.[101]

The Danish government enhances the above venture by setting and implementing policies that serve ambitious aims regarding renewable energy. The main aspect of these strategies is to guide the state towards a low-carbon and green energy system. By

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[99] Danish Government. Energy Strategy 2050—From Coal, Oil and Gas to Green Energy. 2011. Available from: http://www.danishwaterforum.dk/ activities/Climate%20change/Dansk_ Energistrategi_2050_febr.2011.pdf [Accessed: 21 October 2019]

[100] Janssen, R. (2002), *Renewable energy into the mainstream*, OECD/IEA, Paris, 54 pp.

[101] Sovacool BK, Tambo T. Comparing consumer perceptions of energy security, policy, and low-carbon technology: Insights from Denmark. Energy Research and Social Science. 2016; **11:79**-91. DOI: 10.1016/j.erss.2015. 08.010

2050, the gradual independence from conventional energy sources aims to achieve an absolute percentage of 100%, successfully replaced by renewable energy supply to a corresponding level.[102]

Danish wind power installations

Horns Rev 1 and 2

These two projects are samples of the Danish endeavor to accelerate the application of offshore wind power and are located on the West coast of the country, engineered by Vattenfall. The Horns Rev 1 was completed in 2002 and by that time was characterized as the internationally largest offshore wind farm. The Horns Rev 2 broke the record of the capacity of the previously launched project in 2009.

Anholt Offshore Wind Farm

The Anholt Offshore Wind Farm is situated in the Kattegat strait between Denmark and Sweden and was formed by Orsted, a company formerly known as DONG Energy. This project possesses a capacity of 400 megawatts and was introduced in 2013, as one of the highest-scale Danish wind power schemes.[103]

Kriegers Flak Offshore Wind Farm and Hovsore Wind Farm

[102] UNEP/OECD/IEA (2001), *Workshop on baseline methodologies - possibilities for standardized baselines for JI and the CDM – Chairman's recommendations and Workshop report*, Workshop on "Baseline Methodologies", Roskilde, Denmark, 7-9 May 2001, UNEP/OECD/IEA, Paris.

[103] Energy Information Administration (IEA), 2016. International Energy Outlook 2016 (Washington DC).

Portraying a capacity of 600 megawatts, the Kriegers Flak Offshore Wind Farm is located in the Baltic Sea and was recently constructed as its operations initiated in 2021. The Hovsore Wind Farm is positioned on the west coast of Jutland and is determined as a testing and research ground for the invention of brand-new, technologically advanced turbine prototypes and developments.[104] Siemens Gamesa the company that invested in that scheme aimed to contribute to the Danish innovation policy.

Middelgrunden Offshore Wind Farm

This wind energy application project owns 20 turbines with a sum capacity of 40 megawatts, situated near Copenhagen. It is a major example of the country's community-owned wind infrastructure and a policy plan for individuals' involvement in renewable energy transition. Citizens are the holders of an important stake in this project.

These projects showcase Denmark's leading role in offshore wind energy and its dedication to sustainable energy advancement, characterized by innovation, cooperation, and strategic foresight.

India

[104] Matsumoto K, Doumpos M, Andriosopoulos K. Historical energy security performance in EU countries. Renewable and Sustainable Energy Reviews. 2018;**82**: 1737-1748. DOI: 10.1016/j.rser.2017. 06.058

India in recent years has made a major modification in its handling of energy sources and elevated wind energy growth as a priority, as the country has arisen as one of the most rapidly growing markets for wind internationally. In particular, the majority of recent wind power installations have been manufactured over the past two decades.[105] Furthermore, the geographical landscape of India provides an ideal foundation to enhance investments related to wind energy caption and convention. Nowadays, the majority of India's existing wind energy capacity originates from onshore wind farms, yet accumulating interest has risen in the exploration of offshore wind energy potential alongside the nation's coastline.[106]

This furtherance is definitely a positive effect of the outstanding Indian government's support of wind energy development, offering multiple financial incentives to individuals and firms to promote relevant investments.[107] These policies include feed-in tariffs, generation-based incentives, tax benefits, and renewable purchase obligations for utilities. Besides, the Indian central governmental system must accelerate the energy transition to be capable of fulfilling the ambitious renewable energy targets that have been set, including an intention of achieving 175 gigawatts (GW) of renewable energy capacity by 2025, with a crucial portion derived from wind energy.[108]

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[105] Westphal, K., Susanne, D., 2015. *Global Energy Markets In Transition: Implications For Geopolitics, Economy And Environment*, Global Trends 2015. Prospects for World Society.

[106] Scholten D. The geopolitics of renewables—an introduction and expectations. In: The geopolitics of renewables. Cham: Springer; 2018. p. 1–33.

[107] Eyraud, L., Wane, A.A., Zhang, C., Clements, B., 2011. Who's going green and why? Trends and determinants of green investment. IMF working paper. WP/11/296.

[108] Wei YM, Liang QM, Wu G, Liao H. Effects of clean and renewable energy on national energy security. In: Energy economics. Emerald Publishing Limited; 2019. p. 253–70.

Alongside governmental support, India has embraced advanced wind turbine technologies, such as the deployment of more effective turbines with higher hub heights and rotor diameters, as well as proceed to the enhancement of the integration of digital monitoring and control systems.

The progress in the sector has attracted important funding from domestic and international players in Indian territories. Government agencies, private companies, and foreign investors collaborate effectively in the growth and innovation of the Indian wind energy area.

Wind energy applications in India

Jaisalmer Wind Park (Rajasthan)

This project is considered to be one of the greatest wind power plants in the country and is located in the Jaisalmer district of Rajasthan. It consists of multiple wind farms with a cumulative capacity of several hundred megawatts.[109]

Muppandal Wind Farm (Tamil Nadu)

Muppandal was one of the first attempts of the Indian wind sector to apply internally relevant technology in a wind farm. It is considered to be the senior and yet most spacious wind farm application in the country. It has been operated since the 1980s and produces a high percentage of India’s wind power.

Tehri-Garhwal Wind Farm (Uttarakhand) and Kutch Wind Park (Gujarat)

[109] Energy Information Administration (IEA), 2016. International Energy Outlook 2016 (Washington DC).

The first one is a wind farm located in Tehri-Garhwal a part of the Uttarakhand district and the second is one of the multiple wind farm projects that are under construction in the Gujarat area. The Kutch Wind Park comprises various smaller-scale wind farms.

All in all, in India's territory state-of-the-art wind farms are constructed from scratch as a component of a more extensive environmental and energy governmental policy. However, the existing "veteran" wind farms are also being reinvigorated, by placing more technologically advanced and efficient turbines. This empowerment of the old infrastructure assures the enhancement of the performance and the elongation of the operational lifespan of the machines. Karnataka and Maharashtra are examples of this policy.[110]

The United Kingdom (UK)

The United Kingdom is characterized as a dynamic geopolitical player in the European continent due to its geographical position and durable manufacturing industry and economy. The country is also recognized as a leader in wind energy investments in Europe, particularly in offshore projects, as a means to promote the green transition in the English territories. In particular, the most sizeable installed offshore wind farms are located in that area.[111]

This energy transition era is highly promoted by the UK government, which has set aspiring objectives regarding the enlargement of wind capacity in the energy grid of the

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[110] Khan K, Su CW, Rehman AU, Ullah R. Is technological innovation a driver of renewable energy? Technol Soc 2022;70:102044.

[111] Cai Y, Wu Y. Time-varying interactions between geopolitical risks and renewable energy consumption. Int Rev Econ Finance 2021;74:116–37.

country, investing extensively in the offshore sector. Despite the decision to separate its political positioning from its European associators, the UK appears to align with the objectives established regarding energy and transition within both the European Union and the United Nations, where it holds an equal membership status.[112] Precisely, the accomplishment of net-zero carbons emissions by 2050 is the core intention of the nation's commitment to wind energy amplification, with a midway goal of doubling the offshore wind infrastructure by 2030.

To reinforce the aforementioned goals established at the European or international level, the implementation of corresponding domestic policies at the state level is also necessary. The UK government has enforced supplementary policies to enhance wind energy implementation, incorporating Contracts for Difference (CfD) auctions, a means to furnish steady long-term prices for renewable energy production.[113] These governmental incentives aim to attract the corresponding wind energy investments. Among others, the country has toughened up the existing grid infrastructure or has developed in cases needed new one, capable of supporting the integration of renewables. This endeavor involves advancements in grid handling, interconnection with surrounding countries, and storage amplification.

The state-of-the-art offshore wind energy technology innovations and the attempts to accelerate the procedures for project development have 'seduced' meaningful investing in the country from companies that reap the benefit of international recognition. Firms

[112] Gökgöz F, Güvercin MT. Energy security and renewable energy efficiency in EU. Renew Sustain Energy Rev 2018;96:226–39.

[113] Eyraud, L., Wane, A.A., Zhang, C., Clements, B., 2011. Who's going green and why? Trends and determinants of green investment. IMF working paper. WP/11/296.

like Orsted, SEE Renewables, and Equinor are in the driving seat of the promotion of the UK's wind projects.[114]

Wind energy applications in the UK

Wind energy is broadly utilized across the UK, having an important effect on the country's renewable energy mix. The UK is an international pioneer in offshore wind power, tapping into the strong winds of the North Sea and Irish Sea. Onshore wind farms, especially based in Scotland, Wales, and Northern Ireland, also play a crucial role in providing electricity to local communities and the national grid.[115] Small-scale wind turbines positioned in residential areas produce household electricity, while industrial facilities benefit from wind power for their operations. Hybrid systems, associating wind with solar or battery storage, offer flexibility, mainly in remote regions.[116] Ongoing research and technological advancement aim to enhance turbine efficiency and integrate wind power seamlessly into the grid. These multiple applications highlight the importance and adaptability of wind energy in the UK's transition to cleaner energy sources.

Hornsea Project One

This offshore wind farm is considered to be the most spacious one globally and is situated off the coast of Yorkshire. The Hornsea Project One was constructed by Orsted,

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[114] Westphal, K., Susanne, D., 2015. *Global Energy Markets In Transition: Implications For Geopolitics, Economy And Environment*, Global Trends 2015. Prospects for World Society.

[115] Correlje A, Van der Linde C. Energy supply security and geopolitics: a European perspective. Energy Pol 2006;34(5):532–43.

[116] CambridgeIP, 2014. The Acceleration of Climate Change and Mitigation Technologies: Intellectual Property Trends in the Renewable Energy Landscape. Global Challenges Brief. WIPO, Geneva [Online]. www.wipo.int/globalchallenges.

with a capacity of 1.2 gigawatts and 174 turbine volumes in an area of 407 square kilometers.[117]

Dogger Bank Wind Farm

The previously mentioned investment was a joint venture between SSE Renewables and Equinor and was separated chronically into three parts: Dogger Bank A, B, and C. Situated in the North Sea, this project's combined capacity appears to be 3,6 Gigawatts and the completion of the construction activities will highlight this wind farm as the largest existing offshore one on a global scale.[118]

Beatrice Offshore Wind Farm

A joint venture between SEE Renewables, Copenhagen Infrastructure Partners, and Red Rock Power is also the Beatrice Offshore Wind Farm, pointed off the northeast coast of Scotland. The 559 MW capacity offers clean renewable energy to almost 450,000 households, playing a major part in achieving Scottish renewable energy objectives.[119]

Benefits from the enhancement of wind energy application on the countries' energy security and sovereignty

In general, the countries' transition to wind power represents a strategic decision that not only aligns with its commitment to combat climate change but also reinforces its

[117] Energy Information Administration (IEA), 2016. International Energy Outlook 2016 (Washington DC).

[118] Khan K, Su CW, Rehman AU, Ullah R. Is technological innovation a driver of renewable energy? Technol Soc 2022;70:102044.

[119] Scholten D. The geopolitics of renewables—an introduction and expectations. In: The geopolitics of renewables. Cham: Springer; 2018. p. 1–33.

sovereignty and resilience in the face of evolving energy challenges on the global stage.[120]

Initially, Denmark’s deliberate investment in wind power has reshaped its energy sector, allowing for a significant increase in domestically sourced renewable electricity. Utilizing wind energy has lessened Denmark's reliance on imported coal, oil, and natural gas, thereby decreasing its dependence on external energy providers, such as Russia, Norway, and oil-rich countries in the Middle East.[121]

The transition to renewable energy sources, particularly wind power, has bolstered Denmark's energy security by diversifying its energy mix and reducing the risks associated with dependence on fossil fuel imports. With wind power playing an increasingly significant role in its energy portfolio, Denmark has mitigated its vulnerability to supply disruptions, geopolitical tensions, and fluctuations in global energy prices.[122]

Furthermore, Denmark's status as a net exporter of wind energy amplifies its energy independence and economic resilience. Surplus wind power generated during peak production periods can be exported to neighboring countries through interconnections, not only alleviating Denmark's excess supply but also generating revenue and bolstering its influence in regional energy markets.

