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A Review Study on Energy Diplomacy & Energy Economics as 2 Wings of Development!

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Abstract

We live in a World, that the cornerstone of it, is the economy! Although the sustainable and effective development of energy diplomacy will be possible after understanding global trends, economic fundamentals, analysis and mastery of business strategies, in the current situation, specific frameworks and strategies can be envisaged to be implemented at specific levels and designed at larger levels to Be on the agenda. The envisaged framework for the development of cooperation includes three sections: upstream (exploration and development), intermediate (trade, transmission and storage) and downstream (refining and chemical industries, from production to retail). Each section requires a business analysis tailored to its requirements, some of which are outlined below:

Upstream: investment trends of neighboring countries, capital allocation priorities, active actors and contractual patterns;

Intermediate and downstream: energy consumption basket, trends and prospects of supply and demand of oil and petroleum products, road and maritime transport market;

Downstream: Industrial development programs, investment developments in downstream industries, supply of key industries feed and household consumption trends.

Energy diplomacy is a form of diplomacy, and a subfield of international relations. It is closely related to its principal, foreign policy, and to overall national security, specifically energy security. Energy diplomacy began in the first half of the twentieth century and emerged as a term during the second oil crisis as a means of describing OPEC's actions. It has since mainly focused on the securitization of energy supplies, primarily fossil fuels, but also nuclear energy and increasingly sustainable energy, on a country or bloc basis. Energy diplomacy emerged as a term during the second oil crisis as a means of describing OPEC's actions and of characterizing the quest for the United States to secure energy independence and the Cold War relationship between Russia and satellite states regarding oil and gas exports. Since the oil crises, energy diplomacy has mainly focused on the securitization of energy supplies on a country or bloc basis and on the foreign policy to obtain that energy security. Politics is in fact a decision-making process. More specifically, politics refers to the attainment of authority in government and government, and organized control over human society. In addition, the policy is to study or implement the distribution of power and resources in each community as well as the common relationships between different communities. "But well ... the first mistake in politics is to get into it!"

Keywords: Energy Diplomacy; Energy Consumption; Energy Economics

Introduction

Energy diplomacy

Energy diplomacy is a form of diplomacy, and a subfield of international relations. It is closely related to its principal, foreign policy, and to overall national security, specifically energy security. Energy diplomacy began in the first half of the twentieth century and emerged as a term during the second oil crisis as a means of describing OPEC's actions. It has since mainly focused on the securitization of energy supplies, primarily fossil fuels, but also nuclear energy and increasingly sustainable energy, on a country or bloc basis.

Background

Energy diplomacy emerged as a term during the second oil crisis as a means of describing OPEC's actions and of characterizing the quest for the United States to secure energy independence and the Cold War relationship between Russia and satellite states regarding oil and gas exports. Since the oil crises, energy diplomacy has mainly focused on the securitization of energy supplies on a country or bloc basis and on the foreign policy to obtain that energy security.

Ontological Relationship with National Security, Foreign Policy & Energy Security

Foreign politics has been around for thousands of years of our civilization, while energy has only entered in the last 150 years. However, in that period foreign policy and energy have had an increasing number of overlapping and interconnected elements. Foreign policy in its own part is closely linked and dependent on the concept of national security. National security is a principle of actions governing relations of one state with others based on geography, external threats and other national security challenges, of which energy is one. The three concepts, national security, foreign policy and energy security are ontologically structured, where national security is the most general concept, foreign policy is one level lower covering the international aspect of national security risks, and the lowest on the scale is energy diplomacy. Foreign policy is linked to national security as it is the tool which implements overall national security. National security also has a direct link to energy diplomacy. National security denotes the capability of a nation to overcome its internal and external multi-dimensional threats by balancing all instruments of state policy through governance. It aims to protect national independence, security and territorial, political and economic integrity, dealing with a large number of national security risks. Energy is one of the fundamental items on the national security agenda. National security that deals with such external issues and risks is applied and implemented by government departments for external relations. Implementation of the national security strategy involving external factors and international issues is carried out through foreign policy instruments, namely international relations and diplomacy. Energy diplomacy specifically focuses on external energy relations. Despite the ontological hierarchy of the three concepts, it is a recurring theme for them to continuously intersect in practical diplomatic life and the geopolitical reality [1-10].

History

The beginning of the 20th century was the early era of energy diplomacy, which was largely marked by corporate players. Such diplomacy was dominated by the corporations that produced and distributed fossil fuel, rather than sovereign governments, as in the case of Royal Dutch Shell and Standard Oil. National security on a national level as a concept in its own right has not yet been formulated, but the energy issues were increasing in importance. Carving up the global oil reserves and markets was carried out persistently, alike during the 1908 negotiations between Royal Dutch Shell legendary head Mr. Deterding and the US Standard Oil director Mr. Teagle; or on the occasion of signing the US "As-Is" Pool Association agreement in 1928. The corporations were competing and racing over privileges, quotas and allocations. The governments were not too far behind, supporting them and often facilitating the race, but the influential corporations dominantly shaped the industry and foreign policy.

Post World War II era experienced fall of empires, rise of colonies, global shifts in geopolitical influence of UK, US, Russia and others. It is the OPEC that has succeeded in the 1960s and 1970s to gain ground in relation to the international oil corporations, nationalizing and regaining control over the national fossil fuel resources in several large producing countries. The oil shocks after WWII were the ones that greatly contributed to the growth of security concerns and diplomatic efforts in the energy sphere. The most important occurrences were the Suez Crisis of 1956-1957 and the OPEC oil embargo of 1973-1974. Whole economies were brought near to a standstill, escalating energy issues as top security concerns. Soon came other disruptions, albeit smaller, caused by the Iranian revolution of 1979, the Iran-Iraq War of 1980 followed by the first Persian Gulf War in 1990-1991. Turbulences on the oil market that disturbed and endangered economies were also caused by the 2003 Iraq invasion, oil price spike of 2007-2008, Russian Ukrainian gas dispute in 2009, and others including smaller disruptions. Oil passages are still a global security concern as 40% of all oil transits via four conduits of the straits of Hormuz, Malacca, Rab-el-Mandeb and the Suez Canal. International Energy Agency (IEA) expects that these quantities will rise from 40% to 60% by 2030. Any longer interruption would cause another large-scale economic downfall.

Therefore, energy diplomacy has entered the domain of foreign policy through the national security passageway. Numerous grave national and international risks associated with energy security and energy diplomacy have paved this way and assured that energy is viewed and judged as a security concern, so it acquired all the features of a security issue, and is constantly monitored for level of risk, potential prevention or intervention in the diplomatic field. Next to the security path, energy concerns have entered foreign policy considerations via another path, the economy. A valid example is Australia, which has in 2018 decided to form a new policy body titled energy diplomacy. Australia, being by far the largest global exporter of coal, has only been mildly affected by the shifts on the market and geopolitics of energy, so its security risk concerning energy has not been very high.

The Rise of Energy Risks and Main Issues

Energy diplomacy is a growing diplomatic field, aimed at providing energy security. Energy has entered the sphere of diplomacy and foreign policy as a result of its rising impact on national security and economy. Energy, the ability to do any work, powers the economy. Its uninterrupted flow, inward for importing countries, and outward for exporting, must be secured at all times. Until the last few decades of the 20th century the

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question of energy was not treated as a matter of such urgency nor in geopolitics. The availability, affordability and supply were not a security issue. The industrial production and consumption capacities were smaller, and movement of energy was generally safe and dependable. Throughout the industrial revolution the increasing need for energy grew at a remarkable pace, spiraling in the 20th century. Only in the last 50 years, between 1971 and 2017 world total primary energy supply grew by more than 250%. Energy use worldwide is yet to grow by one-third by 2040. The changed situation generated a series of factors that required energy security and energy diplomacy to be elevated onto the national security agenda. National security departments worldwide closely monitor the severe escalation of energy use. The modern consumer and the contemporary economy have gradually grown to critically depend on energy. Hence, economy and energy have become inseparable concepts. Energy has become a synonym for the economy and power, and not having enough of it became a concern of the utmost national security. Access to energy resources has decided on war outcomes, security of supply shaped national and international agendas, oil and gas producing countries organized together into coalitions, tapping into the newly discovered energy resources to back their political and geopolitical goals. Oil and gas companies became some of the most influential organizations in the global business and power-influencing arena. Oil price volatility caused by oil shocks spelled economic fortunes or disasters for many participants in the international arena affecting national and geopolitical strategies. The economic consequences were considerable, so energy had to be included on the list of security and foreign policy issues of states.

Nature of Energy Diplomacy

Energy diplomacy refers to diplomatic activities designed to enhance access to energy resources and markets. It is a system of influencing the policies, resolutions and conduct of foreign governments and other international factors by means of diplomatic dialogue, negotiation, lobbying, advocacy and other peaceful methods. The general relationship between foreign policy and energy diplomacy is conceptually one of principal and agent. Foreign policy sets the goals and overall political strategy while energy diplomacy is a mechanism for achieving the goals. Energy diplomacy is an instrument of foreign policy. The purpose of energy diplomacy is to safeguard economic and energy security. Energy diplomacy channels economic and trade relations of a state with other states and organizations safeguarding Energy security through availability, reliability and affordability.

Diplomatic efforts aimed at providing energy security grew in importance and complexity. It matured and spun off from general foreign policy and public diplomacy into a separate diplomatic niche field, energy diplomacy, mostly after the 1970s oil crises. This diplomatic activity has several other popular names like “geopetroleum politics”, or “petro-politics” or pipeline diplomacy, but it mostly covers the same field. Energy diplomacy has developed its own programs, goals, instruments, tactics and action plans, such as the European Union Energy Diplomacy Action Plan. Thus, at the institutional level, energy diplomacy typically focuses on such topics as targets and guidelines; regulations and energy saving; the development of nuclear energy; research and development and demonstration; oil sharing; energy transportation; energy exploration; energy early warning and response; and, in the context of global warming, energy sustainability and energy transition for hydrocarbon exporting states. Commercial energy diplomacy, a hybrid of commercial diplomacy and energy diplomacy, involves political support for foreign-investing energy businesses.