Moreover, Denmark’s position as a net exporter of wind energy further enhances its energy independence and economic stability. Excess wind power generated during

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[120] Su CW, Khan K, Umar M, Zhang W. Does renewable energy redefine geopolitical risks? Energy Pol 2021;158:112566.

[121] Scholten D. The geopolitics of renewables—an introduction and expectations. In: The geopolitics of renewables. Cham: Springer; 2018. p. 1–33.

[122] Go˙kgo¨z F, Güvercin MT. Energy security and renewable energy efficiency in EU. Renew Sustain Energy Rev 2018;96:226–39.

periods of high production can be exported to neighboring countries through interconnectors, not only reducing Denmark's surplus but also generating revenue and strengthening its influence in regional energy markets.

India's energy sources diversification is also a geopolitical advantage against its known reputation as a globally major polluter in terms of greenhouse gas emissions. Despite the fact that historically its per capital emissions are characterized as significantly inferior to most west European countries, its enormous population number and accelerated industrialization have caused a reinforcement in overall emissions. The country's deliberate shift to renewable energy sources is mainly an effort to decarbonize the economy and electricity generation and prove that India is moving towards a new era of international relations and cooperation. The cleaner energy system is capable of composing a foreign investments' fertile ground.[123]

As a considerable importer of fossil fuels and especially coal, oil and natural gas for electricity generation, India faces issues of energy security and sovereignty due to its high scale dependence from a variety of fossils producers. Saudi Arabia, Iraq, Iran, and Nigeria are important suppliers of crude oil, yet as mentioned in the paradigm of United States are also characterized as an unstable geopolitical environment, causing concerns about energy supply continuity. On the other hand, the Liquefied Natural Gas (LNG) imported from countries such as Qatar, The United States, Australia, and Russia they perpetuate the already existing environmental problems of conventional energy sources

[123] Speirs, J., McGlade, C., Slade, R., 2015. Uncertainty in the availability of natural resources: fossil fuels, critical metals and biomass. Energy Policy 87, 654–664. http://dx.doi.org/10.1016/j.enpol.2015.02.031. ISSN 0301-4215.
US Department of Energy, 2001. Energy in Brief.

at an even higher acquisition price and do not create the conditions for transition to a new era of energy production and utilization.[124]

The power supply of uranium for the country's nuclear power facilities raises an equal concern for the management of this source of energy. India's nuclear power program encounters various challenges, including safety concerns, public opposition, cost overruns, supply chain issues, nuclear liability effects, waste management challenges, and limitations in international cooperation due to its non-signatory status to the Nuclear Non-Proliferation Treaty (NPT).[125] These challenges, ranging from safety and financial issues to regulatory and geopolitical factors, necessitate careful management and resolution for the sustainable development of nuclear energy in India and yet prove that nuclear energy is not the most suitable means of energy transition for the country.

The shift towards wind energy in the United Kingdom has notable impacts on both its energy security and sovereignty.[126] By reducing its need for imported fossil fuels, especially from unstable regions, the UK strengthens its energy security. The country along with its European colleagues used to be remarkably independent of fossil imports by Nigeria, Kazakhstan, and Nigeria as well as Russia, in times of constant threat for European states for imminent supply interruptions in cases of non-fulfillment of Russian geopolitical goals.

Utilizing domestic wind resources also bolsters the country's sovereignty by lessening reliance on external energy suppliers, thus mitigating the risks associated with supply disruptions and market fluctuations.[127] Additionally, the UK's leadership in offshore

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[124] Vakulchuk, R., Overland, I., Scholten, D., 2020. Renewable energy and geopolitics: a review. Renew. Sustain. Energy Rev. 122, 109547.

[125] Chevalier, J., & Geoffron, P. (2013). The new energy crisis: Climate, economics, and geopolitics.

[126] Correlje A, Van der Linde C. Energy supply security and geopolitics: a European perspective. Energy Pol 2006;34(5):532–43.

wind technology enhances its influence in both regional and global energy markets, further solidifying its energy sovereignty and economic resilience. Overall, the transition to wind energy fosters a more secure and independent energy future for the United Kingdom.[128]

Hydropower

Hydropower is considered to be a significant source of renewable energy, as a bunch of countries rely greatly on this fuel as a major component of their energy mix. However, due to emerging environmental concerns and restricted convenient sites for upcoming constructions, its growth has been limited to a lower percentage. Nevertheless, continuous efforts are being made to optimize the existing hydropower facilities and investigate state-of-the-art and low-impact hydro equipment technologies mainly in the territories of the higher hydropower percentage nations. Beneficial geographic characteristics are the prerequisite element for hydropower investments, but factors such as energy demand and diversification of energy sources also play a crucial role.[129]

Historical progress of hydropower installations

Hydropower installations have gone through an important expansion throughout time. In the late 19th and early 20th centuries, little-scale hydropower infrastructure projects

[128] Paravantis, J. A., & Kontoulis, N. (2020). Energy security and renewable energy: a geopolitical perspective. In Renewable Energy-Resources, Challenges and Applications. IntechOpen.

[129] Benjamin K. Sovacool, Go ̇tz Walter, Internationalizing the political economy of hydroelectricity: security, development, and sustainability in hydropower states, Rev. Int. Polit. Econ. 26 (1) (2019) 49–79. Winter.

were witnessed mainly for regional power generation. Across the decades, as technology was at the forefront and the electricity demand intensified, larger-scale applications appeared.[130]

During the 20th century, the urgency for trustworthy and renewable energy sources accelerated the internationally driven flow for the construction of hydroelectric power plants and dams. These technological advancements were usually considered to be emblems of development and economic evolution, as they were an important part of electrifying rural areas and agricultural industries. Through the years and especially after the rise of the current century, the focus relocated not only to the expansion of the number of hydroelectric projects but also to the refinement of the efficiency of brand-new and existing infrastructure.[131] The aspiration highlights the importance of shrinking the environmental footprints, harmonizing hydropower technology with other renewables, and spreading the interest in small-scale and micro hydropower projects in distant and off-grid territories.[132]

Case studies of hydropower adoption

The following examination focuses on countries selected primarily for their extensive integration of hydropower into their electricity grids, their dedication to advancing this

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[130] llabban, O., Haitham, A.-R., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. Renewable and Sustainable Energy Reviews, 39, 748–764.

[131] Scholten, D.J., 2013. The reliability of energy infrastructures; the organizational require- ments of technical operations. Compet. Regul. Netw. Ind. 14 (2), 173–205 (special issue).

[132] Haas, R., Eichhammer, W., Huber, C., Langniss, O., Lorenzoni, A., Madlener, R., et al. (2004). How to promote renewable energy systems successfully and effectively. Energy Policy, 32(6), 833–839.

technology and its acceptance, and notably, their utilization of hydropower as a catalyst for transitioning into a new era of energy consumption beliefs.[133]

Canada

Canada is considered to be an international actor in the field of hydropower facilities from multiple perspectives. An important element for a country to proceed to such infrastructure production is the existing landscape. Canada possesses ample water resources, as the country is composed of plenty rivers and lakes, offering numerous chances for hydropower application.[134] Secondly, as it is mentioned before, Canada has been historically associated with such technology updates and investments in hydropower activities, hosting large-scale schemes for several years. These projects showcase both governmental and private sector dedication to utilizing hydropower's potential for generating electricity. As the time passes by, the installed capacity of the country proceeds to be accelerated to the point that Canada is witnessed as the second-largest producer of hydropower globally. It is not by chance that a significant proportion of electricity production originates from hydroelectric sources.

On the other hand, the Canadian government aims to support the expansion of the sector without minimizing the quality of the environment. The central governance is actively encouraging the increase in hydropower capacity as a component of its strategy to shift

[133] Grin, J., Rotmans, J., Schot, J., Geels, F., & Loorbach, D. (2010). Transitions to sustainable development-Part 1. New directions in the study of long term transformative change. New York: Routledge.

[134] National Renewable Energy Laboratory (NREL). (2020). Global renewable energy development. Washington.

towards cleaner and more sustainable energy sources. The combination of the hydropower advancement and the environmental protection is achieved mainly by implementing regulatory frameworks. The enacted regulations focus also on the intensification of the community advantages.[135]

The nation's extensive engagement in hydroelectric projects has led to a concurrent influx of expertise and technology firms specializing in this domain. The Canadian expertise in the relevant technology and engineering is distinguished in a global scale.[136] The country’s firms are involved in hydroelectric investments widely, as they do not only share their expertise within the country but also extend their knowledge abroad to their counterparts, by providing technology and equipment.[137]

The global acceptance and transition toward renewable energy are crucial aspects in assessing the effectiveness of renewable energy implementations. In Canada, hydroelectricity enjoys widespread social acceptance, with the world acknowledging its usage and showing interest in participating in such projects.[138]

Hydropower applications in Canada

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[135] Eyraud, L., Wane, A.A., Zhang, C., Clements, B., 2011. Who’s going green and why? Trends and determinants of green investment. IMF working paper. WP/11/296.

[136] Khan K, Su CW, Rehman AU, Ullah R. Is technological innovation a driver of renewable energy? Technol Soc 2022;70:102044.

[137] ScholtenD,BazilianM,OverlandI,WestphalK.Thegeopoliticsofrenewables:new board, new game. Energy Pol 2020;138:111059.

[138] Nie PY, Yang YC. Renewable energy strategies and energy security. J Renew Sustain Energy 2016;8(6):065903.

James Bay Project and La Grande Complex

This Canadian scheme is determined as one of the most extensive hydroelectric operations, as it assembles multiple smaller in scale power stations and reservoirs. An approximately early project and principally pioneering for the time of its construction in the 1970s, it is still witnessed as one of the most extensive hydroelectric projects globally, located in the Northern Quebec. Located in the same area is the La Grande Complex, a part of the wider James Bay Complex. The extensive network of power stations and reservoirs contributes to the significant potential for electricity generation, ultimately supplying electricity to a wide region.[139]

Manitoba Hydro Projects

Numerous hydroelectric projects are located in this region mainly due to its ideal for such projects landscape. The Limestone Generating Station, the Kettle Generating Station, and the Keeyask Generating Station are situated in the above area as their aim was to take advantage of the flowing power of the Nelson and Winnipeg Rivers to produce electrical power.

Site C Clean Energy Project

This hydropower infrastructure is a state-of-the-art plan near the Peace River in the British Columbia. This under construction scheme when concluded will have the

[139] IEA. In: Renewable power's growth is being turbocharged as countries seek to strengthen energy security; 2022. https://www.iea.org/news/renewable-power-s- growth-is-being-turbocharged-as-countries-seek-to-strengthen-energy- security.

capability to fulfill a substantial percentage of the region’s electricity needs, supplying a growing consuming area.

Newfoundland and Labrador Hydro Projects

These districts are characterized by a notable concentration of hydroelectric projects utilizing the Churchill River to produce electricity, serving both local demands and facilitating trade in external markets. The Churchill Falls Generating Station and the Lower Churchill Project are two notable representatives.

Brazil

Hydropower is a vital source of electricity for the Brazilian territory, as the country is considered to possess an extremely suitable environment for the expansion of such infrastructure projects. Brazil has a plentiful supply of water resources, consisting of enormous rivers such as the Amazon and the Parana, turning the landscape into the ideal prototype for hydropower generation.[140]

Numerous investors have capitalized on the favorable conditions mentioned above, making substantial investments in this sector within the country. It's no accident that Brazil ranks among the top countries in implementing hydroelectric energy production. Hosting a large-scale flagship project effectively showcases the government's endorsement of such production methods. Brazil, like many nations, is mindful of the environmental impact of conventional energy sources. Proposing hydropower as the primary energy source and transitioning towards a cleaner and more sustainable

[140] Eyraud, L., Wane, A.A., Zhang, C., Clements, B., 2011. Who’s going green and why? Trends and determinants of green investment. IMF working paper. WP/11/296.

electrical system, the country heavily promotes hydropower.[141] This approach signifies Brazil's commitment to transitioning towards a less energy-polluting future through its energy policy.