Energy diplomacy employs foreign policy methods to ensure a steady flow of energy and security of energy supplies. Energy producing and energy consuming countries apply them differently. Energy producing states mostly focus on using energy diplomacy to expand their exports and presence on the global markets. The example is the energy diplomacy of an exporting state, Russia, who aims to secure access to buyers for oil and gas. It is similar with the energy diplomacy of the Organization of the Petroleum Exporting Countries (OPEC), whose focus is similarly export and keeping external demand. Energy consuming and importing states apply energy diplomacy to secure energy supplies and steady inflow, like China’s oil diplomacy in Africa or more recently, with Iran. There are also hybrid strategies, which are retained by states that are both large consumers and producers; such are India and the United States.

Energy Diplomacy and The Energy Transition

Although the integration of energy diplomacy into foreign policy for some states has been security and the others economy, the energy transition is reshaping those dynamics so that questions of security and economy will follow a new geopolitical reality. The dynamics of the relationship with foreign policy and national security is thus undergoing a fundamental change energy transition. Providing energy security has traditionally included several key notions: availability, reliability and affordability, but in the past two decades another crucial aspect is added environmental sustainability and transition to low carbon energy.

This has initiated a huge shift in how energy is perceived, its toll on the environment and it prompted policies to curb climate change. It was spearheaded by policy makers in the EU. With the proliferation of more renewable energy in the energy mix, like solar, tidal, energy efficiency, wind or water, the geography of resources will not be limited to only a few resource rich countries, but much more evenly spread throughout the world. The way national energy risks are perceived is gradually changing, as energy availability will be significantly improved and more prevalent all over the planet. The energy transition into low carbon energy is already shaping the dynamic relationship of geopolitics, national security strategies, foreign policies and energy diplomacy various

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scholars argue that renewable energy may cause more small-scale conflicts but reduce the risk of large conflicts between states.

The global energy mix has been dominated by fossil fuels for decades with relatively little change. The share of fossil fuels in total final energy consumption fell from about 85% in the early 1970s but has stagnated at about 80% since that time. However, this situation is beginning to change due largely to the rapidly falling costs of renewable energy technologies and growing awareness of the negative environmental impacts of carbon dioxide emissions from fossil fuel combustion. Consistent with the various definitions of "energy transition", changes in our energy and economic system throughout the remainder of this century will be characterized by a shift from reliance almost entirely on fossil to a much greater reliance on renewable energy. This rise of renewable energy will be accompanied by increased electrification and digitalization across all energy sectors as well as decentralization of energy supply. This multifaceted, low-carbon energy transition will fundamentally alter the geopolitics of energy in a number of ways, including a changing of power relations among and between energy producers and consumers. Hydrocarbon-exporting countries face potentially negative economic and political impacts from reduced energy exports while energy importing countries can benefit from greater energy self-reliance and, in some cases, the export of clean energy technologies.

As such challenges and opportunities evolve, management of international relations via diplomacy will become an increasingly important instrument of foreign policy as countries strive for strategic positioning in the future energy landscape. While various forms of multilateral diplomacy are important in concurrently aligning the energy transition interests of multiple stakeholders, bilateral diplomacy is the most direct means of pursuing national interests. The Gulf Cooperation Council (GCC) countries rely significantly on oil export revenues to meet their budgetary needs and therefore face a potentially challenging future should a low-carbon energy transition result in a significant reduction in global demand for oil. To counter this challenge, GCC countries need to forge strong bilateral relationships that will yield security of energy demand as well as new economic opportunities that arise from a low-carbon energy transition. The United Arab Emirates (UAE) is a GCC country that has been developing strategic bilateral relationships regionally and globally in an effort to effectively position for such an energy transition. This paper considers energy diplomacy as it relates to the geopolitics of a low-carbon energy transition. The UAE's bilateral energy diplomacy directions serve as a case study for the development of foreign policy recommendations that support the UAE's ongoing efforts and provide guidance for other hydrocarbon-exporting countries facing an uncertain future energy landscape.

Methodology

The research method employed for this work is the case study method. This method enables the exploration of complex issues and is considered a robust approach when an in-depth investigation is needed to examine a particular topic. The energy diplomacy of hydrocarbon-exporting countries during a low-carbon energy transition is one such complex topic for which the case study method is useful. The UAE is selected as the case study for this paper because it is a major hydrocarbon-exporting country that has an articulated, strategic emphasis on diplomacy in its foreign affairs. Evidence that these efforts have been effective is provided by the country's establishment of diplomatic relations with 189 countries and formalization of these relations through the establishment of 82 embassies abroad and the hosting of 110 foreign embassies and 15 regional and international organizations in the country. Furthering these diplomatic efforts, in 2017 the UAE launched its Soft Power Strategy, which aims to increase the UAE's global reputation abroad by highlighting to the world its identity, heritage, culture and global contributions. The pillars of this strategy are diplomacy in its many forms, including humanitarian, scientific and academic, cultural and economic.

1. Background

Energy Transition and its Geopolitical Impacts

Predicting the ultimate extent of a low-carbon energy system transition and the pace at which it will occur is a somewhat complex matter that depends on multiple socio-political factors. Nonetheless, current trends point toward a significant increase of renewable energy in the power sector by the middle of this century coupled with major advances in transportation electrification. As evidence of the trend, renewable energy, excluding large hydro, was responsible for 61% of new power generation capacity worldwide in 2017 and the annual growth in electric passenger car sales has remained at nearly 60% every year from 2015 through 2018. Given such developments, Bloomberg New Energy Finance (BNEF) projects that by 2050 renewable energy will account for approximately 64% of global electricity generation while electricity generation itself will increase by nearly 57% to 38,685 TWh. In even more ambitious projections, IRENA has stated that if the climate objectives of the 2015 Paris Agreement are to be met, by 2050 85% of global power generation must come from renewable energy with solar and wind energy having the predominant share.

In the transportation sector, BNEF projects that by 2040 55% of all new car sales and 33% of all light duty vehicles on the road could be electric, resulting in the displacement of about 7.3 million barrels per day (mbpd) of transportation fuel and an additional 2,000 TWh of electricity demand. Because of this trend in vehicle electrification coupled with shared mobility and improved vehicle efficiency, oil demand for petrochemical production will begin to outpace oil demand for transportation. According to the IEA, petrochemicals are expected to account for more than one-third of the growth in new oil demand between now and 2030, and nearly half of the growth in new oil demand to 2050.

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Although current trends have led to a growing consensus that an "energy transition" is underway, social and political dynamics will be a key determinant of the extent to which clean energy technologies are adopted. Among the many published global energy outlooks, those published by the Institute of Energy Economics, Japan (IEEJ) and Equinor are two that provide insight into how such a low-carbon energy transition may unfold differently based on uncertain social, economic and political dynamics that may unfold globally in the coming years. Rapid and significant proliferation of clean energy requires a world in which strong global energy governance that prioritizes sustainability emerges. Weak global energy governance, on the other hand, is more likely to retard the deployment of clean energy technologies, particularly when accompanied by international political strife. Hence, geopolitics is at the core of energy transition. Just as geopolitics are foundational to the energy transition, the widespread diffusion of clean energy into the global energy system will significantly impact geopolitics. The geopolitical impacts of renewable energy derive from the following intrinsic features of renewable energy:

- Global abundance with many countries having access to multiple renewable resources that include sun, wind, hydro, biomass, geothermal or ocean
- Intermittency of the fastest growing forms of renewable energy, solar and wind
- Opportunity for distribution of generation rather than reliance on centralized generation
- Dependence on technologies that are made from minerals and rare-earth metals that are geographically concentrated in selected parts of the world

Based on these characteristics, power relations between energy producers and consumers will be altered as energy markets become increasingly defined by the combination of resource abundance, energy self-reliance and interconnectivity of electrical grids rather than the historical combination of energy resource scarcity and geographical concentration that requires transport of energy over long distances to reach end markets. Furthermore, the increased importance of electricity as an energy carrier will make digitalization a key component of a low-carbon energy transition and further empower those countries that are the most advanced in digital capabilities. Given such expected geopolitical impacts of a low-carbon energy transition, countries must be prepared to adapt their foreign relations for the protection of their national interests [11-20].

Energy diplomacy

Although there is no exact definition for energy diplomacy, it pertains to government-related foreign activities that aim to ensure a country's energy security while also promoting business opportunities related to the energy sector. Among the set of foreign policy tools that can be leveraged to support a country's energy interests during a global energy transition, diplomacy is one of the most important and can be either bilateral or multilateral in scope. A large-scale transformation of the energy system to one predominantly based on clean energy will certainly require aligning the interests of multiple parties through multilateral diplomacy. Global energy governance is perhaps the most important form of multilateral diplomacy for a large-scale energy system transformation as it seeks to ensure on a global scale security of energy supply and demand, economic development, international security, environmental sustainability and domestic good governance. Global energy governance is particularly challenging, however, because energy governance most often lies within national borders. This bounded notion of energy governance creates a "paradox of sovereignty" whereby countries fail to act collectively despite the fact that globalization of energy markets increasingly diminishes their control over their individual energy interests. Although global energy governance is being pursued by a variety of intergovernmental organizations, clubs, forums, networks, partnerships, multilateral institutions and United Nations entities, the potential for strong governance remains unrealized due to fragmentation of the actors involved and their genuinely different interests. Therefore, while it is imperative that countries engage in the pursuit of global energy governance via the prominent organizations such as the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA) and the Organization of Petroleum Exporting Countries (OPEC), other means of diplomacy will be more effective in the directed pursuit of national interests. Bilateral diplomacy, which involves direct diplomatic engagement between two countries, is both efficient and flexible because with fewer parties involved, coordination costs are lower and interests are easier to align. As outlined in the Vienna Convention on Diplomatic Relations, diplomacy between nations involves the protection of the interests of one country within the borders of another through information gathering, the promotion of friendly relations and negotiation. Given this scope, bilateral diplomacy can be particularly effective when encompassing the pursuit of common interests between countries as well as addressing differences and commonalities related to culture, politics and economy.