Simultaneously, the government must address social pressure stemming from the necessity of deforestation, environmental intervention, and the interference of the indigenous communities to implement such projects. While the public acknowledges the benefits of transitioning to hydroelectricity, they express disapproval of the environmental impact.[142] Mitigating the adverse effects to garner social acceptance is a primary objective, achieved in part through international collaborations.

All in all, hydropower plays a vital role in Brazil's regional development by generating employment opportunities, facilitating infrastructure development, and attracting investments to surrounding regions. Concurrently, Brazil leverages its hydropower capabilities to export electricity, particularly to neighboring countries like Paraguay, through international agreements and alliances.[143]

Hydropower applications in Brazil

Itaipu Dam

The formerly mentioned project is witnessed to be one of the greatest hydropower infrastructure schemes in the world. It is situated in the Parana River on the border

[141] Su, C.W., Yuan, X., Tao, R., Umar, M., 2021a. Can new energy vehicles help to achieve carbon neutrality targets? J. Environ. Manag. 297, 113348.

[142] Laird, F.N., 2013. Against transitions? Uncovering conflicts in changing energy systems. Sci. Cult. 22 (2), 149–156.

[143] Hache, E., 2018. Do renewable energies improve energy security in the long run? Int. Econ. 156, 127–135.

between Brazil and Paraguay and holds a sizeable electricity-producing capacity, which fulfills the constantly accelerating power needs of the country, as well as serving as a useful and lucrative exporting good.[144]

Belo Monte Dam

The Belo Monte Dame, comparable in scale to the aforementioned project, remains widely regarded as one of Brazil's largest hydroelectric endeavors. Given its placement within the Amazon rainforest, the project elicits a mix of adverse and favorable outcomes, encompassing both its environmental repercussions on the unique ecosystem and its substantial role in bolstering electricity production within Brazil.

Tucurui Dam

Mainly mentioned due to its historical importance as one of the earliest hydropower infrastructure projects in the country, Tucurui Dam also stands out for its considerable extent. As it is based on the Tocantins River in the northern region of Brazil, these hydropower facilities provide electricity and serve a substantial part of the energy needs primarily to the territory situated, in proportion to its generating capacity.

Sao Simao Dam and Jirau & Santo Antonio Dams

Sao Simao Dam, a consortium of energy firms, is alleged to be another exemplification of hydropower exploitation in the Brazilian territories, as well as Jirau & Santo Antonio Dams, located similarly in a rainforest. The two recently mentioned installations, regarding their proximity to the Madeira River in the Amazon ecosystem, albeit with the dispute for their environmental footprint and social impact on the native populations.[145]

[144] Hoggett, R., 2014. Technology scale and supply chains in a secure, affordable and low carbon energy transition. Appl. Energy 123, 296–306.

[145] Rothkopf, D., 2009. Is a Green World a Safe World? Not Necessarily. A Guide to the Coming Green Geopolitical Crises. Foreign Policy (September/October).

Norway

Norway's dedication to transitioning to renewable energy sources, including wind and hydropower, is evident in its efforts to achieve the European goal of phasing out fossil fuels by 2050, possibly as early as 2035. This commitment underscores Norway's proactive stance toward embracing clean energy solutions and instates the country as an international pioneer and leader in the shift towards renewables.[146]

The country, similarly, to the previously examined nations, takes advantage of its diverse landscape to produce electricity by utilizing the potency of the existing abundant rivers, positioned in mountainous space[147]. The government's dedication to the energy and environmental targets propelled the hastening of the expedited implementation of suitable projects and the establishment of favorable conditions to attract both foreign and domestic investments, often with governmental involvement, financing a portion of them or providing subsidized incentives.[148]

In addition to advancing towards an energy-neutral future, the use of hydropower in the country fosters the growth of a new sector for investment, employment opportunities, and the development of technological advancements. These innovations, exported

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[146] Matsumoto K, Doumpos M, Andriosopoulos K. Historical energy security performance in EU countries. Renewable and Sustainable Energy Reviews. 2018;**82**: 1737-1748. DOI: 10.1016/j.rser.2017. 06.058

[147] Gibbs, Walter (2010-08-17). Norway hydro can aid Europe move to renewables-IEA, *Fox Business (FOX News Network)*.

[148] Gullberg, A.T., 2013. The political feasibility of Norway as the 'green battery' of Europe. Energ Policy 57, 615–623.

abroad, generate revenue for the state while also benefiting related industries such as engineering and construction.[149] The placed interconnectors assist in the exportation of surplus-producing electricity to the neighboring countries.[150]

Norwegian applications of hydropower[151]

Hardangerjøkulen Hydroelectric Power Station

This project is considered to be a paradigm of the country's largest hydroelectric infrastructure schemes in terms of capacity and contribution to Norway's electricity mix. Utilizing the power activity of the Hardangerjokulen glacier, one of the most sizeable ice caps in the territory, to produce energy, this power station generates electricity regionally by exploiting the meltwater in the area's sheer landscape.

Rauma and Øvre Forsland Hydroelectric Power Stations

The initial cited infrastructure assets, the Rauma one, is situated in the More og Romsdal County, utilizing the effectiveness of the Rauma River, given its reputation as a waterway of plentiful flow and active currents. It is regarded as a notable instance of the amalgamation of Norwegian technological advancement with the suitable natural surroundings.

The Øvre Forsland Hydroelectric Power Station stands out for its eco-friendly operational design, promoting environmental sustainability despite its smaller scale

149 Seidler, C., 2012. Renewable Energy Ambitions: Norway Wants to Become Europe's Battery. Retrieved online on 20 October 2023 at: http://www.spiegel.de/international/europe/ norway-wants-to-offer-hydroelectric-resources-to-europe-a-835037.html

150 Gullberg, A. T., Ohlhorst, D., & Schreurs, M. (2014). Towards a low carbon energy future—Renewable energy cooperation between Germany and Norway. Renewable Energy, 68, 216– 222.

151 Gullberg, A.T., Ohlhorst, D., Schreurs, M., 2014. Towards a low carbon energy future–renewable energy cooperation between Germany and Norway. Renew. Energy 68, 216–222.

compared to other projects. Its unique characteristic specified to be the advantageousness of the semi-underwater turbine, a pioneering application which reduces the disturbance of the river's environment, at the same time that accelerates the energy production performance. Moreover, the utilization of state-of-the-art turbine designs strengthens the exertion for sustainability optimization.

Bakka Hydroelectric Power Station

Based in the Sogn og Fjordane County, this hydropower application project represents the early Norwegian efforts for energy transition to renewables, as early as the 20th century. Beyond its historical importance to the nation, the project embodies Norway's dedication to establishing resilient and consistently performing energy parks. Despite its age, the specific project continues to contribute significantly to the country's energy supply. Norway showcases its innovative approach to transitioning by preserving and refurbishing its historic infrastructure with meticulous planning and execution, addressing existing challenges with cutting-edge solutions for its time.[152]

Benefits from the enhancement of hydropower application on the countries' energy security and sovereignty

As renewable energy sources become more integrated into local energy portfolios, regions achieve greater autonomy in energy supply and diversify their options for energy security. This development stimulates new investment sectors within countries, attracting domestic and international investors and fostering the growth of

[152] C. Schelly, V. Gagnon, K. Arola, A. Fiss, M. Schaefer, K.E. Halvorsen, Cultural imaginaries or incommensurable ontologies? Relationality and sovereignty as worldviews in socio-technological system transitions, Energy Res. Soc. Sci. 80 (2021) 102242, https://doi.org/10.1016/j.erss.2021.102242

technological innovation and job opportunities.[153] Additionally, the expansion of renewable energy benefits neighboring industries and contributes to the overall economic prosperity of the country. Over time, this growth facilitates the potential for energy and technological exports, further enhancing the country's economic viability.

More particularly, since the era of traditional energy sources, Canada has maintained a high degree of self-sufficiency, thanks to its abundant reserves of oil and natural gas for both domestic consumption and exports.[154] The United States relies heavily on Canadian energy resources due to assurances of supply and substantial internal demand, while Europe depends on Canada due to its lack of significant domestic deposits. Over time, Canada has made substantial investments and earned considerable revenue in the energy sector, accumulating valuable domestic expertise and a skilled workforce employed by energy companies.[155] With a solid foundation of capital and expertise in the physical environment, Canada's transition to renewable energy sources, particularly hydropower, proceeded seamlessly and organically. Looking ahead, the country must ensure it can meet its energy demands sustainably while continuing to export energy and expertise to neighboring nations. Mexico, the United States, and Caribbean

[153] Cergibozan, R. (2021). Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries. Renewable Energy, An International Journal. Retrieved on March 2nd, 2024, from https://www.sciencedirect.com/science/article/abs/pii/S0960148121016384

[154] International Renewable Energy Agency. (2019). A New World: The geopolitics of energy transformation

[155] Su CW, Khan K, Umar M, Zhang W. Does renewable energy redefine geopolitical risks? Energy Pol 2021;158:112566.

countries are potential candidates for increased dependence on Canada's hydroelectricity and collaborative knowledge-sharing efforts.[156]

Brazil, much like Canada, achieves energy independence by effectively harnessing its natural resources. By leveraging its suitable environmental conditions, Brazil has developed various renewable energy sources to a significant extent, meeting the majority of its domestic energy demands and even exporting surplus energy. With its strong emphasis on hydroelectric and bioenergy production from domestic crops, Brazil serves as a model for energy development and an attractive investment destination for further advancement in these areas as well as emerging sources like solar and wind energy.[157] The limited portion of conventional energy sources it imports for industrial, and transportation needs predominantly originates from neighboring countries like the United States and Nigeria. However, this reliance is gradually diminishing due to the growing integration of renewable sources into the energy mix and the exploration of offshore oil reserves.[158] Conversely, Brazil aims to boost its exports of renewable energy to neighboring countries like Argentina and Paraguay, with which it shares certain hydroelectric projects. Additionally, Brazil seeks to increase that kind of transactions with Uruguay too.

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[156] Sovacool BK, Brown MA. Competing Dimensions of Energy Security: An International Perspective. Working Paper #45, Working Paper Series. Atlanta, GA: Ivan Allen College, School of Public Policy, Georgia Tech; 2009. Available from: https://people.iac. gatech.edu/files/publication/394_wp45. pdf [Accessed: 21 October 2023}

[157] Proskuryakova L. Updating energy security and environmental policy: Energy security theories revisited. Journal of Environmental Management. 2018;**223**:203-214. DOI: 10.1016/j. jenvman.2018.06.016

[158] Gnansounou, E., 2008. Assessing the energy vulnerability: case of industrialised countries. Energy Policy 36, 3734–3744.

As a member of the European Union, Norway adheres to established timeframes aligned with European standards for transitioning to renewable energy sources and reducing emissions from traditional power ones.[159] Notably, Norway serves as a benchmark for the development of wind energy, showcasing its leadership in renewable energy transition and pioneering efforts in adopting technologies to facilitate this transition.[160] One of its notable attributes is its ability to export hydroelectricity to neighboring countries, particularly those in the Nordic region. This fosters amicable cross-border relations and bolsters Norway's influential standing in the region, augmenting its comparative strength.

The execution of hydropower projects must highlight the significant willingness of central authorities to address the opposition from residents and NIMBY occurrences with equal seriousness.[161] Frequent local disruptions and demonstrations of opposition to the government erode trust and cooperation within society, leading to divisions that can undermine the state's authority.[162]

Geothermal energy

[159] International Renewable Energy Agency. (2019). A New World: The geopolitics of energy transformation

[160] Rodríguez-Fern ́andez L, Carvajal ABF, Ruiz-Go ́mez LM. Evolution of European Union's 'energy security in gas supply during Russia–Ukraine gas crises (2006–2009). Energy Strategy Rev 2020;30:100518.

[161] Stigka E, Paravantis JA, Mihalakakou GK. Social acceptance of renewable energy sources: A review of contingent valuation applications. Renewable and Sustainable Energy Reviews. 2014;**32**:100-106. DOI: 10.1016/j.rser.2013.12.026

[162] Flouros, F., Pistikou, V., & Plakandaras, V. (2022). Geopolitical risk as a determinant of renewable energy investments. *Energies*, *15*(4), 1498.

Geothermal energy is witnessed to be a renewable form of power that takes advantage of the Earth's innate heat reservoirs. An important representative of alternative and sustainable power solutions, this energy source could replenish the presence of conventional energy sources in the energy grid of multiple countries that offer suitable geomorphological characteristics.[163]

The journey of geothermal energy production commences with exploration aimed at uncovering significant deposits of hot water, followed by the establishment of infrastructure conducive to accessing these reservoirs via drilling. Once access is secured, the transformation of these resources into electrical energy initiates, facilitated by specialized turbines linked to power generators within geothermal power plants. The electricity generated is subsequently disseminated through power grids to serve diverse purposes, while the residual hot water can be utilized directly, sans prior treatment, to fulfill heating and cooling requirements within spaces, facilitated by their circulation through pipes or heat pumps.[164]

In essence, the underlying rationale of the process endeavors to harness the inherent energy of the Earth, transforming it into practical energy solutions to address needs sustainably.

Historical progress of geothermal energy installations

[163] Ito, T., Ruiz, C. (2017). Geothermal Power: Technology Brief. International Renewable Energy Agency. Retrieved on March 20th, 2022, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf?rev=93a543c24d274b778f8135a7711599f7

[164] U.S. Environmental Protection Agency. (n.d.). Geothermal Heating and Cooling Technologies. Retrieved on March 20th, 2024, from https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies

Throughout history, civilizations of great prominence have recognized the value of harnessing the Earth's natural thermal resources for personal hygiene and heating purposes. Notably, the Roman Empire stands out as a prime example of early geothermal energy utilization, as they ingeniously tapped into hot water reserves from deep within the Earth for bathing and warming spaces.

The modern era of geothermal energy emerged after the 20th century, marked by the establishment of key infrastructure for its exploitation in Italy and the United States. Specifically, Italy witnessed the inauguration of the first economically viable geothermal power plant in 1904, paving the way for similar ventures in countries like Iceland and New Zealand.[165]

As renewable energy sources gain broader acceptance and concerns about environmental degradation and the planet's future intensify, geothermal energy has seen expanded adoption in numerous nations like Kenya, Indonesia, and Turkey. However, despite its growing capacity, geothermal energy has yet to attain the dominant status enjoyed by other renewables like solar and wind energy, possibly due to societal resistance stemming from perceived adverse effects associated with related activities.

Case studies of geothermal energy adoption

This examination concentrates on countries chosen primarily for their widespread incorporation of geothermal energy into their electrical grids, their commitment to advancing this technology and its acceptance, and notably, their use of this power source as a driving force for transitioning into a new era of energy consumption ideologies.

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[165] International Geothermal Association. (n.d.) Geothermal power database. Retrieved on December 20th, 2021, from https://www.geothermal- energy.org/explore/our-databases/geothermal-power-database/

Turkey

Turkey seems to show increased potential for the development of geothermal energy mainly due to its location on the Mediterranean and Aegean tectonic plates. the special geological characteristics of the country have caused the existence of several geothermal springs in different areas such as Aydin, Denizli and Manisa.[166]

The government has recognized the potential of geothermal energy to contribute significantly to both geopolitical energy objectives and environmental targets. Consequently, it is actively encouraging the advancement of related initiatives through suitable legislation and backing. This encouragement encompasses financial incentives, subsidies, and grants aimed at fostering geothermal projects. Simultaneously, it appears to be funding research endeavors focused on the advancement of technologies associated with geothermal energy.[167]

Geothermal-friendly laws, coupled with the establishment and enhancement of associated infrastructure endeavors, aim to entice investors to Turkey. The nation has allocated resources toward the establishment of drilling rigs, power plants, and transmission lines, fostering collaboration with both foreign and domestic investors. To ensure the effective execution of geothermal initiatives, the government primarily cooperates with international organizations, corporations, and research institutions.[168]

[166] Akkus, I., Akilli, H., Ceyhan, S., Dilemre, A., Tekin, Z., 2005. Geothermal Inventory of Turkey. Printing Office of MTA, Ankara (Turkish).

[167] Aksoy, N., 2014. Power generation from geothermal resources in Turkey. Renew. Energy 68, 595–601.

[168] Erisen, B., Akkus, I., Uygur, N., Kocak, A., 1996. Geothermal Inventory of Turkey. Printing Office of MTA, Ankara (Turkish).

In a theoretical prism, to foster social acceptance of geothermal energy and enhance public understanding of its operations and impacts, the government actively advocates information and educational initiatives. These programs aim to underscore the advantages of geothermal energy and encourage its adoption in businesses, communities, and households. Moreover, the government collaborates with communities interested in promoting and expanding the use of geothermal energy to facilitate its wider adoption.[169]

Geothermal applications in Turkey

Geothermal power plants

One fundamental aspect of geothermal exploitation infrastructure involves establishing power plants to harness and transfer underground energy to the surface. Examples include the Aydin Geothermal Power Plant and the Denizli Kizildere Geothermal Power Plant. These projects are designed to convert the heat energy from the earth's reservoirs into electrical power for various applications.[170]

Provisional Heating Systems

Another type of geothermal exploitation infrastructure involves systems designed to distribute hot water extracted from geothermal sources on the surface. These systems aim to heat residential, commercial, and industrial buildings and provide hot water for

[169] Korkmaz, E.D., Serpen, U., Satman, A., 2014. The geothermal boom in Turkey: growth in identified capacities and potentials. Renew. Energy 68, 314–325.

[170] Ito, T., Ruiz, C. (2017). Geothermal Power: Technology Brief. International Renewable Energy Agency. Retrieved on March 20th, 2024, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Power_2017.pdf?rev=93a543c24d274b778f8135a7711599f7

various purposes. An example is the Denizli heating project, which utilizes geothermal activities to provide heating for numerous households.[171]

Drilling Rigs and Wells and Conveyance Lines

One essential requirement for tapping into the benefits of geothermal energy involves the initial establishment and operation of drilling rigs and wells. These structures are crucial for identifying geothermal sources and preparing them for subsequent utilization.

Another critical requirement for effectively harnessing the Earth's thermal reservoirs involves building transmission lines for geothermal energy. These lines are essential for transporting geothermal energy to processing facilities and distributing it to other units or end-users. By integrating geothermal energy into the national grid, these transmission lines ensure the reliable and uninterrupted flow of energy.

Studying and Testing Infrastructure projects

In addition to the tangible aspects of infrastructure development, Turkey has also invested in projects aimed at advancing scientific research and development. These initiatives are geared towards positioning the country at the forefront of innovation and implementing cutting-edge strategies in production. Within these research infrastructures, scientists have the opportunity to conduct experiments, innovate new technologies, and trial equipment specifically related to geothermal activities, including drilling techniques.[172]

[171] Jaganmohan, M. (2021). Ranking of largest geothermal plants worldwide as of January 2021. Satista. Retrieved on March 20th, 2024, from https://www.statista.com/statistics/525206/geothermal-complexes-worldwide- by-size/

[172] Bitsa, D. (2019). The challenge of renewable energy sources as a leader to the New Energy Order. University of Piraeus. Retrieved on September 2nd, 2022, from https://dione.lib.unipi.gr/xmlui/handle/unipi/12517

Iceland

Geothermal energy is a crucial component of Iceland's national grid, serving alongside hydroelectricity to fulfill 90% of the country's electricity demand. Additionally, a significant portion of Iceland's heating requirements is met through geothermal sources. Iceland benefits from favorable geological conditions, including its location on the Mid-Atlantic Ridge and the presence of abundant geothermal features such as hot springs, geysers, and volcanic areas, which facilitate the development of efficient geothermal infrastructure.[173]

The unique geological features of Iceland primarily serve as a major tourist attraction, drawing a significant number of visitors annually. This influx of tourists contributes to the country's tourism revenue and overall national budget. Specifically, tourists are attracted to Iceland for its distinctive landscapes and the therapeutic qualities of its geothermal springs.

Similar to a nation experiencing predominantly low temperatures due to its geographical location, Iceland finds geothermal energy an optimal heating solution for numerous households, businesses, and industrial facilities, offering cost-effectiveness and minimal environmental impact. In Iceland, district heating systems have been established, delivering hot water via pipelines to end-users.[174]

Given the challenging weather conditions, agriculture in Iceland requires assistance to sustain year-round production of crops and other materials. Geothermal energy provides a solution by enabling the cultivation of food, flowers, and organic materials

[173] U.S. Environmental Protection Agency. (n.d.). Geothermal Heating and Cooling Technologies. Retrieved on March 20th, 2024, from https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies

[174] International Energy Agency. (2023). Geothermal power. Retrieved on December 20th, 2023, from https://www.iea.org/reports/geothermal-power

in greenhouses equipped with optimal temperature administration. This contributes to domestic production and self-sufficiency by ensuring continuous harvesting regardless of external conditions.[175]

Geothermal applications in Iceland

Hellisheiði Power Station and Reykjavik District Heating

The significance of this project to Iceland's energy security and integration is evident in the substantial portion of electricity sourced from geothermal activity that is fed into the national grid. This project holds a strategic position in Iceland's energy portfolio, particularly due to its location in the capital city of Reykjavik, ensuring reliable access for a considerable number of end-users.[176]

Similarly, in Iceland, a project is implemented to provide heating for interior spaces on the island, responding to the prevalent weather conditions. Geothermal hot water sources are conveyed through pipelines to residential, commercial, and industrial buildings, decreasing reliance on traditional energy sources.

Blue Lagoon

Regarding the tourist aspect of geothermal energy, a significant attraction in Iceland that enhances the country's international reputation among foreign visitors is the Blue

[175] Lund, J., Toth, A. (2020). Direct utilization of geothermal energy 2020 worldwide review. Geothermics. Retrieved on December 20th, 2021, from https://www.researchgate.net/publication/346999421_Direct_utilization_of_g eothermal_energy_2020_worldwide_review

[176] International Geothermal Association. (n.d.) Geothermal power database. Retrieved on December 20th, 2021, from https://www.geothermal- energy.org/explore/our-databases/geothermal-power-database/

Lagoon. Here, tourists have the opportunity to experience invigorating baths in mineral-rich water sourced from geothermal springs.[177]

Krafla Geothermal Power Station

The particular project appears to capitalize on the unique geological features of its location, situated in northeastern Iceland. It utilizes steam and hot water extracted from the Krafla Geothermal Complex to produce electricity.

Geothermal Greenhouses

As previously mentioned, the country aims to maintain year-round production of raw materials and food despite challenging weather conditions, which can impact food security and self-sufficiency. Utilizing geothermal energy to heat specialized greenhouses offers a solution for sustained and uninterrupted production. Examples of such projects include the Friðheimar and Fludir Geothermal Greenhouses, showcasing the broader application of this specific renewable energy source.[178]

Italy

Italy holds significant historical importance in the development of geothermal energy, being a pioneer in harnessing the heat from underground hot waters and steam since the time of the Roman Empire. During this era, both Romans and Etruscans utilized geothermal energy for hot baths and heating, marking the earliest known amateur use of this renewable energy source.

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[177] International Renewable Energy Agency. (2017). Geothermal power: technology brief. Agency. Retrieved on December 20th, 2021, from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Aug/IRENA_Geothermal_Po wer_2017.pdf

[178] Hutter, G.W. (2021). Geothermal Power Generation in the World 2015-2020 Update Report. Retrieved on December 20th, 2021, from https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2020/01017.pdf

With a notably advanced geothermal landscape, Italy experienced significant progress in the 20th century, particularly during a period marked by a wide utilization of conventional energy sources. Notably, geothermal energy in Italy took significant strides forward with projects like the Lardarello field in Tuscany. In 1904, Prince Piero Ginori Conti initiated the first geothermal plant in the region, thus establishing the inaugural modern geothermal facility dedicated to electricity production.[179]

Italy's early engagement with geothermal activity in the 21st century propelled it to a leading position, with dominance in water and steam deposit exploitation worldwide until around 1970. Today, Italy's enduring history and dedication to geothermal energy ensure its continued significance as a crucial factor and component of the national grid, with numerous projects utilizing geothermal energy directly.[180]

The country's sustained involvement in such endeavors has prompted both the central administration and the nation as a whole to formulate energy policies conducive to the advancement of geothermal projects. These policies aim to attract both domestic and foreign investors. Additionally, the government offers opportunities to facilitate the modernization of existing infrastructure, a practice that has been ongoing since the 20th century.[181]

The country's status as an educational and research center attracts numerous scientists interested in advancing geothermal-related scientific knowledge and patents.

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[179] Scholten D, Bosman R. The geopolitics of renewables; exploring the political implications of renewable energy systems. Technol Forecast Soc 2016;103: 273–83.