The depth of bilateral diplomatic relations that one country establishes with another can be positioned as special, normal or peripheral. While normal engagement between countries involves regular engagement via embassies, consulates and other diplomatic channels, special relations typically involve a broader number of actors, employ diverse modes of engagement and serve a distinct strategic purpose. Such special bilateral relations typically arise between countries with strong political, security or economic links. Geopolitical challenges that will arise during an energy transition make the establishment of special bilateral diplomatic relations increasingly important. Once bilateral diplomatic relations are established, the effectiveness of these

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relations in supporting a country's energy interests depends on the power or influence that a country is able to establish with its counterparts. "Soft power" is a very important concept in this regard because soft power is defined as the means by which one country gets other country to do what it wants via perceived legitimacy, attractiveness of ideology and culture, and societal norms. In essence, soft power is about affecting behavior without commanding it. Although countries with sufficient resources may succeed in an energy transition by exercising "hard power" tactics of coercion and/or payment, most countries lack the physical and/or financial resources to implement a hard power approach to achieving their foreign energy policy objectives. Pascual has outlined how hard power tactics can work in energy markets via his Rules of Six framework and applied this framework to a selected set of countries and regions. His analysis shows that such tactics are not likely to be successful during an energy transition for all but a small number of countries the possess substantial natural, military and/or economic resources, such as China. Even China, however, has been aggressively pursuing the establishment of soft power to achieve its energy interests. Hence, the importance of trust and collaborative partnership in energy relations makes bilateral diplomacy, which is a key tool of soft power, essential for international relations during an energy transition.

2. GCC Bilateral Energy Diplomacy

Strategic objectives

As with all forms of foreign policy, foreign energy policy is designed to protect and support national interests. National energy interests are concerned with energy related societal goals, including universal access to reliable and affordable energy that supports economic development. Energy security, including energy availability, is perhaps the defining feature of national energy policy, although other essential elements are energy affordability, energy efficiency, environmental preservation, energy sector regulation and energy sector governance. For GCC countries, energy security and economic efficiency in the power sector are key energy policy concerns. Hence, renewable energy, electricity trade, natural gas supply and nuclear energy would be expected to play an important role in the foreign energy policies and bilateral energy diplomacy efforts of GCC countries.

Although GCC countries have historically had access to cheap and abundant supplies of natural gas and oil to meet their domestic energy demands, this situation has begun to change in recent years. While oil remains abundant in the GCC with the region accounting for about 30% of proven crude oil reserves and 28% of oil exports globally, all GCC countries with the exception of Qatar have experienced a shortfall of domestic natural gas production to meet growing domestic demands. This shortfall in regional natural gas supply has triggered countries throughout the GCC to explore their options for increasing natural gas supply as well as reducing natural gas demand. Although Qatar has abundant natural gas resources, Qatar's political differences with Saudi Arabia, Bahrain and the UAE have made it impossible for it to be a key natural gas supplier across the GCC. Rather, bilateral energy relations between GCC countries is currently limited to pipeline natural gas exports from Qatar to both the UAE and Oman via the Dolphin pipeline and liquefied natural gas (LNG) shipments to Kuwait. Given this situation, GCC countries, are pursuing the development of their own indigenous natural gas resources as well as the deployment of clean energy, including both nuclear and renewables, to achieve domestic energy security at the lowest possible cost.

Although the procurement and domestic deployment of renewable energy is unlikely to have any significant implications for the bilateral diplomatic relations of GCC countries, development of challenging sour and shale natural gas resources as well as the deployment and operation of nuclear energy requires significant foreign engagement for access to specialized skills and technologies. The UAE's access to South Korean nuclear technology and training, for example, is based on a bilateral agreement signed in 2009 between the UAE and South Korea. Both Russia and China have significant interest in using their nuclear technology capabilities to establish foreign influence and so are positioning strongly for Saudi Arabia's proposed nuclear program. Despite the importance of domestic energy security and economic efficiency, the more pressing foreign energy policy concern for GCC countries that arises specifically from a low-carbon energy transition is monetization of hydrocarbon resources. With the exception of Qatar, which is a major global exporter of LNG, GCC countries are primarily concerned with securing markets for their crude oil exports and hydrocarbon products.

Global demand for crude oil is expected to remain significant in the coming decades but the extent of demand is highly uncertain. If demand for oil falls significantly as some scenarios suggest, the price of oil is expected to fall as well. This means that even if GCC countries remain major oil exporters because they are low cost producers and succeed with current efforts to contain domestic energy demand growth, resulting government revenues could be very negatively affected. For example, in IEEJ's Peak Oil Demand scenario, a large-scale shift to electric vehicles reduces global oil demand to 88.7 mbpd by 2050, which is a 33 mbpd reduction relative to their Reference scenario. The projected impact on Middle Eastern countries in this scenario is $1.6 trillion in foregone oil export revenues in 2050, which would be equivalent to 13% of nominal GDP for these countries and based primarily on reduced oil prices rather than reduced demand for Middle Eastern oil. Rowland and Mjelde have also shown that Middle Eastern countries, and particularly those in the GCC, are likely to have robust demand for their oil exports in the coming decades but face significant uncertainty in their oil export revenues. Their study shows that a 2.5%-10% reduction in world oil demand would reduce the oil export revenues of GCC countries by anywhere from 5% to 40% depending on the particular country and the extent of global oil demand reduction.

Substantially reduced oil export revenues would have a major impact on GCC countries under their current economic

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structures. Across the GCC countries, fiscal revenues are more than 50% derived from hydrocarbon exports and any significant diversification in GDP is largely based on investments and expenditures made using hydrocarbon export revenues. It is therefore critical for GCC countries to diversify their economies to reduce this dependence. Diversification efforts will include a greatly increased focus on petrochemicals for monetization of oil and gas resources as well as the development of new economic sectors that are not directly tied to hydrocarbons. Given the context of GCC countries in a low-carbon energy transition, their priority efforts in energy diplomacy should support long-term monetization of hydrocarbon resources and development of diversified economic sectors. For both priorities, relations with Asia are particularly important. Growing energy interdependence between GCC and Asian economies has supported a pivot in GCC trade relations towards Asia in recent years with China, Japan, India and South Korea serving as vital Asian partners given current levels of energy imports from the GCC. China is perhaps the most important Asian country for strategic consideration given the potential positive impacts of its Belt and Road Initiative on Middle Eastern countries. However, diversified relationships across Asia remain important for GCC countries to create a greater balance of relational power with China. A strategic framework for development of special bilateral diplomatic relations between GCC and Asian countries positions energy at the core, infrastructure and investment as a next level of engagement and finally joint development of advanced technologies as an ultimate ambition. This framework, which is consistent with China's articulated approach to engaging Arab countries, builds on current bilateral energy relations to further support GCC countries in their economic diversification efforts.

UAE Case Study

Based on hydrocarbon trade data, the UAE's core energy relationships are currently with China, India, Japan, South Korea, Singapore and Thailand. Each of these countries factors strongly into the UAE's foreign policy not only as a market for oil exports, but also for broader energy and economic relations. Referring to the classification of bilateral diplomatic relations as special, normal and peripheral, each of the UAE's key Asian energy trade partners has a special relationship with the UAE. However, the special partnerships with Northeast Asian countries and India have each been upgraded since the start of 2017 to a "strategic" level. Furthermore, the major bilateral diplomatic meetings that launched these enhanced relations have resulted in expanded energy partnerships. This strengthening of bilateral relations between the UAE and its Asian partners during an early phase of global energy transition is logical. Falling oil demand reduced oil prices would push high-cost producers out of the market, making oil importing countries more reliant on low cost producers in the Middle East. For this reason, Asian economies that will continue to be significant energy importers should seek long-term partnerships for energy supply with stable countries that are expected to be long-term energy exporters. The UAE is well positioned to fill this role given its stable political environment and ongoing economic diversification aimed at building strong economic foundations.

Through the China National Petroleum Company (CNPC), China has already become a major player in ADNOC's oil and gas sector. Not only has CNPC been awarded stakes in ADNOC's onshore and offshore concessions, ADNOC awarded in July 2018 a USD 1.6 billion contract to CNPC subsidiary BGP for onshore and offshore 3D seismic surveying, which will be completed by 2024. This relationship development follows the 40% stake awarded to CNPC in 2014 in the Al-Yasat joint venture with ADNOC. CNPC is also positioned to engage in the development of Abu Dhabi's abundant sour gas fields as the UAE works to increase its natural gas production.

China Petroleum Engineering and Construction (CPECC) has also represented China in the UAE via its work in constructing the 1.5mn b/d Habshan-Fujairah pipeline, which allows UAE crude oil to be loaded on ships that don't need to pass through the Strait of Hormuz. This bypass option is important because the Strait of Hormuz is a major chokepoint for global oil trade that could have major global economic implications if completely or partly closed due to Middle East conflict.

Notably, the depth of the UAE's relations with China extend beyond those established by ADNOC. Mubadala Investment Company, Abu Dhabi's global multi-sector investment company whose board Chairman is His Highness Sheikh Mohamed bin Zayed Al Nahyan, established the UAE-China Joint Investment Fund as a partnership between Mubadala, China Development Bank Capital and China's State Administration of Foreign Exchange. The fund will invest in assets in the UAE and China and demonstrates the second layer of strategic engagement between GCC and Asian economies, which is joint investment and infrastructure development. The UAE has also strengthened energy relations with Japan, which is currently the country's largest oil export market. Japan has secured stakes in Abu Dhabi's onshore oil concession as well as multiple offshore concessions and exploration rights for onshore exploration in Abu Dhabi. Through the concessions, Japan will remain an oil partner with the UAE at least until 2058. Similar to its engagement with China, the UAE is building strong investment links with Japan as part of the comprehensive strategic partnership between Japan and the UAE.

While the UAE has clearly developed strategic alignment with Asia for its upstream development plans and broader investments, the UAE's ambition for its hydrocarbon sector is to aggressively move into petrochemicals since this is the fastest growing source of global oil demand and is therefore important to the long-term monetization of the country's abundant oil and gas resources. ADNOC is investing USD 45 billion by 2025 to develop Abu Dhabi into what it hopes will be the world's largest integrated refining

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and petrochemicals complex and also taking equity in overseas downstream projects to secure end markets for its products. Overseas opportunities are a key aspect of UAE energy diplomacy as the UAE wants to partner with countries in the development of their refining and petrochemicals capacity rather than having these countries develop their own capacity. ADNOC's strategic commitment to overseas engagement is demonstrated by the 25% equity stake the company has taken in India's proposed Ratnagiri refining and petrochemicals complex. This is ADNOC's first overseas downstream investment and follows the establishment of the comprehensive bilateral strategic partnership with India in 2017. ADNOC has also engaged with CNPC for Chinese investment in UAE petrochemical and refining plants and joint UAE-China investment in downstream assets in China.

In addition to ADNOC, Mubadala is supporting the UAE in its push for downstream activity via investments abroad. The CEO of Mubadala Petroleum and Petrochemicals has stated that petrochemicals are "an enabler for the new industrial revolution" and Mubadala's recent investments abroad reflect this sentiment. In early 2018, Total and Mubadala's Novealis Holdings, which consists of Mubadala subsidiaries Borealis (64% Mubadala owned) and Nova Chemicals (100% Mubadala owned and based in Canada), formed a USD 1.7 billion joint venture to produce petrochemicals on a 50:50 basis at Port Arthur, Texas in the United States. Further, Mubadala and ADNOC are joint owners of the UAE's key petrochemical producer, Bourage (60% ADNOC ownership and 40% Borealis ownership, with Mubadala owning 64% of Borealis directly and 24.9% of Austria's OMV, which owns 36% of Borealis). Borouge currently has three polyolefin plants in Abu Dhabi with a combined capacity of 4.3 million tons per year. This capacity is expected to significantly expand as part of ADNOC's downstream investment strategy.

Although Asia is clearly a key target for the UAE's bilateral energy diplomacy, it should not be overlooked that regional and European countries will play an important role in the country's energy future. The UAE's strong diplomatic relations with the United Kingdom, France and Italy are reflected in the significant engagement of BP, Total and Eni in Abu Dhabi's onshore and offshore oil development. Eni has taken a particularly strong interest in the UAE securing not only offshore oil development concessions, but also major stakes in Abu Dhabi's ultra-sour gas development, oil and gas exploration, refining and petrochemical production activities.

The UAE's strategic bilateral partnership with Russia, which includes energy and regional security as foundational elements, was established in June 2018 to promote common interests in oil, gas and nuclear energy and builds on the 2013 establishment of Mubadala's USD 2 billion Russian Direct Investment Fund (RDIF). The UAE's bilateral partnership with Russia is important because the UAE and Russia have a common interest in prolonging the economic viability of hydrocarbon energy and Russia is an ally for the UAE in establishing geopolitical stability in the Gulf, particularly given Russia's influence with Iran. The UAE may also consider developing closer ties with Russia for downstream investment since both Russia and the UAE have interest in monetizing their hydrocarbon resources overseas. Similar to the UAE, Russia has a strong interest in Asia and so cooperation rather than competition may be the best approach. Cooperation with Russia is in fact the approach being taken by Saudi Arabia.

Common interests in Gulf geopolitical stability and hydrocarbon energy also underpin the UAE's recently strengthened strategic partnership with Saudi Arabia. The UAE and Saudi Arabia have formed a Joint Cooperation Council (JCC) to cover "all military, political, economic, trade and cultural fields" between the countries. The JCC is the implementing body of the UAE-Saudi "Strategy of Resolve" and establishes a new mode of bilateral cooperation following fragmentation of the GCC resulting from political differences between Qatar and the trio of the UAE, Saudi Arabia and Bahrain. The UAE and Saudi Arabia have already begun to align interests to secure Asian downstream markets. Their joint investment in the Ratnagiri refining and petrochemicals complex in India is an example of the type of relationships that can be elaborated.

While it is clear that the UAE's special bilateral energy relationships are well structured, the area of advanced technology with the greatest potential impact on the UAE's ambition to become a diversified, knowledge-based economy is artificial intelligence (AI). AI could contribute as much as USD 96 billion to the UAE's Gross Domestic Product (GDP) by 2030 and as much as USD 182 billion to the UAE's Gross Value Add (GVA) by 2035. Such broad benefits will be achieved through machine learning and other AI techniques that support the UAE in advancing automation, augmentation of human capabilities and stimulation of the country's fundamental innovation potential. Furthermore, AI is central to energy sector digitalization and can support the UAE in integrating renewable energy technologies into the country's power sector, creating an intelligent transportation system and reducing the cost of UAE oil production to improve the long-term profitability of the country's oil exports.

Because AI is expected to have such major economic impacts for the UAE, exploiting strong bilateral ties with countries that are extremely advanced in AI is an important and recommended energy transition strategy for the country. Like the UAE, China, Japan, South Korea, Singapore and India have each launched AI strategies since 2017 that provide foundations for international AI collaboration. So far, however, only India and China have formally engaged the UAE for bilateral cooperation on AI. The UAE therefore needs to expand and deepen its international engagements in AI and China is particularly important given the country's ambitious scheme to become a world leader in AI technology by 2030 and its strong interest in engaging with the UAE.

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Conclusions and Policy Recommendations

The transition to a global energy system based predominantly on clean and renewable energy would have significant social, political and economic implications. Multilateral diplomacy will play a key role in determining the ultimate scale and extent of this transition and its impact on groups of countries and organizations that share common interests. Bilateral energy diplomacy, on the other hand, can support the long-term energy security and economic well-being of individual nations through the fostering of foreign relationships concerning energy supply and demand. Similar to other GCC countries, the key energy diplomacy concern for the UAE that arises from a low-carbon energy transition is development of business opportunities for monetizing the country's hydrocarbon resources and ensuring economic diversification that lessens dependence on oil export revenues. Based on these considerations and the analysis provided in this paper, bilateral energy diplomacy is a priority and the following foreign policy recommendations are made with reference to the insights derived from this UAE case study:

- Develop special bilateral relationships with countries that can provide strategic benefit during a low-carbon energy transition. The UAE has already established special strategic bilateral relationships with a number of countries that are important partners for energy and economic reasons. Additional special relationships may be formed with countries that have strong capabilities in key growth areas such as petrochemicals.

- Engage key national stakeholders beyond the ministry of foreign affairs for the fostering of special bilateral relationships. Special bilateral relationships require regular consultations between partner countries and the UAE's political leadership. These consultations will of course include the UAE Ministry of Foreign Affairs and International Cooperation but should extend to other UAE ministries dealing with energy, industry, environment and technology. Organizations such as ADNOC and Mubadala also play an important diplomatic role in bilateral energy diplomacy.

- Develop and leverage soft power in bilateral energy relationships. The UAE has effectively exercised soft power via multiple bilateral investment relationships established by Mubadala as well as other UAE government organizations. The establishment of UAE-China week is a further effort toward soft power that can be replicated in other key bilateral relations.

- Pursue bilateral collaborations to advance national science & technology capabilities. Digitalization, and particularly AI, is one of the most critical areas of advanced technology development across all industries. The UAE's strong bilateral ties with countries at the forefront of AI, particularly China, make AI collaboration an important opportunity that will have direct benefit for the country's energy sector.

- Engage in multilateral diplomacy to compliment bilateral efforts. Multilateral diplomacy will continue to be important for the UAE to secure a voice in global energy governance. This means that the UAE's current strong engagements with IRENA, OPEC and other multilateral organizations that shaping the global energy dialogue are essential.

While these recommendations are derived from analysis of the UAE context, they are intended to be broadly applicable to the bilateral energy diplomacy of hydrocarbon-exporting countries [21-30].

EU Foreign Ministers Call for End to Financing Fossil Fuels Abroad

"EU energy diplomacy will discourage all further investments into fossil fuel based energy infrastructure projects in third countries, unless they are fully consistent with an ambitious, clearly defined pathway towards climate neutrality," according to draft conclusions from the meeting, seen by Euractiv. Foreign ministers are expected to put green diplomacy at the top of their agenda, saying the EU "will seek to ensure undistorted trade and investment for EU businesses in third countries" as well as "a level playing field, and a fair access to resources and green technologies" in countries like China.Moreover, all EU trade agreements, overseas aid and foreign investment strategies will from now on also need to be aligned with the bloc's climate ambition. "The EU will ensure that its trade policy and its trade agreements are consistent with its climate ambition," the draft statement reads, acknowledging the European Commission's efforts to "make the respect of the Paris Agreement an essential element for all future comprehensive trade agreements".

The climate dimension of trade deals is a growing concern in Europe. An EU-Japan free trade agreement signed in 2018 was the first of its kind to carry a climate clause and a similar provision was added to an EU trade deal with Canada later that year. Environmental clauses in trade deals have since gained further prominence in public debates. Last year, France threatened to veto a draft EU-Mercosur trade agreement if it doesn't include commitments on deforestation. But while Europe has started taking steps to reduce its emissions to net zero by 2050, this alone won't be enough to stop global temperatures from rising 2C above pre-industrial levels, the draft statement says, calling for "urgent, collective and decisive global action". "It is an important step that foreign ministers confirmed their intention to build strong diplomatic alliances both with big emitters and climate vulnerable countries on climate mitigation and adaptation efforts," said Wendel Trio, director at Climate Action Network Europe, an environmental pressure group.

Trio warned however that climate diplomacy will only be effective if the EU also works on phasing out fossil subsidies within its borders, including for gas, and increases financial support for poorer countries. "Cooperation on phasing out fossil subsidies and international fossil finance, as well as supporting partners in the just and orderly transition away from fossil energy systems is

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a crucial first step," said Pieter de Pous, from climate think tank E3G. The energy sector is responsible for over two thirds of global greenhouse gas emissions, so the primary aim of Europe's climate diplomacy should be to accelerate the global energy transition, promoting energy efficiency and the deployment of low-carbon technologies, the draft says. Foreign policy will also need to be reconsidered to support a socially just economic and energy transition that promotes energy diversification. To do this, EU foreign ministers will reaffirm the EU's commitment "to further scale up the mobilisation of international climate finance" as part of a collective effort by industrialised nations to jointly mobilise $100 billion per year in support of climate action in developing countries.

This commitment, made under the UN climate process in 2009, has been put into question by a recent report that showed some countries exaggerated their investments into climate adaptation measures in developing countries. France, for instance, was found to have overstated its adaptation finance by $104 million. Part of this was a declaration stating that $93 million went to climate adaptation in the Philippines when closer analysis showed only 5% was earmarked for adaptation. The EU will also need to step up and work through European and international finance institutions, as well as the G7 and the G20, to make sure that fossil fuel finance does not keep undermining climate diplomacy, said CAN Europe. On Monday, EU foreign ministers will review the whole range of diplomatic relations with third countries from an environmental perspective, including EU-Africa relations and EU-US relations under the new Biden administration. While China is not directly mentioned, references to "level playing field, and a fair access to resources and green technologies" are all pointing in the direction of Beijing. But it will be another Asian country, Japan, that will steal the spotlight at Monday's meeting, with foreign minister Toshimitsu Motegi attending the gathering virtually, a first in EU-Japan relations.