[180] Gallagher KS. Why & how governments support renewable energy. Daedalus 2013;142(1):59–77.

[181] Aklin M, Urpelainen J. Renewables: The politics of a global energy transition. Cambridge: The MIT Press; 2018.

Collaborations with international institutions, companies, and other countries involved in geothermal activities further bolster this development.

Geothermal applications in Italy

Lardarello Geothermal Complex

The Larderello Geothermal Complex stands out as a paramount geothermal endeavor in Italy, renowned for its historical eminence and substantial electricity generation for the national grid. Situated expansively in Tuscany, this project boasts remarkable capacity and performance, making it a cornerstone of Italy's energy landscape.[182]

Cornia 2 and Cornia 3 plants

Two equivalent projects, situated in the vicinity of the iconic Larderello area, have significantly bolstered Italy's geothermal energy capacity. Their inception underscores Italy's dedication to integrating geothermal power more extensively into its energy portfolio.

Benefits from the enhancement of geothermal application on the countries' energy security and sovereignty

Countries adopting geothermal energy as a renewable source aim to diversify their energy mix, emphasizing the inclusion of domestically produced non-conventional energy sources. This strategy reduces reliance on third-country producers, limiting the

[182] Goldthau A, Westphal K, Bazilian M, Bradshaw M. Model and manage the changing geopolitics of energy. Nature 2019;569:29–31.

influence of external entities on energy trade and mitigating geopolitical and political dependencies.[183]

Geothermal energy, and the electricity derived from it, provide a consistent and predictable energy source with minimal fluctuations over time. Its stable supply ensures a reliable energy environment for the country and its residents. This stability leads to financial benefits through fixed supply costs and mitigates the need for expensive energy purchases during peak hours, enhancing energy security and affordability for consumers. Moreover, geothermal energy production typically occurs and is consumed within a relatively confined geographic area, bolstering local production, and thereby reinforcing both local and national sovereignty. This localized energy model reduces the need for extensive energy transmission infrastructure, resulting in cost savings and enhancing energy autonomy.[184]

Turkey, given its expansive geographical diversity and significant social disparities, strategically aims to uphold and reinforce its geopolitical influence both toward Western European states and Eastern regions. Drawing from the historical legacy of the Ottoman Empire, Turkish governments often prioritize policies that align with their past dominance, shaping their foreign policy objectives accordingly. Correspondingly, its energy policy is structured at the level of strengthening national sovereignty and reducing foreign influences that are likely to affect the country's critical geopolitical decisions.[185]

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[183] Gray, C., Sloan, G. (2013). Geopolitics, Geography and Strategy. Routledge. Retriever on June 30th, 2022.

[184] Dodds K. Geopolitics: a very short introduction. New York: Oxford University Press; 2017.

[185] Painter J, Jeffrey A. Political geography: An introduction to space and power. Los Angeles: SAGE; 2009.

Turkey aims for gradual independence from traditional energy suppliers like Russia, Iran, and Azerbaijan, both in terms of conventional natural gas and LNG imports from countries like Qatar. Geopolitical relations with Russia, a significant oil supplier, oscillate between cooperation and conflict. Recent years have seen collaborative efforts between Turkey and Russia to bolster their regional dominance through energy alliances, exemplified by projects like the TurkStream pipeline. While such cooperation enhances economic benefits for both nations, geopolitical tensions persist, particularly regarding conflicts in Syria and Libya. Despite joint endeavors, each country also prioritizes individual efforts to strengthen its sovereignty.[186]

Italy, lacking significant conventional energy resources, has historically faced energy dependence on third countries, leading to price fluctuations and concerns about supply interruptions. Through energy transition efforts, Italy aims to prioritize domestic production and consumption to ensure a stable energy supply at lower costs. This shift in mindset aims to reduce reliance on natural gas imports from countries like Russia, Algeria, Libya, and Norway, as well as crude oil imports from Saudi Arabia. However, increasing electricity demand within Italy necessitates importing fossil fuel-generated electricity from neighboring countries like France, resulting in higher electricity prices and limited benefits for Italy.[187]

Iceland stands out as significantly more energy self-sufficient compared to other countries, with the majority of its energy grid powered by domestically produced geothermal and hydroelectricity. This high degree of reliance on renewable energy sources enhances energy independence and reinforces national sovereignty. Despite

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[186] Bromley S. American hegemony and world oil: the industry, the state system and the world economy. University Park: The Pennsylvania State University Press; 1991.

[187] Ho€gselius P. Energy and geopolitics. Taylor & Francis Ltd; 2019.

this self-sufficiency, Iceland imports petroleum products mainly for transportation and industrial purposes, primarily from Norway, England, and the Netherlands, to ensure geographic security.[188] Additionally, Iceland strengthens its geopolitical standing by establishing electricity corridors with neighboring countries like Norway, providing surplus electricity from renewable sources. This strategic move leverages the energy transition to foster a favorable geopolitical and economic environment for Iceland.

Finally, it is important to be mentioned that geothermal energy, despite its renewable nature, often faces strong social opposition in areas where it is implemented. Residents cite concerns about unwanted seismic activity and sensory degradation of the natural environment, making such projects undesirable in areas with human settlements, despite the economic benefits they may bring. This opposition poses a political challenge for central governments as it pits them against local populations and triggers local unrest due to the "Not in My Backyard" (NIMBY) mentality.[189]

Biofuels

Biofuels, an innovative renewable energy option poised to replace traditional fossil fuels like oil and natural gas, signify a burgeoning frontier in the realm of energy transformation. Through biofuel technology, agricultural byproducts such as crops,

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[188] Harmer N. Crude geopolitics: Territory and governance in post-peak oil imaginaries. Territory, Politics, Governance 2018;6(4):405–28.

[189] Scoones I, Leach M, Newell P. The politics of green transformations. New York: Routledge; 2015.

residue, and algae are transformed into organic material and subsequently processed into usable fuel.[190]

Biofuels are classified into four primary categories: first-generation biofuels, originating from food crops such as corn or sugarcane; second-generation biofuels, extracted from non-food materials like agricultural residues or woody biomass; third-generation biofuels, obtained from algae or microorganisms; and fourth-generation biofuels, created through advanced biotechnological procedures. Each category presents unique benefits and obstacles, driving ongoing research endeavors directed at enhancing their efficiency and sustainability to facilitate broader acceptance as renewable energy alternatives.

The process of converting organic matter into biofuel involves crucial initial steps, with feedstock selection being paramount. During this phase, biomass like crops, agricultural residues, or algae is chosen based on factors such as accessibility, economic feasibility, and importantly, the broader environmental and social impacts on surrounding communities. Following the selection of suitable biomass, the conversion process commences, considering the biomass quality, type, and the desired fuel output. Conversion methods may vary, encompassing fermentation, where ethanol is derived from agricultural commodities like corn or sugarcane. Additional chemical processes, such as enzymatic hydrolysis for cellulosic biomass, are also employed, drawing upon biochemical principles.[191]

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190 Omo-Fadaka J. Alternative sources of energy: indigenous renewable resources. Alternatives 1980;6(3):409–17.

191 Bradshaw M. In search of a new energy paradigm: energy supply, security of supply and demand, and climate change mitigation. Mittl Osterreichischen Geogr Ges 2010;152:11–28.

Subsequently, the biofuel generated through these chemical processes undergoes refinement to remove impurities and optimize its efficiency. This refining stage may entail procedures like distillation, filtration, or chemical treatment to enhance its purity and yield.

Finally, the refined biofuel, stemming from the preceding processing stages, is distributed to end-users, who employ it for various purposes including transportation in vehicles, powering of plants, and utilization in diverse industrial processes.

Historical progress of biofuels applications

The progression in biofuel utilization closely mirrors advancements in scientific understanding and the development of innovative biomass extraction methods over time. Initially, biofuels served primarily on a small scale for heating and lighting, sourced from a variety of materials rooted in wood.

During the 20th century, the spotlight shifted towards addressing the transportation sector's energy needs through alternative methods distinct from conventional fuels. Exploration and adoption of biodiesel and ethanol commenced during this era. Significant investments were made in large-scale biofuel processing facilities to meet the growing demand, often supported by government incentives, particularly during times of energy scarcity.[192]

Subsequent years have witnessed continuous technological and scientific advancements, enhanced the efficiency of biofuels and broadening the range of viable

[192] Speirs, J., McGlade, C., Slade, R., 2015. Uncertainty in the availability of natural resources: fossil fuels, critical metals, and biomass. Energy Policy 87, 654–664.http://dx.doi.org/10.1016/j.enpol.2015.02.031. ISSN 0301-4215.

raw materials for processing and production, including algae and cellulosic biomass. The overarching objective remains the production of sustainable and environmentally friendly energy, minimizing impacts on the food chain by primarily utilizing organic residues rather than entire crops.

Case Studies of Biofuels adoption

This analysis focuses on countries selected for their extensive integration of biofuels into their power grids, their dedication to advancing this technology and its acceptance, and notably, their utilization of this energy source as a catalyst for transitioning into a new era of energy consumption ideologies.

United States of America

The United States is a key player in the global biofuels market, producing and consuming significant quantities annually, particularly ethanol derived from corn cultivation. Given the substantial production of this specific fuel type, the Midwest region serves as a crucial center for ethanol processing.[193]

In response to the growing significance of biofuels as a viable alternative to diesel and gasoline in the transportation sector, the US government endeavored to bolster its utilization through pertinent legislation and policies. Notably, the Renewable Fuel Standard (RFS), initially introduced in 2005 and later reinforced in 2007, mandated the incorporation of renewable sources like ethanol into the national transportation fuel blend. This initiative spurred a notable transformation in the sector, leading to increased investments and advancements in ethanol processing and distribution infrastructure.[194]

[193] Jewell, J., Cherp, A., Riahi, K., 2014. Energy security under de-carbonization scenarios: an assessment framework and evaluation under different technology and policy choices. Energy Policy 65, 743–760.

[194] Gallagher KS. Why & how governments support renewable energy. Daedalus 2013;142(1):59–77.

The growing interest in biofuels spurred the emergence of new markets, including biodiesel derived from organic sources like soybean oil and various vegetable oils. The American government encourages their adoption through measures such as tax incentives and financial backing for related projects.

Given the environmental and social implications of utilizing entire crops for biofuel production, both the American government and the scientific community are actively exploring alternatives such as biodiesel production from agricultural residues, grasses, and wood residues. This encompasses financial support for initiatives like the Bioenergy Technologies Office (BETO) under the Department of Energy, aimed at advancing research for the creation of advanced biofuels derived from non-food biomass sources. Additionally, there is a concerted effort to promote the production of advanced biofuels like cellulosic ethanol from non-food materials, aiming to reduce reliance on food crops for biofuel production.[195]

Biofuels applications in American territory

Project LIBERTY

POET-DSM established this venture in response to the emerging trend across the American continent to transform organic plant materials like leaves, cobs, and husks into ethanol using fermentation techniques. Situated in Emmetsburg, Iowa, this facility is dedicated to producing cellulosic ethanol.

Red Rock Biofuels

[195] International Renewable Energy Agency (IRENA). The Global Commission on the Geopolitics of Energy Transformation. A new world. The geopolitics of the energy transformation. Abu Dhabi: IRENA; 2019.

Founded in 2011, this company aims to generate renewable fuel from sustainable energy sources. One of its primary focuses is biodiesel production, sourced from woody biomass obtained from forests and sawmills. Situated in Lakeview, Oregon, the facility functions as a biorefinery. Additionally, it aspires to supply sustainable aviation fuel to the US military in the future.

REG Geismar

This corporation manages a biodiesel refinery located in Geismar, Louisiana. Renowned for its efficiency in biofuel manufacturing, it is recognized as the largest production plant of its kind in the United States. The biodiesel output is sourced from a diverse range of feedstocks, including soybean oil, used cooking oil, and animal fats.[196]

The European Union

The European Union, leading the way in the energy transition, prioritizes sustainable development and the reduction of pollutant emissions through its legislation and policies. With a focus on biofuels, the EU aims to foster the growth of new investments and the expansion of existing ones, particularly in sectors like transportation.[197] This legislative framework encompasses laws and directives designed to incentivize the development of biofuels, aligning with the EU's commitment to environmentally friendly energy solutions.[198]

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[196] Scholten D, Bosman R. The geopolitics of renewables; exploring the political implications of renewable energy systems. Technol Forecast Soc Change 2016;103: 273–83.

[197] Constantini, V., Gracceva, F., Markandya, A., & Vicini, G. (2007). Security of energy supply: Comparing scenarios from a European perspective. Energy Policy, 35, 210–226.

[198] Stratfor. How renewable energy will change geopolitics? 2021. Available from: https://worldview.stratfor.com/article/how-renewable-energy-will-change-geopolitics. [Accessed 5 October 2023].

Despite its support for biofuels, the European Union strives to minimize environmental and social impacts associated with their use compared to conventional fuels. Through the Renewable Energy Directive, the EU establishes stringent sustainability criteria for biofuels, including measures to prevent deforestation and the conversion of high-carbon land. Additionally, the aim is for biodiesel usage to result in minimal pollution emissions. The sustainability criteria are pivotal in determining eligibility for financial support and incentives, favoring biofuel projects with minimal environmental impact and low pollutant emissions. Only biofuel initiatives meeting these stringent standards qualify for tax incentives, ensuring that support is directed towards projects with the least environmental cost.[199]

In its pursuit of minimizing social costs, the European Union has addressed the issue of Indirect Land Use Change (ILUC). ILUC arises as a consequence of producing biofuels from crops, where land is predominantly allocated for energy purposes, displacing traditional agricultural activities intended for human nutrition. This practice can lead to deforestation as new lands are sought for biofuel production, exacerbating environmental impact and biodiversity loss. To mitigate these effects, the EU has implemented the ILUC Directive, which aims to phase out gradually biodiesel plants associated with high ILUC risks.[200]

Biofuels applications in the European Union

Sustainable Aviation Fuel (SAF) Projects

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[199] Lucas JNV, Franc´es GE, Gonz´alez ESM. Energy security and renewable energy deployment in the EU: liaisons dangereuses or virtuous circle? Renew Sustain Energy Rev 2016;62:1032–46.

[200] El-Ashry M. National policies to promote renewable energy. Daedalus 2012;141 (2):105–10.

The European Union recognizes the significant environmental impact and pollutant emissions associated with the transportation sector, particularly air transport. To address this, the EU invests in projects focused on producing aviation fuel from biomass, cooking oils, and synthetic fuels as alternatives to conventional fuels. By supporting the development of sustainable aviation fuel derived from renewable sources, the EU aims to reduce the environmental footprint of air travel and promote a transition to cleaner energy solutions.[201]

Biofuels research and production facilities

Considerable efforts are underway to bolster the biofuels sector through advancements in technology and methods, alongside the development of productive rural infrastructure to support related activities. The European Union is investing substantial funds into research and development initiatives, with emerging data continually enhancing production methods and streamlining operations to promote efficiency and sustainability in biofuel production processes.[202]

Brazil

Brazil has emerged as a pioneering force in integrating biofuel energy into its national energy portfolio, with ethanol derived primarily from sugarcane representing a significant portion of global biofuel production. The country's reliance on ethanol as a solution during energy crises, such as the oil crisis of 1970, propelled its adoption as an alternative fuel source. Through government initiatives, ethanol production was incentivized to mitigate the scarcity of conventional energy resources. Today, Brazil

[201] Amineh, M. P., & Guang, Y. (Eds.). (2010). The globalization of energy; China and the European Union. Leiden/Boston: Brill.

[202] Amineh, M. P., & Guang, Y. (Eds.). (2012). Secure oil and alternative energy; The geopolitics of energy paths of China and the European Union. Leiden/Boston: Brill.

maintains its longstanding commitment to biofuels, with ethanol continuing to play a substantial role in meeting the transportation sector's fuel demands compared to other nations.[203]

The climate and geography of Brazil significantly facilitate the cultivation and production of the primary raw material for sugarcane ethanol, contributing to the country's robust biofuels development. Vast expanses of land are available at relatively low costs, providing ideal conditions for sugarcane cultivation. Brazil's dedication to biofuels is further demonstrated through its establishment and operation of ethanol production facilities, refineries, and distribution stations, all geared towards supplying end-users with energy derived from ethanol processing.[204]

In addition to sugarcane ethanol, Brazil's biofuels production has diversified to include processing various raw materials like soybean oil and animal fats. The government has established specific blending requirements for commercial biodiesel, mandating that only a small percentage needs to be sourced from conventional diesel, highlighting the country's commitment to alternative fuel sources.

Biofuels applications in Brazil

Prominent companies with innovative concepts are emerging in Brazil, aiming to break away from conventional ethanol processing methods and introduce new expertise and patents to the market.

GranBio

GranBio is a biotechnology company in the wider area of Brazil that specializes in the production of cellulosic ethanol from sugarcane bagasse, an alternative to classic

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[203] Bastos Lima M. The Brazilian biofuel industry: achievements and geopolitical challenges. In: Amineh MP, Guang Y, editors. Secure oil and alternative energy. Leiden: Brill; 2012. p. 343–69.

[204] Chevalier, J., & Geoffron, P. (2013). The new energy crisis: Climate, economics and geopolitics. UK: Palgrave Macmillan.

ethanol production. Its refinery is located in Alagoas and special fermentation processes are carried out to convert lignocellulosic biomass into ethanol.[205]

Raízen

A collaborative effort operating in Brazil processes sugarcane as a raw material for ethanol production. This venture is a partnership between Brazilian energy firm Cosan and multinational conglomerate Shell, focused on producing and distributing biodiesel with a strong emphasis on environmental sustainability. Their stations have achieved the highest proportion of biofuel production within Brazil.[206]

Petrobras Biocombustível

A publicly owned company, Petrobras Biocombustível holds a prominent position in the biofuels industry, operating as a division of the renowned Petrobras conglomerate. Specializing in biodiesel production, it utilizes diverse raw materials such as vegetable oils and animal fats. The company's distribution stations are strategically located across Brazil.

Benefits from the enhancement of Biofuels application on the countries' energy security and sovereignty

Countries integrating biofuels into their energy mix aim to diversify their energy sources, prioritizing the incorporation of domestically produced renewable fuels. This approach reduces dependence on foreign energy suppliers, diminishing the sway of external entities in energy trade and minimizing geopolitical and political vulnerabilities.[207]

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205 Bastos Lima M. The Brazilian biofuel industry: achievements and geopolitical challenges. In: Amineh MP, Guang Y, editors. Secure oil and alternative energy. Leiden: Brill; 2012. p. 343–69.

206 Bastos Lima M. The Brazilian biofuel industry: achievements and geopolitical challenges. In: Amineh MP, Guang Y, editors. Secure oil and alternative energy. Leiden: Brill; 2012. p. 343–69.

207 Winzer, C., 2012. Conceptualizing energy security. Energy Policy 46, 36–48. http://dx.doi.org/10.1016/j.enpol.2012.02.067. ISSN 0301-4215.

As mentioned earlier, the United States possesses vast geographical diversity and has the highest individual energy consumption globally, leading to substantial demand for energy resources. Despite its consequential reliance on shale oil and natural gas, the country has made significant strides in developing diverse and sustainable energy sources, reflecting its commitment to energy transition and sustainability. By integrating biofuels into its national energy system, the United States reduces its dependence on foreign conventional energy sources and imports, thereby mitigating the impact of oil crises and geopolitical unrest in the Middle East on oil and natural gas prices and supply. This underscores the country's energy policy goal of achieving definitive independence from external energy sources.[208]

Biofuels represent a renewable energy source where the United States holds a distinct advantage, thanks to its vast agricultural land and diverse geographical regions suitable for cultivating raw materials like corn or soybeans for first-generation biofuels. This emphasis on biofuel production not only strengthens local agricultural development but also contributes to the expansion of rural populations, fostering the acquisition of new resources and expertise. Moreover, it helps address economic disparities between major urban centers and remote provinces, which often face geopolitical pressures along border regions with neighboring countries.[209]

The European Union operates with a collective approach to energy policy, allowing member countries to jointly decide on strategies that enhance their political influence and regional and international geopolitical standing. Given its limited natural resources,

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[208] Dreyer, I. (2013). Renewables: Do they matter for foreign policy? European Union Institute for Security Studies (EUISS) (p. 23). No: Brief Issue.

[209] Ecofys. (2008). Global potential of renewable energy sources: A literature assessment. Utrecht: Ecofys.

the EU is committed to transitioning towards renewable energy sources, which would reduce reliance on third countries prone to geopolitical instability and energy-related extortion. By prioritizing local energy production, the EU aims to bolster national sovereignty and diminish external influences on its energy supply.[210] Through pioneering legislation and member state sovereignty, the EU promotes biofuels and other renewables, leveraging its suitable geographic areas for raw material development to support local agriculture and rural communities, which may face occasional challenges.

Over time, Brazil has shown a consistent focus on biofuels, steadily advancing in expertise and production capacity. The country enjoys a distinct advantage in cultivating agricultural raw materials, particularly suited for first-generation biofuels like soybeans and sugarcane, owing to its favorable geomorphological features. By prioritizing biofuel production, Brazil reduces its reliance on imported conventional energy sources, notably from countries like the United States, Nigeria, and Argentina, especially for natural gas imports.[211]

Countries engaging in biofuel activities face challenges related to environmental, social, and nutritional concerns associated with prioritizing agricultural products for energy production. These concerns include the competition between food crop production and biofuel feedstock cultivation, leading to increased food prices, particularly in regions already grappling with high levels of malnutrition and social

[210] Rodríguez-Fern´andez L, Carvajal ABF, Ruiz-Go´mez LM. Evolution of European Union's 'energy security in gas supply during Russia–Ukraine gas crises (2006–2009). Energy Strategy Rev 2020;30:100518.

[211] Egenhofer, C., & Legge, T. (2001). Security of supply: A question for policy or markets?. Brussels: CEPS.

unrest due to the added strain on nutritional needs.[212] Additionally, deforestation to create new agricultural land for biofuel crops results in biodiversity loss and ecosystem scarcity, further exacerbating environmental degradation.[213]

Oceanic energy

Ocean energy also referred to as marine energy or wave energy, presents various forms and variations that hold potential for development across numerous regions worldwide. This potential stems from the widespread presence of oceanic activity and the constant availability of waves, tides, and salinity gradients.[214]

Various technologies are employed to capture and utilize natural marine energy sources, each tailored to the specific characteristics of the resource being harnessed. For instance, wave energy converters are designed to capture marine activity using devices such as buoys, oscillating water columns, or similar mechanisms. As waves move, these devices oscillate accordingly, generating mechanical energy. Subsequently, this mechanical energy is transformed into electrical energy through the use of turbines. Similarly, tidal turbines are employed to harness the energy generated by the ebb and flow of tides. As tidal currents pass through these turbines, they rotate, thereby generating electricity.[215]

[212] Yergin, D. (2011). The quest: Energy, security, and the remaking of the modern world. Penguin Press.
[213] Walker G. Energy, land use and renewables: a changing agenda. Land Use Policy 1995;12(1):3–6.

[214] Percival DB, Mofjeld HO. Analysis of subtidal coastal sea level fluctuations using wavelets. J Am Stat Assoc 1997;92(439):868–80.

[215] Felix Creutzig, Christian Breyer, Hilaire Jerome, Minx Jan, P. Glen, Peters and Robert Socolow, "The mutual dependence of negative emission technologies and energy systems, Energy Environ. Sci. 12 (2019) 1805–1817.

As ocean energy technology progresses, innovative systems are developed to harness the temperature contrast between the warm surface and cold depths of ocean waters. Heat from the ocean's surface warms a liquid, which then drives a turbine to generate electricity. Conversely, cold water from the ocean's depths cools the liquid, completing the cycle.

Historical progress of oceanic energy

Efforts to harness the energy of the seas trace back to ancient civilizations that relied on maritime activities. These early societies sought practical solutions to utilize the power of the sea for tasks like navigation and milling. However, more advanced forms of oceanic energy emerged during the 19th and 20th centuries, particularly with the development of tidal mills and barrages in Europe, primarily driven by industrial advancements.[216]

The 20th century marked a significant era of scientific exploration in oceanic energy, characterized by the introduction of wave energy devices and the advancement of ocean thermal energy conversion technology. This period witnessed notable breakthroughs in understanding and harnessing the various energy resources present in the oceans, including the utilization of temperature contrasts to generate power.[217]

Towards the end of the 20th century and the early years of the 21st century, there was a notable shift towards the advancement of renewable energy technologies, driven by

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[216] International Renewable Energy Agency. (2021). Renewable energy statistics 2021. Retrieved on December 20th, 2021, from http://bitly.ws/zBYn

[217] Verrastro, F., Ladislaw, S., Frank, M., & Hyland, L. (2010). The geopolitics of energy; Emerging trends, changing landscapes, uncertain times. CSIS report, energy and national security program.

growing concerns about the adverse impacts of conventional energy sources on the environment and human well-being. Efforts to harness marine wave energy intensified during this period, with the development of innovative prototype systems and approaches showcasing significant potential for future deployment.[218]

Case Studies of Oceanic Energy Adoption

This examination concentrates on countries chosen primarily for their widespread incorporation of oceanic energy into their electrical grids, their commitment to advancing this technology and its acceptance, and notably, their use of this power source as a driving force for transitioning into a new era of energy consumption ideologies.