Motegi was invited to explain Japan's strategy for a "Free and Open Indo-Pacific" region, according to a brief statement posted on the website of the Japanese foreign ministry. However, Europeans are likely to be interested in other subjects. While the Asian country has announced a goal to reduce emissions to net zero by 2050, its industry has become increasingly reliant on coal since the Fukushima nuclear incident in 2011. And under current plans, coal, oil and gas will still account for 56% of Japan's energy use by 2030, critics say. Moreover, Tokyo came under fire recently when evidence emerged that the country's overseas lender had approved a loan to finance the construction of new coal plant in Vietnam. Japan was also found to be the worst offender in exaggerating its climate adaptation spending.

Japan Uses 'Environmental' Fund to Finance Vietnamese Coal Plant

A Japanese state-owned bank is using a green fund to finance a Vietnamese coal power plant, sparking accusations of "egregious greenwashing". The Japan Bank for International Cooperation (JBIC) announced last month it would invest $636 million in the controversial Vung Ang 2 project, through its Growth Investment Facility.

In response to questions from opposition lawmaker Mizuho Fukushima, seen by Climate Home News, the finance ministry revealed the loan came from a part of the facility targeted at "environmental preservation". Launching the facility in May 2018, Japanese finance minister Taro Aso told a meeting of Asian Development Bank governors it would "provide support for a variety of infrastructure projects that contribute to environmental preservation" like public transport and wind power. However, the bank's press releases show the "development of quality infrastructure for environmental preservation and sustainable growth" (QI-ESG) fund has supported five gas-fired power projects, compared to two in wind power and one in solar panel manufacturing. A total of 220 billion yen ($2bn) had been allocated to 11 projects as of November 2020, the finance ministry told Fukushima. A policy presentation dated August 2020 by a senior JBIC official lists gas and high-efficiency coal-fired power generation as eligible for "environmental" funding, despite the fact burning fossil fuels is the main driver of global warming.

Vung Ang 2 is a planned 1,200 MW plant in central Vietnam. It will be built next to the existing Vung Ang plant. According to local media, in 2017 local residents blocked coal trucks leading to this plant in protest at the pollution and road damage they cause. The plant will emit several times more sulphur dioxide, nitrogen oxide and fine particulate matter than would be allowed if it were in Japan, according to analysis from the Center for Research on Energy and Clean Air. Ayumi Fukakusa, a campaigner from Friends of the Earth Japan, said: "It is, in the first place, unacceptable that JBIC support new coal projects, moreover with the fund which was advertised as 'green and quality infrastructure'". She said there was a "double standard", with Japan pledging to reach net zero emissions domestically by 2050 but financing coal abroad. JBIC finances its activities partly through issuing bonds, which are guaranteed by the Japanese government, making them a safe investment. Ulf Erlandsson, a former pension fund manager who set up the Anthropocene Fixed Income Institute as a climate watchdog for international bond markets, called on investors to boycott JBIC. He told Climate Home News: "We already have argued for JBIC to be excluded from international bond portfolios due to its coal financing. With the information that JBIC explicitly uses funds indicated as 'ESG' to provide such funding, we are comfortable putting JBIC in a frontrunner position for the 'most egregious greenwashing of the decade' award."

Zsolt Lengyel, secretary of the Institute for European Energy and Climate Policy, said this "outrageous" case showed a need for more accountability from sovereign issuers to bond buyers. "Finance streams must show real life impacts including their climate impacts. These must be verifiable and verified independently. This transaction is a proof that we lack such

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systems. Unless we build them fast, we will cripple the energy transition and be swept away by gargantuan greenwashing," said Lengyel. Analyst Simon Nicholas, from the Institute for Energy Economics and Financial Analysis, said that Vietnam does not need more coal power. "JBIC is encumbering Vietnam with old power technology at a time when the country is reducing focus on coal and seeing renewable energy installation skyrocket," he said. "Vietnam installed almost 5GW of utility-scale solar power in 2019 and an astonishing 9GW of rooftop solar in 2020. Wind power is also expanding fast in Vietnam. Such renewable energy growth undermines the rationale for further coal-fired power development." Japanese public banks have previously counted coal power projects towards the country's climate finance pledges. Japan International Cooperation Agency (JICA) loaned $1.4bn to support a coal plant in Bangladesh, claiming this funding was "contributing to the mitigation of climate change" because the plant was less polluting than other coal plants. Japanese "climate finance" has also backed coal plants in India, Indonesia and Vietnam, Associated Press revealed in 2014. The Japanese foreign ministry at the time defended using climate funds in this way. "We don't have anything to hide or disguise," the official said.

OPEC

The Organization of the Petroleum Exporting Countries (OPEC, is an intergovernmental organization or cartel of 13 countries. Founded on 14 September 1960 in Baghdad by the first five members (Iran, Iraq, Kuwait, Saudi Arabia, and Venezuela), it has since 1965 been headquartered in Vienna, Austria, although Austria is not an OPEC member state. As of September 2018, the 13 member countries accounted for an estimated 44 percent of global oil production and 81.5 percent of the world's "proven" oil reserves, giving OPEC a major influence on global oil prices that were previously determined by the so-called "Seven Sisters" grouping of multinational oil companies. The stated mission of the organization is to "coordinate and unify the petroleum policies of its member countries and ensure the stabilization of oil markets, in order to secure an efficient, economic and regular supply of petroleum to consumers, a steady income to producers, and a fair return on capital for those investing in the petroleum industry." Economists often cite OPEC as a textbook example of a cartel that cooperates to reduce market competition, but one whose consultations are protected by the doctrine of state immunity under international law. The organization is also a significant provider of information about the international oil market.

The formation of OPEC marked a turning point toward national sovereignty over natural resources, and OPEC decisions have come to play a prominent role in the global oil market and international relations. The effect can be particularly strong when wars or civil disorders lead to extended interruptions in supply. In the 1970s, restrictions in oil production led to a dramatic rise in oil prices and in the revenue and wealth of OPEC, with long-lasting and far-reaching consequences for the global economy. In the 1980s, OPEC began setting production targets for its member nations; generally, when the targets are reduced, oil prices increase. This has occurred most recently from the organization's 2008 and 2016 decisions to trim oversupply. The current OPEC members are the following: Algeria, Angola, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, and the Republic of the Congo, Saudi Arabia, the United Arab Emirates and Venezuela. Former OPEC members are Ecuador, Indonesia and Qatar. A larger group called OPEC+ was formed in late 2016 to have more control on the global crude oil market.

Current Member Countries

As of January 2020, OPEC has 13 member countries: five in the Middle East (Western Asia), seven in Africa, and one in South America. According to the U.S. Energy Information Administration (EIA), OPEC's combined rate of oil production (including gas condensate) represented 44% of the world's total in 2016, and OPEC accounted for 81.5% of the world's "proven" oil reserves. Approval of a new member country requires agreement by three-quarters of OPEC's existing members, including all five of the founders. In October 2015, Sudan formally submitted an application to join, but it is not yet a member. For countries that export petroleum at relatively low volume, their limited negotiating power as OPEC members would not necessarily justify the burdens imposed by OPEC production quotas and membership costs. Ecuador withdrew from OPEC in December 1992, because it was unwilling to pay the annual US$2 million membership fee and felt that it needed to produce more oil than it was allowed under its OPEC quota at the time. Ecuador then rejoined in October 2007 before leaving again in January 2020. Ecuador's Ministry of Energy and Non-Renewable Natural Resources released an official statement on 2 January 2020 which confirmed that Ecuador had left OPEC. Similar concerns prompted Gabon to suspend membership in January 1995; it rejoined in July 2016. In May 2008, Indonesia announced that it would leave OPEC when its membership expired at the end of that year, having become a net importer of oil and being unable to meet its production quota. It rejoined the organization in January 2016, but announced another "temporary suspension" of its membership at year-end when OPEC requested a 5% production cut.

Qatar left OPEC on 1 January 2019, after joining the organization in 1961, to focus on natural gas production, of which it is the world's largest exporter in the form of liquified natural gas (LNG). Some commentators consider the United States to have been a de facto member of OPEC during its formal occupation of Iraq, due to its leadership of the Coalition Provisional Authority, which governed the country in 2003-2004. However, no U.S. representative attended OPEC meetings during this period in an official capacity.

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Observers

Since the 1980s, representatives from Egypt, Mexico, Norway, Oman, Russia, and other oil-exporting nations have attended many OPEC meetings as observers. This arrangement serves as an informal mechanism for coordinating policies.

Vienna Group

A number of non-OPEC member countries also participate in the organization's initiatives such as voluntary supply cuts in order to further bind policy objectives between OPEC and non-OPEC members. This loose grouping of countries includes: Azerbaijan, Bahrain, Brunei, Kazakhstan, Malaysia, Mexico, Oman, Russia, Sudan and South Sudan.

Leadership and Decision-Making

The OPEC Conference is the supreme authority of the organization and consists of delegations normally headed by the oil ministers of member countries. The chief executive of the organization is the OPEC Secretary General. The Conference ordinarily meets at the Vienna headquarters, at least twice a year and in additional extraordinary sessions when necessary. It generally operates on the principles of unanimity and "one member, one vote", with each country paying an equal membership fee into the annual budget. However, since Saudi Arabia is by far the largest and most-profitable oil exporter in the world, with enough capacity to function as the traditional swing producer to balance the global market, it serves as "OPEC's de facto leader"

International Cartel

At various times, OPEC members have displayed apparent anti-competitive cartel behavior through the organization's agreements about oil production and price levels. In fact, economists often cite OPEC as a textbook example of a cartel that cooperates to reduce market competition, as in this definition from OECD's Glossary of Industrial Organization Economics and Competition Law: International commodity agreements covering products such as coffee, sugar, tin and more recently oil (OPEC: Organization of Petroleum Exporting Countries) are examples of international cartels which have publicly entailed agreements between different national governments. OPEC members strongly prefer to describe their organization as a modest force for market stabilization, rather than a powerful anti-competitive cartel. In its defense, the organization was founded as a counterweight against the previous "Seven Sisters" cartel of multinational oil companies, and non-OPEC energy suppliers have maintained enough market share for a substantial degree of worldwide competition. Moreover, because of an economic "prisoner's dilemma" that encourages each member nation individually to discount its price and exceed its production quota, widespread cheating within OPEC often erodes its ability to influence global oil prices through collective action.