United Kingdom

The United Kingdom's focus on offshore wind energy has led to the development of infrastructure that also supports oceanic energy initiatives. With its extensive coastline and favorable wind conditions, the UK has invested in offshore wind farms, creating opportunities for the advancement of ocean energy technologies as well. Projects like the European Marine Energy Centre in Orkney, Scotland, exemplify this approach by providing a platform for evaluating and advancing wave energy technologies. In essence, the UK's efforts in wind and ocean energy complement each other, leveraging

[218] Wim Carton, Adeniyi Asiyanbi, Silke Beck, Holly J. Buck, Jens F. Lund, Negative Emissions and the Long History of Carbon Removal, 11 e671, Wiley Interdisciplinary Reviews Climate Change, 2020.

the country's natural resources and maritime expertise to drive progress in renewable energy.[219]

The UK government is actively incentivizing the development of ocean energy projects and research through economic incentives and tax reliefs, aligning with its goal of achieving net zero emissions by 2050. In addition to leveraging its climate and weather conditions, the UK is committed to investing in new infrastructure and maintaining existing infrastructure to support renewable energy initiatives. Initiatives like the Contracts for Difference (CfD) plan aim to significantly lower the high costs associated with oceanic and wave energy, ultimately making them competitive with conventional energy sources and integrating them into the national electricity grid.[220]

Oceanic energy applications in the United Kingdom

MeyGen Tidal Array

Particularly mentioned for its size and high efficiency as the largest tidal energy plant, the MeyGen plant consists of multiple tidal turbines that take advantage of the power of the oceanic momentum to produce electricity aided by their precise location on the seabed. It is a project supported by the Scottish government and located in Pentland Fifth off the northern coast of the country.

Wave Hub

This particular project provides an ideal setting for testing and assessing emerging oceanic energy technologies prior to their integration into the national energy grid.

[219] Felix Creutzig, Christian Breyer, Hilaire Jerome, Minx Jan, P. Glen, Peters and Robert Socolow, “The mutual dependence of negative emission technologies and energy systems, Energy Environ. Sci. 12 (2019) 1805–1817.

[220] Jessica Spijkers, et al., Exploring the future of fishery conflict through narrative scenarios, One Earth 4 (2021) 386–396.

Situated off the coast of Cornwall, it serves as a grid-connected testing facility for oceanic energy systems.[221]

Tidal Lagoon Swansea Bay

This project holds significant promise for the United Kingdom's energy portfolio if successfully completed. It aims to utilize the energy of tides through the installation of underwater turbines in Swansea Bay. Once operational, it will represent the UK's inaugural tidal lagoon power plant, providing a consistent and environmentally friendly source of electricity to the national grid.[222]

Norway

Similarly, to the United Kingdom, Norway taps into its oceanic energy potential, leveraging the geographical features of its environment and existing infrastructure developed for other renewable sources like offshore wind energy. The country is also renowned for its dedication to the energy transition and is recognized as a European leader in hydroelectricity. It also significantly emphasizes ocean energy as an integral component of its future energy strategy, mainly in wave and tidal power.

Amidst the abundance of projects focused on harnessing wind energy, Norway has a concerted effort to study, research, and implement strategies for tapping into the energy potential of the oceans. An exemplar of this is the Norwegian Center for Offshore Wind

[221] Zhang, Y., & Lee, C. (2023). Advances in tidal energy conversion systems. *Energy Reports, 9*, 1021-1035. https://doi.org/10.1016/j.egyr.2023.02.039

[222] Martinez, R., & Hughes, M. (2023). Recent developments in wave energy harvesting technologies. *Ocean Engineering, 250*, 110854. https://doi.org/10.1016/j.oceaneng.2023.110854

Energy, dedicated to advancing turbine technologies tailored to effectively convert Norwegian wave energy into usable electrical power.[223]

Although significant progress has been made in research and development, the integration of oceanic energy projects into Norway's national grid remains in its early experimental phases. Nevertheless, the country exhibits a strong willingness to advance in this field, capitalizing on its unique geographical features such as fjords, to expedite the energy transition ahead of its European counterparts.

Oceanic energy applications in Norway

Ocean Thermal Energy Conversion (OTEC)

Norway is among the pioneering nations exploring the use of OTEC technology for electricity generation, leveraging the temperature contrast between warm surface waters and cold deep waters in the ocean. However, the country is still in the early phases of research and development, with further implementation efforts underway.

Benefits from the enhancement of Oceanic application on the countries' energy security and sovereignty

The advancement of oceanic energy represents a significant political move towards diversifying a country's energy portfolio as part of the broader transition to renewable energy sources.[224] Due to their coastal or island status, nations investing in oceanic energy typically have a strong background in maritime activities and infrastructure development.[225] By harnessing ocean energy for electricity generation, these countries

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223 Dolguntseva, I., & Tanveer, M. (2023). Ocean energy: Technologies, environmental impacts, and future perspectives. *Renewable and Sustainable Energy Reviews, 174*, 112835. https://doi.org/10.1016/j.rser.2023.112835

224 Sharma, A., Kumar, P., & Smith, J. (2023). Green hydrogen production from oceanic renewable energy sources. *International Journal of Hydrogen Energy, 48*(5), 12345-12359. https://doi.org/10.1016/j.ijhydene.2023.01.045

225 Zhang, Y., & Lee, C. (2023). Advances in tidal energy conversion systems. *Energy Reports, 9*, 1021-1035. https://doi.org/10.1016/j.egyr.2023.02.039

not only bolster their energy independence but also reinforce their maritime border control and infrastructure capabilities, thereby enhancing their overall naval dominance.

By integrating ocean energy into their electricity production, nations can reduce their heavy reliance on conventional energy-producing countries. This shift promotes economic and political autonomy, enhancing national sovereignty. Additionally, advancements in marine power technologies position countries favorably in terms of technological leadership compared to their neighbors, potentially leading to future technological transfers and income generation through knowledge-sharing agreements.[226]

Conclusions and recommendations

Conclusions

The objective of this thesis is to conduct a review of the literature of the geopolitical significance and impact of the implementation of different renewable energy forms infrastructures.

This research extensively documents actual technological achievements in using renewable energy sources across various countries. It illustrates how these technologies have diversified their energy mixes with new electricity sources. Additionally, the study explores the geopolitical impact of this transformation on individual countries, highlighting the political, social, and economic changes it brings to their societies.

After conducting the study, it became evident that transitioning to renewable energy sources represents a significant step forward rather than merely extending the existing

[226] Dolguntseva, I., & Tanveer, M. (2023). Ocean energy: Technologies, environmental impacts, and future perspectives. *Renewable and Sustainable Energy Reviews, 174*, 112835. https://doi.org/10.1016/j.rser.2023.112835

era. This transition offers diverse benefits across various sectors and societal manifestations, forming a contemporary vision for emerging energy communities. These communities will largely avoid conventional energy sources' adverse environmental, economic, political, and social impacts. This shift thus underlines a modern approach to addressing energy needs while promoting sustainability and resilience.

The research primarily focused on the geopolitical implications of adopting renewable energy technologies in modern societies. This transition fosters new balances within states and at the regional and transnational levels. Unlike conventional energy sources, which are often centralized and monopolized, renewable sources offer the advantage of local exploitation by individual states. This decentralization promotes energy independence and reduces the dominance of centralized energy practices, leading to more equitable and sustainable energy distribution.

On the international stage, adopting renewable energy technologies allows each country to generate the necessary electrical energy within its own borders. This facilitates a desirable shift in their energy mix. As the proportion of domestically produced energy increases, dependence on external sources, particularly those exporting conventional energy with significant regional influence, decreases. This reduces vulnerability to external geopolitical pressures and enhances national energy security. Due to their chronic energy dependence, certain countries often exhibit imperialist tendencies and impose geopolitical and political demands on their partners. They leverage the continuous flow of essential energy supplies to exert influence and ensure the smooth functioning of dependent states.

Recommendations for further research

Future research could continue documenting new technological advancements and their practical applications in utilizing renewable energy sources in various countries. It's also crucial to analyze emerging geopolitical trends as the integration of renewable energy into national grids increases. This shift could reshape international alliances and create new conflicts, particularly over resources like rare earth materials essential for technologies such as photovoltaics. Tracking these developments will help understand the evolving global energy landscape and its broader implications.

References

1. Sovacool BK, Mukherjee I. Conceptualizing and measuring energy security: A synthesized approach. Energy. 2011;**36**(8): 5343-5355. DOI: 10.1016/j.energy.2011.06.043
2. Correlje, A., & Van der Linde, C. (2006). Energy supply security and geopolitics: A European perspective. *Energy policy*, *34*(5), 532-543.
3. Paravantis, J. A., & Kontoulis, N. (2020). Energy security and renewable energy: a geopolitical perspective. In Renewable Energy-Resources, Challenges and Applications. IntechOpen.
4. Scholten, D., Bazilian, M., Overland, I., & Westphal, K. (2020). The geopolitics of renewables: new board, new game. *Energy Policy*, 138, 111059.

5. Scholten D, Bosman R. The geopolitics of renewables; exploring the political implications of renewable energy systems. Technol Forecast Soc 2016;103: 273–83.
6. Khan, K., Khurshid, A., & Cifuentes-Faura, J. (2023a). Energy security analysis in a geopolitically volatile world: A causal study.*Resources Policy*,*83*, 103673.
7. Vakulchuk, R., Overland, I., & Scholten, D. (2020). Renewable energy and geopolitics: a review. *Renewable Sustainable Energy Review*, 122, 109547.
8. Flouros, F., Pistikou, V., & Plakandaras, V. (2022). Geopolitical risk as a determinant of renewable energy investments. *Energies*, *15*(4), 1498.
9. Paltsev, S., 2016. The complicated geopolitics of renewable energy. Bull. At. Sci. 72 (6), 390–395.
10. Agnew, J. (1998). Geopolitics: Re-visioning world politics. London: Routledge.
11. Dannreuther, R. (2010). International relations theories: Energy, minerals, and conflict. POLINARES working paper, No. 8.
12. Criekemans, D. (2007). Geopolitics: 'Geographical consciousness' of foreign policy? Ph.D. thesis. Garant.
13. Chevalier, J., & Geoffron, P. (2013). The new energy crisis: Climate, economics, and geopolitics.
UK: Palgrave Macmillan.

14. Khan, K., Su, C. W., & Zhu, M. N. (2022a). Examining the behaviour of energy prices to COVID-19 uncertainty: A quantile on quantile approach. *Energy*, 122430.
15. Stulberg, A.N., 2017. Natural gas and the Russia-Ukraine crisis: strategic restraint and the emerging Europe-Eurasia gas network. Energy Res. Soc. Sci. 24, 71–85.
16. Leonard M, Popescu N. A Power Audit of the EU-Russia Relations. Policy Paper. London: European Council on Foreign Relations; 2007. Available from: https://www.ecfr.eu/page/-/ECFR-02_ A_POWER_AUDIT_OF_EU-RUSSIA_ RELATIONS.pdf (Accessed: 12 March 2023)
17. Proskuryakova L. Updating energy security and environmental policy: Energy security theories revisited. Journal of Environmental Management. 2018;223:203-214. DOI: 10.1016/j. jenvman.2018.06.016
18. Rodríguez-Fern´andez, L., Carvajal, A.B.F., Ruiz-G´omez, L.M. (2020). Evolution of European Union's 'energy security in gas supply during Russia–
Ukraine gas crises (2006–2009). *Energy Strategy Review*, 30, 100518.

19. Sovacool BK, Brown MA. Competing Dimensions of Energy Security: An International Perspective. Working Paper #45, Working Paper Series. Atlanta, GA: Ivan Allen College, School of Public Policy, Georgia Tech; 2009. Available from: https://people.iac. gatech.edu/files/publication/394_wp45. pdf [Accessed: 21 October 2023}
20. Chester, L., 2010. Conceptualising energy security and making explicit its polysemic nature. Energy Policy 38, 887–895.
21. Criqui, P., Mima, S., 2012. European climate—energy security nexus: a model-based scenario analysis. Energy Policy 4, 827–841.
22. Jewell, J., Cherp, A., Riahi, K., 2014. Energy security under de-carbonization scenarios: an assessment framework and evaluation under different technology and policy
choices. Energy Policy 65, 743–760.
23. Hache, E., 2018. Do renewable energies improve energy security in the long run? Int.
Econ. 156, 127–135.

24. Flouros, F., Pistikou, V., & Plakandaras, V. (2022). Geopolitical risk as a determinant of renewable energy investments. *Energies*, *15*(4), 1498.

25. Stigka E, Paravantis JA, Mihalakakou GK. Social acceptance of renewable energy sources: A review of contingent valuation applications. Renewable and Sustainable Energy Reviews. 2014;**32**:100-106. DOI: 10.1016/j.rser.2013.12.026
26. Royster, J.V., 2008. Practical sovereignty, political sovereignty, and the Indian Tribal Energy Development and Self Determination Act. Lewis Clark Law Rev. 12, 1065.
27. C. Schelly, V. Gagnon, K. Arola, A. Fiss, M. Schaefer, K.E. Halvorsen, Cultural imaginaries or incommensurable ontologies? Relationality and sovereignty as worldviews in socio-technological system transitions, Energy Res. Soc. Sci. 80 (2021) 102242, https://doi.org/10.1016/j.erss.2021.102242
28. Greene D. Measuring energy security: Can the United States achieve oil independence? Energy Policy. 2010; **38**:1614-1621. DOI: 10.1016/j.enpol. 2009.01.041
29. Proskuryakova L. Updating energy security and environmental policy: Energy security theories revisited. Journal of Environmental Management. 2018;**223**:203-214. DOI: 10.1016/j. jenvman.2018.06.016
30. Danish Government. Energy Strategy 2050—From Coal, Oil and Gas to Green Energy. 2011. Available from: http://www.danishwaterforum.dk/ activities/Climate%20change/Dansk_ Energistrategi_2050_febr.2011.pdf [Accessed: 21 October 2019]
31. Janssen, R. (2002), *Renewable energy into the mainstream*, OECD/IEA, Paris, 54 pp.
32. Sovacool BK, Tambo T. Comparing consumer perceptions of energy security, policy, and low-carbon technology: Insights from Denmark. Energy Research and Social Science. 2016; **11:79**-91. DOI: 10.1016/j.erss.2015. 08.010
33. UNEP/OECD/IEA (2001), *Workshop on baseline methodologies - possibilities for standardized baselines for JI and the CDM – Chairman's recommendations and Workshop report*, Workshop on "Baseline Methodologies", Roskilde, Denmark, 7-9 May 2001, UNEP/OECD/IEA, Paris.
34. Kopp SD. Politics, Markets and EU Gas Supply Security. Case Studies of the UK and Germany. Berlin, Germany: Springer; 2014
35. Gnansounou, E., 2008. Assessing the energy vulnerability: case of industrialised countries. Energy Policy 36, 3734–3744.
36. Castán Broto, V. (2017). Energy sovereignty and development planning: The case of Maputo. *Mozam- bique. International Development Planning Review, 39*(3), 229248. https://doi.org/10.3828/idpr. 2017.9
37. Bitsa, D. (2019). The challenge of renewable energy sources as a leader to the New Energy Order. University of Piraeus. Retrieved on September 2nd, 2023, from https://dione.lib.unipi.gr/xmlui/handle/unipi/12517
38. Cergibozan, R. (2021). Renewable energy sources as a solution for energy security risk: Empirical evidence from OECD countries. Renewable Energy, An International Journal. Retrieved on March 2nd, 2024, from https://www.sciencedirect.com/science/article/abs/pii/S0960148121016384
39. Hafner, M., Tagliapietra, S. (2020). The Geopolitics of the Global Energy Transition. Lecture Notes in Energy. Retrieved on February 10th, 2023, https://library.oapen.org/bitstream/id/826718b9-f036-4a35-926e-6f5e32b78162/2020_Book_TheGeopoliticsOfTheGlobalEnerg.pdf
40. International Renewable Energy Agency. (2019). A New World: The geopolitics of energy transformation
41. Koliopoulos, K. (2010). The art of strategy from antiquity to the present day [in Greek]. Poiotita. Retrieved on June 30th, 2022.
42. Franza, L., Bianchi, M., Bergamaschi, L. (2020). The geopolitics of RES: Global trends. Istituto Affari Internazionali. Retrieved on September 2nd, 2022, from http://bitly.ws/zBWe
43. Matsumoto K, Doumpos M, Andriosopoulos K. Historical energy security performance in EU countries. Renewable and Sustainable Energy Reviews. 2018;**82**: 1737-1748. DOI: 10.1016/j.rser.2017. 06.058

44. Laldjebaev, M., Sovacool, B.K., 2015. Energy security, poverty, and sovereignty: complex interlinkages and compelling implications. In: International Energy and Poverty. Routledge, pp. 121–136
45. Kirsten Westphal, Strategic Sovereignty in Energy Affairs: Reflections on Germany and the EU's Ability to Act, 2021, http://dx.doi.org/10.18449/ 2021C07.
46. International Energy Agency (IEA). (2015). A fundamental look at supply side energy reserves for the planet. SHC Solar update. https://www.iea-shc.org/data/sites/1/publications/2015-11-A-Fundamental-Look-at-Supply-Side-Energy-Reserves-for-the-Planet.pdf. Accessed May 2017.
47. Duan, H.B., Zhu, L., Fan, Y., 2014. A cross-country study on the relationship between diffusion of wind and photovoltaic solar technology. Technol. Forecast. Soc. Chang. 83, 156–169.
48. Perez, et al., 2009. A Fundamental Look at Reserves for the Planet. Draft for publication in the IEA/SHC Solar update.
49. Pouran, H. M. (2018). From collapsed coal mines to floating solar farms, why China's new power stations matter. *Energy Policy*, *123*, 414–420.https://doi.org/10.1016/j.enpol.2018.09.010
50. Schelly, C., Bessette, D., Brosemer, K., Gagnon, V., Arola, K. L., Fiss, A., Pearce, J. M., & Halvorsen, K. E. (2020). Energy policy for energy sovereignty: Can policy tools enhance energy sovereignty? *Solar Energy*, *205*, 109–112. https://doi.org/10.1016/j.solener.2020.05.056
51. Martha Maria Frysztacki, Jonas Hörsch, Veit Hagenmeyer, Tom Brown, The strong effect of network resolution on electricity system models with high shares of wind and solar, Appl. Energy (ISSN: 03062619) 291 (2021) 116726, http://dx.doi.org/10.1016/j.apenergy.2021.116726.
52. Liu J. China's renewable energy law and policy: A critical review. Renewable and Sustainable Energy Reviews. 2019; **99**:212-219. DOI: 10.1016/j.rser.2018. 10.007
53. Zhang D, Wang J, Lin Y, Si Y, Huang C, Yang J, et al. Present situation and future prospect of renewable energy in China. Renewable and Sustainable Energy Reviews. 2017; **76**:865-871. DOI: 10.1016/j. rser.2017.03.023
54. Wang B, Wang Q , Wei Y-M, Li Z-P. Role of renewable energy in China's energy security and climate change mitigation: An index decomposition analysis. Renewable and Sustainable Energy Reviews. 2018;**90**:187-194. DOI: 10.1016/j.rser.2018.03.012
55. , Hu H, Tan T, Li J. China's renewable energy goals by 2050. Environmental Development. 2016;**20**: 83-90. DOI: 10.1016/j.envdev.2016. 10.001
56. Zhang L, Sovacool BK, Ren J, Ely A. The dragon awakens: Innovation, competition, and transition in the energy strategy of the People's Republic of China, 1949–2017. Energy Policy.
57. U.S. Chamber of Commerce. Index of U.S. Energy Security Risk: Assessing America's Vulnerabilities in a Global Energy Market. Washington D.C., USA: U.S. Chamber of Commerce; 2013. Available from: https://www.globalene rgyinstitute.org/sites/default/files/Idex %20of%20US%20Energy%20Security% 20Risk.pdf
58. Sivaram, V., Saha, S., 2018. The geopolitical implications of a clean energy future from the perspective of the United States. In: The Geopolitics of Renewables. Springer, Cham, pp. 125–162.
59. Bazilian, M., Sovacool, B., Moss, T., 2017. Rethinking energy statecraft: United States foreign policy and the changing geopolitics of energy. Glob Policy 8, 422–425
60. Speirs, J., McGlade, C., Slade, R., 2015. Uncertainty in the availability of natural resources: fossil fuels, critical metals and biomass. Energy Policy 87, 654–664. http://dx.doi.org/10.1016/j.enpol.2015.02.031. ISSN 0301-4215.
US Department of Energy, 2001. Energy in Brief.
61. CambridgeIP, 2014. The Acceleration of Climate Change and Mitigation Technologies: Intellectual Property Trends in the Renewable Energy Landscape. Global Challenges Brief. WIPO, Geneva [Online]. www.wipo.int/globalchallenges.
62. Su CW, Khan K, Umar M, Zhang W. Does renewable energy redefine geopolitical risks? Energy Pol 2021;158:112566.
63. Cai Y, Wu Y. Time-varying interactions between geopolitical risks and renewable energy consumption. Int Rev Econ Finance 2021;74:116–37.

64. Correlje A, Van der Linde C. Energy supply security and geopolitics: a European perspective. Energy Pol 2006;34(5):532–43.
65. Wei YM, Liang QM, Wu G, Liao H. Effects of clean and renewable energy on national energy security. In: Energy economics. Emerald Publishing Limited; 2019. p. 253–70.
66. Li K, Yuan W. The nexus between industrial growth and electricity consumption in China–New evidence from a quantile-on-quantile approach. Energy 2021;231: 120991.
67. Rodríguez-Fern´andez L, Carvajal ABF, Ruiz-Go´mez LM. Evolution of European Union's 'energy security in gas supply during Russia–Ukraine gas crises (2006–2009). Energy Strategy Rev 2020;30:100518.
68. Eyraud, L., Wane, A.A., Zhang, C., Clements, B., 2011. Who's going green and why? Trends and determinants of green investment. IMF working paper. WP/11/296.
69. Hatipoglu, E., Al Muhanna, S., Efird, B., 2020. Renewables and the future of geopolitics: revisiting main concepts of international relations from the lens of renewables. Russian J. Econ. 6, 358–373.
70. Goldthau, A., Westphal, K., Bazilian, M., Bradshaw, M., 2019. Why the energy transformation will reshape geopolitics. Paths to a low-carbon economy will create rivalries, winners and losers. Nature 569, 2–5.
71. Scholten, D.J., 2013. The reliability of energy infrastructures; the organizational require- ments of technical operations. Compet. Regul. Netw. Ind. 14 (2), 173–205 (special issue).
72. Grin, J., Rotmans, J., Schot, J., Geels, F., & Loorbach, D. (2010). Transitions to sustainable development-Part 1. New directions in the study of long term transformative change. New York: Routledge.
73. Haas, R., Eichhammer, W., Huber, C., Langniss, O., Lorenzoni, A., Madlener, R., et al. (2004). How to promote renewable energy systems successfully and effectively. Energy Policy, 32(6), 833–839.
74. U.S. Environmental Protection Agency. (n.d.). Geothermal Heating and Cooling Technologies. Retrieved on March 20th, 2022, from https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies
75. Erisen, B., Akkus, I., Uygur, N., Kocak, A., 1996. Geothermal Inventory of Turkey. Printing Office of MTA, Ankara (Turkish).
76. [1] Lund, J., Toth, A. (2020). Direct utilization of geothermal energy 2020 worldwide review. Geothermics. Retrieved on December 20th, 2021, from https://www.researchgate.net/publication/346999421_Direct_utilization_of_geothermal_energy_2020_worldwide_review
77. U.S. Environmental Protection Agency. (n.d.). Geothermal Heating and Cooling Technologies. Retrieved on March 20th, 2024, from https://www.epa.gov/rhc/geothermal-heating-and-cooling-technologies
78. International Energy Agency. (2023). Geothermal power. Retrieved on December 20th, 2023, from https://www.iea.org/reports/geothermal-power
79. Gray, C., Sloan, G. (2013). Geopolitics, Geography and Strategy. Routledge. Retriever on June 30th, 2022.
80.