OPEC has not been involved in any disputes related to the competition rules of the World Trade Organization, even though the objectives, actions, and principles of the two organizations diverge considerably. A key US District Court decision held that OPEC consultations are protected as "governmental" acts of state by the Foreign Sovereign Immunities Act, and are therefore beyond the legal reach of US competition law governing "commercial" acts. Despite popular sentiment against OPEC, legislative proposals to limit the organization's sovereign immunity, such as the NOPEC Act, have so far been unsuccessful.

Conflicts

OPEC often has difficulty agreeing on policy decisions because its member countries differ widely in their oil export capacities, production costs, reserves, geological features, population, economic development, budgetary situations, and political circumstances. Indeed, over the course of market cycles, oil reserves can themselves become a source of serious conflict, instability and imbalances, in what economists call the "natural resource curse". A further complication is that religion-linked conflicts in the Middle East are recurring features of the geopolitical landscape for this oil-rich region. Internationally important conflicts in OPEC's history have included the Six-Day War (1967), Yom Kippur War (1973), a hostage siege directed by Palestinian militants (1975), the Iranian Revolution (1979), Iran-Iraq War (1980-1988), Iraqi occupation of Kuwait (1990-1991), September 11 attacks by mostly Saudi hijackers (2001), American occupation of Iraq (2003-2011), Conflict in the Niger Delta (2004-present), Arab Spring (2010-2012), Libyan Crisis (2011-present), and international Embargo against Iran (2012-2016). Although events such as these can temporarily disrupt oil supplies and elevate prices, the frequent disputes and instabilities tend to limit OPEC's long-term cohesion and effectiveness.

Market Information

As one area in which OPEC members have been able to cooperate productively over the decades, the organization has significantly improved the quality and quantity of information available about the international oil market. This is especially helpful for a natural-resource industry whose smooth functioning requires months and years of careful planning.

Publications and Research

In April 2001, OPEC collaborated with five other international organizations (APEC, Eurostat, IEA, OLADE, and UNSD) to improve the availability and reliability of oil data. They launched the Joint Oil Data Exercise, which in 2005 was joined by IEF and renamed the Joint Organizations Data Initiative (JODI), covering more than 90% of the global oil market. GECF joined as an eighth partner in 2014, enabling JODI also to cover nearly 90% of the global market for natural gas. Since 2007, OPEC has published the "World Oil Outlook" (WOO) annually, in which it presents a comprehensive

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analysis of the global oil industry including medium- and long-term projections for supply and demand. OPEC also produces an "Annual Statistical Bulletin" (ASB), and publishes more-frequent updates in its "Monthly Oil Market Report" (MOMR) and "OPEC Bulletin".

Crude Oil Benchmarks

A "crude oil benchmark" is a standardized petroleum product that serves as a convenient reference price for buyers and sellers of crude oil, including standardized contracts in major futures markets since 1983. Benchmarks are used because oil prices differ (usually by a few dollars per barrel) based on variety, grade, delivery date and location, and other legal requirements. The OPEC Reference Basket of Crudes has been an important benchmark for oil prices since 2000. It is calculated as a weighted average of prices for petroleum blends from the OPEC member countries: Saharan Blend (Algeria), Girassol (Angola), Djeno (Republic of the Congo) Rabi Light (Gabon), Iran Heavy (Islamic Republic of Iran), Basra Light (Iraq), Kuwait Export (Kuwait), Es Sider (Libya), Bonny Light (Nigeria), Arab Light (Saudi Arabia), Murban (UAE), and Merey (Venezuela). North Sea Brent Crude Oil is the leading benchmark for Atlantic basin crude oils, and is used to price approximately two-thirds of the world's traded crude oil. Other well-known benchmarks are West Texas Intermediate (WTI), Dubai Crude, Oman Crude, and Urals oil [31-40].

Spare Capacity

The US Energy Information Administration, the statistical arm of the US Department of Energy, defines spare capacity for crude oil market management "as the volume of production that can be brought on within 30 days and sustained for at least 90 days...OPEC spare capacity provides an indicator of the world oil market's ability to respond to potential crises that reduce oil supplies." In November 2014, the International Energy Agency (IEA) estimated that OPEC's "effective" spare capacity, adjusted for ongoing disruptions in countries like Libya and Nigeria, was 3.5 million barrels per day (560,000 m3/d) and that this number would increase to a peak in 2017 of 4.6 million barrels per day (730,000 m3/d). By November 2015, the IEA changed its assessment "with OPEC's spare production buffer stretched thin, as Saudi Arabia -which holds the lion's share of excess capacity - and its Persian Gulf neighbors pump at near-record rates."

How OPEC (and Non-OPEC) Production Affects Oil Prices

The Organization of the Petroleum Exporting Countries (OPEC) will continue with its supply adjustments for the oil market, the OPEC Secretary General said on Saturday. "We will continue to do what we know best to ensure we attain stability in the oil market on a sustainable basis," Mohammad Barkindo said in a webinar organized by Italian think-tank ISPI. Oil prices fell on Thursday after OPEC and its allies stuck to their existing policy of monthly oil output increases despite fears a release from U.S. crude reserves and the new Omicron coronavirus variant would put renewed pressure on prices. Barkindo said in terms of oil demand the estimate at the moment was for a growth of 5.7 million barrels per day. "In 2022 we expect another 4.2 million," he said.

He said the uncertainty and volatility on the markets was also due to extraneous factors such as the ongoing Covid pandemic and not necessarily the fundamentals of oil and gas. "Now we are on course of returning the level of consumption in 2022 to pre-COVID levels," he said. Barkindo said that the forecast was for oil and gas to account for more than 50% of the global energy mix in 2045 or even to midcentury. "In all the pronouncements we had from Glasgow we have not yet seen any concrete road map or plans of how to replace this 50% ... without creating unprecedented turmoil in the energy markets," he said, referring to the Glasgow climate conference.

Organization of the Petroleum Exporting Countries (OPEC) is an organization that sets production targets among its members to manage oil production. OPEC member countries produce about 40% of the world's crude oil. Additionally, OPEC's oil exports represent about 60% of the total petroleum traded internationally, according to the United States Energy Information Administration. Because of this market share, OPEC's actions have a huge influence on international oil prices. In particular, OPEC's largest producer of crude oil, Saudi Arabia, has the most frequent effect on oil prices. Historically, crude oil prices have seen increases in times when OPEC production targets are reduced.

The Impact of OPEC and OPEC+ on Oil Prices

Countries involved in global oil production are either members of OPEC, OPEC+, or non-OPEC nations. OPEC has 13 members: Algeria, Angola, Congo, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, the United Arab Emirates, and Venezuela. Ten non-OPEC nations joined OPEC to form OPEC+ in late 2016 to have more control on the global crude oil market. These countries were: Azerbaijan, Bahrain, Brunei, Kazakhstan, Malaysia, Mexico, Oman, Russia, South Sudan, and Sudan. Not surprisingly, OPEC+ has a level of influence over the world economy that is even larger than OPEC's. Responding to the highly dynamic economic and geopolitical developments, these groups make changes to their oil production capacities, which impact the oil supply levels and result in oil price volatility.

OPEC's Control of the Market

OPEC's oil exports account for roughly 60% of the total petroleum traded worldwide. The Energy Information Agency also reports that more than 80% of the world's proven crude oil reserves lie within the boundaries of the OPEC countries. Of that, roughly two-thirds lay within the Middle Eastern region in 2018. Additionally, all OPEC member nations have been continuously

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improving technology and enhancing explorations leading to further enhancements to their oil production capacities at reduced operational costs.

Saudia Arabia

Within the OPEC group, Saudi Arabia is the largest crude oil producer in the world and remains the most dominant member of OPEC. It is also the leading exporter of crude oil globally. Each time there is a cut in Saudi oil production, there is a sharp rise in oil prices, and an increase in Saudi oil production stimulates a drop in oil prices. Since the 1973 Arab oil embargo, Saudi Arabia has managed to call the shots as far as oil prices are concerned, by controlling supply. All major oil price fluctuations in recent history can be attributed to changing production levels in Saudi Arabia, along with other OPEC nations.

OPEC+

OPEC+ controls over 50% of global oil supplies, according to Tamas Varga, senior analyst at PVM Oil Associates and quoted by CNBC. OPEC+ remains influential due to three primary factors:

1. An absence of alternative sources equivalent to its dominant position.

2. A lack of economically feasible alternatives to crude oil in the energy sector.

3. The comparatively low-cost price advantage against the relatively high-cost non-OPEC production.

In short, OPEC+ has the economic capability to disrupt or enhance the supply of oil to substantial levels at any time, severely affecting oil prices. For example, the 1973 Arab oil embargo by OPEC saw prices quadruple from $3 to $12 per barrel and, more recently, the sudden ramp-up in production by Saudi Arabia in March 2020 led to a sharp decline in the price of oil. On April 20, 2020, following the temporary lack of coordination between Russia and Saudi Arabia added to the lockdown, the front-month May 2020 WTI crude contract dropped 306%, or $55.90, for the session, to settle at negative $37.63 a barrel on the New York Mercantile Exchange. This suggests that holders of oil had to pay in order to get takers to their production.

The Impact of Non-OPEC Production on Oil Prices

Non-OPEC oil producers are crude oil-producing nations outside of the OPEC group and shale oil producers. Interestingly, some of the top oil-producing countries are non-OPEC nations. This includes the United States of America, which is the number one producer, Canada, and China. Most non-OPEC countries have high consumption levels and, thus, limited capacity to export. Many are net oil importers despite being high producers, which means they have minimal influence on oil prices. However, with the discovery of shale oil and shale gas, non-OPEC oil producers, particularly the United States, have enjoyed increased production and greater market share in recent times. While this has been a game-changer of sorts, shale oil technology requires substantial upfront investments, which acts as a deterrent to shale oil producers. So far, the jury is out as to whether non-OPEC producers can have a material impact on the price of crude oil. High production levels from non-OPEC members from 2002 to 2004 and in 2010 did not result in price declines and instead brought higher oil prices. This is probably because non-OPEC members did not have sufficient market share to affect the market price of oil. High production from 2014 to 2015, however, did cause prices to decline. Market pundits have opined that the decline in prices was probably due to an increase in supply from OPEC producers to counter the threat posed to their hegemony by non-OPEC producers.

OPEC and Non-OPEC Countries vs. Market Forces

Oil prices are also affected by geopolitical developments and economic interests. Additionally, “black swan” events, or unexpected events, greatly affect the supply/demand paradigm. One such event occurred in January 2020 when the global economy was roiled by the pandemic. The plummeting global demand for oil led to a fracturing of OPEC+, specifically between Saudi Arabia and Russia, the two largest oil exporters. In response, Saudi Arabia ratcheted up production. This overt attempt to capture market share led to a precipitous decline that saw the price of West Texas Intermediate (WTI) breach $20/barrel. An “extraordinary” meeting between OPEC and non-OPEC (read: Saudi Arabia and Russia) led to an agreement to cut production by about 10 million barrels per day (B/D). In what was a classic buy-the-rumor-sell-the-fact trade, oil prices rose and then cratered as the market was not impressed by a global supply cut of 10 million B/D while global demand was projected to decline by 30 million B/D?

Special Considerations

The dynamics of the oil economy are complex, and oil prices depend on more than the rules of demand and supply, although at its most primal level, the market is the final arbiter of the price of oil. Under normal global market conditions, OPEC+ will continue to maintain its dominance in oil price determination. Despite challenges, such as fracking technology and oil discovery in non-OPEC regions, OPEC’s share of the Global market allows the organization to manipulate production quotas and continue to be a central player in oil price determination.

OPEC Fund Approves US$352m for Global Development Operations

The OPEC Fund for International Development (the OPEC Fund) has approved US$352 million for sustainable development operations across the world at the organization’s 178th Session of the Governing Board, held virtually today.

Members of the Governing Board also reviewed several milestones achieved as part of the OPEC Fund Strategic Framework 2030, including inaugural credit ratings for the organization from S&P Global (AA; Positive Outlook) and Fitch Ratings (AA+;

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Stable Outlook). The Strategic Framework 2030 is designed to diversify the OPEC Fund's financial resources and deliver greater development impact for partner countries. The OPEC Fund's new financing will support the following public sector projects:

Bosnia and Herzegovina

€25 million (US$27.15 million) loan for the Corridor Vc Motorway, Section Nemila-Donja Gracanica (Zenica North), to improve travel connections for some 150,000 people in the city of Zenica, the country's most important center for mining and steel production. This loan will finance a 17.6-km road section including roads, tunnels and viaducts. Corridor Vc will improve the connectivity of Bosnia and Herzegovina with its neighbors and the Western Balkans region. Reduced travel times are expected to boost trade and tourism, strengthening the local economy.

Côte d'Ivoire

US$60 million loan for the Northern Agro-Industrial Pole Project (2 PAI-Nord). The project will support the construction and rehabilitation of social and market infrastructure, including rural roads, healthcare centers and schools, warehouses and collection centers, as well as infrastructure relating to fisheries and livestock production. It will boost food security and household incomes for some 400,000 people and promote the export of cash crops. Capacity building and institutional strengthening are also part of the project.

Dominican Republic

US$60 million loan for the Program to Expand Electricity Networks and Reduce Technical Losses in Distribution Systems to support the government's effort to reduce electricity distribution losses and improve the efficiency of the electrical infrastructure nationwide. Civil works will include the construction of new substations and distribution networks and the rehabilitation of existing ones in provinces situated in the north and east of the country. Around 1.3 million people are to benefit from the program.

Ghana

US$20 million loan for the Integrated Rural Development Project (Phase 2) to expand socio-economic infrastructure and improve livelihoods for some 120,000 individuals across high-poverty districts selected via a demand-driven approach. Works will include constructing and equipping classrooms, teachers' quarters, health clinics, market infrastructure and drainage works, as well as providing credit to small- and medium-sized enterprises (SMEs) involved in various activities along the agriculture value chain - particularly those impacted by the COVID-19 pandemic.

Kenya

US$40 million loan for the Development of Urban Roads in Five Counties, Phase 1 project to construct a 66-km road network in the northeastern region in Wajir Country, a high-poverty area populated by 720,000 people. On completion, the project will facilitate trade, improve access to social services and marketplaces, and enhance employment opportunities.

Lesotho

US$19 million loan for the Regeneration of Landscapes and Livelihood (ROLL) Project to improve livelihoods and promote resource-use practices, reducing environmental degradation in more than 2,200 villages populated by some 630,000 people. Project components include a 'Regeneration Coalition Facility' that will bring together various stakeholders to identify measures needed to accomplish these aims, and a 'Regeneration Opportunities Fund' that will catalyze investments in land regeneration projects. Technical assistance will also be provided to rural SMEs wanting to shift to more sustainable practices, while seed funding will support research and development.

Malawi

US$15 million loan for the Dowa Town Water Supply and Sanitation Project to expand and upgrade the existing water supply system to meet current demand and expand supply. The project will include construction of a water treatment plant, a pumping station and a 51 km-long distribution pipeline, as well as the installation of new communal water points and the rehabilitation of existing ones. Also planned is the replacement of the sewage system at the Dowa district hospital and the installation of sanitation facilities at the Dzaleka refugee camp. The project is expected to improve the health and living conditions for around 100,000 people.

Nicaragua

US$23 million loan for the Empalme La Tronquera - Pueblo Nuevo Rural Road Project to promote sustainable development and regional integration in the northern department of Estelí, where agriculture is the main economic activity. The project includes the upgrading of a 22-km road - presently usable only during the dry season - to provide year-round access for some 110,000 people. The improved road will facilitate the transport of crops to marketplaces and enhance connectivity to social services and employment opportunities.

Rwanda

US$18 million loan for the Nyacyonga-Mukoto Road Project to upgrade a 36-km stretch that will improve connections for circa 2.8 million people engaged in economic activities that include agriculture, mining and tourism. In addition to strengthening livelihoods, the project will improve access to production areas, markets and social amenities. The project will also help boost trade with neighboring countries, particularly DR Congo and Uganda.

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Turkmenistan

US$45 million loan for the Marine Merchant Fleet Project. It will include the construction of three new vessels for rail, passenger and dry cargo. Once operational the new ships will increase the utilization of the Turkmenbashi seaport on the Caspian Sea, part of the Europe-Caucasus-Asia transport corridor and one of the largest ports in the country. The project will also offer technology-transfer by providing training in shipbuilding and repair to the shipyard's staff. In addition to boosting trade and economic activity, the project will create job opportunities, particularly for young graduates. The OPEC Fund's new financing will also support a US$25 million private sector operation to support infrastructure projects in selected Latin America and Caribbean countries.

About the OPEC Fund

The OPEC Fund for International Development (the OPEC Fund) is the only globally mandated development institution that provides financing from member countries to non-member countries exclusively. The organization works in cooperation with developing country partners and the international development community to stimulate economic growth and social progress in low- and middle-income countries around the world. The OPEC Fund was established by the member countries of OPEC in 1976 with a distinct purpose: to drive development, strengthen communities and empower people. Our work is people-centered, focusing on financing projects that meet essential needs, such as food, energy, infrastructure, employment (particularly relating to MSMEs), clean water and sanitation, healthcare and education. To date, the OPEC Fund has committed more than US$22 billion to development projects in over 125 countries with an estimated total project cost of US$187 billion. Our vision is a world where sustainable development is a reality for all [41-50].

Russia's Energy 'Diplomacy' in Moldova

In October 2021, Moldova came under the spotlight when Russia, its primary provider of gas, slashed supplies by a third and refused to extend the existing contract.The crisis was resolved at the end of October when Russia and Moldova signed a new contract, in which Moscow has used Moldova's gas dependence to extract geopolitical concessions, weaken the new pro-western Chisinau government and drive a wedge between the EU and Moldova.

A Chronic Failure to Reform

Moldova became a classic case of state capture when political elites - including nominally pro-European political elites - engaged in massive rent-extraction. Up until 2020, when pro-reform forces came to power, Moldovan politics offered rapid route to riches for both the nominally pro-European parties and the pro-Russian Socialist Party; each was responsible for playing up ethnic and geopolitical cleavages in the country to mobilize votes and shore up legitimacy. These predatory elites hollowed out Moldova economically and politically by a chronic failure to reform, in particular the energy sector which became a major source of rent. However, this started to change when the pro-reform forces came to power as a result of the 2020 presidential and then 2021 parliament elections. The pro-reformist Maia Sandu defeated the incumbent president Igor Dodon (58 per cent to 42 per cent) in November of that year. And then her party got 58 per cent of the vote in the parliamentary elections which followed in July 2021. Her Party of Action's (PAS) winning formula was to focus on corruption and domestic reforms - rather than playing the 'geopolitical' card, a favourite strategy of their predecessors. As Sandu put it, the elections marked 'the end of the reign of thieves in Moldova'.

A Gas Crisis is Initiated

Russia's response to these results was to initiate a gas crisis. Up until the victory of the pro-reform forces, Russia had annually renewed a gas contract signed in 2007. However, in September 2021, Russia refused to renew the contract as it had done many times before and instead insisted on a new contract, which allowed Russia to create linkages between energy prices, debt settlement, a halt on energy market reforms and, it can be logically inferred, further integration with the EU. Moldova's national energy company, Moldovgaz, is 63.5 per cent de facto owned by Gazprom with the Moldovan government owning the remaining 35.5 per cent. (Moldova was forced to give Gazprom a controlling stake when faced with a cut in supplies in January 2006). It is therefore hardly surprising that no efforts were made to de-monopolise the sector and diversify energy supplies.This lack of modernization can be explained by the somewhat surreal fact that in any negotiations and planning, Moldovagaz - majority owned by Gazprom - represents the Moldovan side in negotiations with Gazprom. So, when it came to signing of the new five-year contract in October 2021, Russia, through Gazprom, was able to institute a contract which made gas prices conditional on various geopolitical conditions.

It is noteworthy that Moldova's original 2007 gas contract had been renewed annually despite the supposed accrual of debt. However, the very nature of this debt is suspect. While Moldova's debt is said to be approximately $700 million, the debt of the much smaller breakaway Transnistria was around $7.3 billion. The exact level and source of the debt remain murky. Russia appears to be making Moldova liable to repay at least some of Transnistria's debt while only demanding the debt settlement with Moldova, but not with Transnistria.

High Stakes for Moscow

Moreover, the contract is used to derail liberalisation of the energy market in line with EU's energy market rules (through

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the so-called unbundling of supplies and distribution) which Moldova had committed itself to since the country joined the Energy Community in 2010. Referring to 'the non-application of forced reorganization and sanctions against Moldovagaz', the new gas contract forces Moldova to postpone implementing the unbundling of supplies and distribution by making it conditional on resolving the energy debt. Furthermore, Moldova ominously agreed to create an 'intergovernmental commission on economic cooperation' with Russia, which effectively blocks Moldova's economic integration with the EU. (This demand is hardly new as Russia previously requested, and was granted, a seat at the negotiating table on a bilateral trade agreement between the EU and Ukraine. The trilateral EU-Ukraine-Russia negotiations have made it clear that Russia is seeking a veto over European integration of all neighboring countries.) Targeting Moldova's new reformist government reflects high personal stakes for Moscow. Moldova's caretaker (kurator) in the Kremlin is Dimitrii Kozak, who in 2003 masterminded the so-called 'Kozak Memorandum'. This sought to reintegrate breakaway Transnistria into a Moldova-Transnistria federation.It was thwarted at the last minute but the Russian leadership has not given up on its plan. Now using his position as the deputy head of Presidential Administration, Kozak is masterminding Russia's rehashed policy towards Moldova and has attempted to bring back his Memorandum as a political blueprint for a 'settlement'.

Russia's Heavy-Handed Energy 'Diplomacy'

The new Moldovan government is caught in a crossfire of domestic expectations and Russian geopolitical demands. The gas crisis shows that while the new government may wish for geopolitics to go away, they are a weapon Russia will deploy at will. The Moldovan government is brand new so it has relatively little experience of dealing with Russia's heavy-handed 'energy diplomacy'. But the EU has been on the receiving end of this before - this is a direct replica of Russia's strategy toward Armenia and Ukraine - and neither ended well for the target countries or for the EU. So, Russia's plans for Moldova are likely to have similar consequences for the EU's latest attempts to be a convincing foreign policy actor.

Middle East LNG Hedging in China's Energy Diplomacy

China's energy mix is currently changing to include more natural gas and liquefied natural gas (LNG). Combined piped gas and ship-borne LNG currently comprise around 8 percent of China's energy mix, half of which is imported. Import sources are roughly evenly split three ways between the Central Asian Gas Pipeline crossing from Kazakhstan carrying mostly Turkmenistan gas, the Russian Power of Siberia pipeline gas, and ship-borne LNG, with China having a long-term stake in Russia's Arctic Yamal LNG project. China's geoeconomic policy around natural gas imports has clear potential for politicization, with impacts on both the supply countries and for other buying countries like Japan. China has previously politicized the sell-side of strategic commodities, banning rare earth exports to Japan, and has consistently politicized the buy-side of Australian iron ore under the China Iron and Steel Association cartelization scheme. Creating new buy-side dependencies in LNG and piped gas creates new forms of institutional power through which to exercise foreign policy via strategic price-setting and import volume control. Imports of gas, though, are already showing signs of greater institutional control and monopolization than in the iron ore trade. China's gas imports are increasingly coordinated by a single entity, PipeChina. Established in 2019, Pipe China has begun to absorb China's gas infrastructure from the three existing upstream oil and gas state owned enterprises (SOEs) with the ostensible goal of marketizing the midstream to promote market competition for downstream SOEs, local governments, and private enterprises to lease capacity. PipeChina has already taken over the majority of China's LNG regasification terminals, with three additional large regasification terminal projects to come under its control upon completion. When Shandong's Longkou Nanshan LNG facility comes online, PipeChina will control 35.6 Bcm of coastal regasification facilities, more than three times the combined capacity of remaining LNG terminals, as well as the 55 Bcm Central Asia Gas Pipeline and the 38 Bcm Power of Siberia pipeline.

China's wider hydrocarbon and petrochemical geoeconomic access policies are also more internationalized than previous industrial commodities under the rapid growth era. China's petrochemical industry is organized into a cartel under the China Petrochemical International Capacity Cooperation Enterprise Alliance - effectively an attempt to cartelize both supply and demand-sides to create a whole value chain approach to achieving strategic access to energy resources through the Belt and Road economies. Coordinating industrial park investment, leveraging policy bank capital, and securing institutionalization of commodity prices can ensure not only stable supply, but political control of offshore industrial production bases and their inputs.

Around half of China's hydrocarbon imports are from the Middle East, and China's expanded hydrocarbon investment in the Middle East has acute geoeconomic implications. But China's political geography concept of the Middle East is different to the United States, Europe, or Japan's. Although China is the world's largest importer of oil, with China's Middle East oil sources becoming increasingly important, there are confused and conflicting geoeconomic policies surrounding Central Asia, the "Arab states," Turkey, and the Caucasus region, which blur the line between Central Asia and Iran, the Arabian peninsula, and East Africa. Enjoying this article? Just $5 a month. China is also struggling to articulate a "Near Abroad" foreign policy, a Soviet Union international relations term now borrowed and redeployed by China. The four Near Abroads in the Soviet Union were the Baltics, Eastern Europe, the Caucasus, and Central Asia. Both foreign and China analysts use the Near Abroad term in the China context, and although it is not the official policy of either China's Ministry of Commerce or Ministry of Foreign Affairs, China-

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Pakistan policy taxonomy often conforms to Near Abroad thinking and much of China's Belt and Road policymaking in Eurasia, the Middle East, and East Africa corresponds to a Near Abroad foreign policy concept.

Just as understanding domestic energy policy in the Middle East requires a close reading of the domestic policy priorities and access discourses of the United States, European Union, and Japan, China's domestic policy institutions, political personnel, and policy discourses, as well as its means to achieving and maintaining geoeconomics access, will become crucial through the 2020s. Qatar, the world's largest LNG exporter, exported 104.8 Bcm in 2018, but with China's total gas dependency projected to be 550 Bcm per year by 2030, the global dynamic of Qatar as largest exporter and Japan as largest importer is changing. This has clear implications for stable market suppliers such as Qatar, Australia, the United States, Indonesia, Malaysia, and Papua New Guinea, as well as Japan's energy security as traditionally the largest LNG importer, being now displaced by China.

For exporting nations in the Middle East and Central Asia, as well as Russia, there is as yet no great political risk in developing greater export capacity with China or with allowing Chinese capital to invest in upgrading domestic industrial structures in host economies. Yet the geoeconomics of LNG in particular have long centered on an East Asian import dependency, with the institutionalization of prices through import policies mostly set by Japan. In LNG, China is now mirroring a Japan import dependency energy strategy, meaning a new array of China policies aimed at mitigating dependency will emerge alongside greater buy-side activity in global hydrocarbon markets. This gravity of institutional rule-setting and price-taking behaviors is now shifting from Japan to China in the LNG trade. And China's strategic import dependency hedging in LNG through Pipe China is perhaps the clearest indicator of future institutions and policies across a wider range of commodities.

Energy Economics

Energy economics is a broad scientific subject area which includes topics related to supply and use of energy in societies. Considering the cost of energy services and associated value gives economic meaning to the efficiency at which energy can be produced. Energy services can be defined as functions that generate and provide energy to the "desired end services or states". The efficiency of energy services is dependent on the engineered technology used to produce and supply energy. The goal is to minimize energy input required (e.g., kWh, mJ, see Units of Energy) to produce the energy service, such as lighting (lumens), heating (temperature) and fuel (natural gas). The main sectors considered in energy economics are transportation and building, although it is relevant to a broad scale of human activities, including households and businesses at a microeconomic level and resource management and environmental impacts at a macroeconomic level. Energy related issues have been actively present in economic literature since the 1973 oil crisis, but have their roots much further back in the history. As early as 1865, W.S. Jevons expressed his concern about the eventual depletion of coal resources in his book The Coal Question. One of the best-known early attempts to work on the economics of exhaustible resources (incl. fossil fuel) was made by H. Hotelling, who derived a price path for non-renewable resources, known as Hotelling's rule. The development of energy economics theory over the last two centuries can be attributed to three main economic subjects - the rebound effect, the energy efficiency gap and more recently, 'green nudges'.

The Rebound Effect (1860s to 1930s)

While energy efficiency is improved with new technology, expected energy savings are less-than proportional to the efficiency gains due to behavioural responses. There are three behavioural sub-theories to be considered: the direct rebound effect, which anticipates increased use of the energy service that was improved; the indirect rebound effect, which considers an increased income effect created by savings then allowing for increased energy consumption, and; the economy-wide effect, which results from an increase in energy prices due to the newly developed technology improvements.

The Energy Efficiency Gap (1980s to 1990s)

Suboptimal investment in improvement of energy efficiency resulting from market failures/barriers prevents the optimal use of energy. From an economic standpoint, a rational decision-maker with perfect information will optimally choose between the trade-off of initial investment and energy costs. However, due to uncertainties such as environmental externalities, the optimal potential energy efficiency is not always able to be achieved, thus creating an energy efficiency gap.

Green Nudges (1990s to Current)

While the energy efficiency gap considers economical investments, it does not consider behavioural anomalies in energy consumers. Growing concerns surrounding climate change and other environmental impacts have led to what economists would describe as irrational behaviours being exhibited by energy consumers. A contribution to this has been government interventions, coined 'green nudges' by Thaler and Sustein (2008), such as feedback on energy bills. Now that it is realized people do not behave rationally, research into energy economics is more focused on behaviors and impacting decision-making to close the energy efficiency gap. Energy efficiency can be considered as a central pillar of global warming mitigation, with important co-benefits, including productivity gains, resource conservation and a lower dependence on foreign energy sources. The notion of energy efficiency is intrinsically linked to that of energy service, i.e., "those functions performed using energy which are means to obtain or facilitate desired end services or states" (Fell 2017). As general-purpose technologies (Bresnahan and Trajtenberg 1995),

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energy services are diffuse, ubiquitous across all sectors of the economy. Against this background, energy efficiency is defined as a technology minimizing the quantity of energy input (e.g., kWh, MJ, etc.) required to produce a given level of energy service (e.g., lumen, temperature, passenger.km, etc.). This technological notion has an economic meaning once one considers the cost of energy and seeks to attach economic value to energy services. Though primarily studied in the building (insulation, appliances) and transportation sector, energy efficiency infuses nearly all human activities, at both the microeconomic level of households and businesses and the macroeconomic considerations of resource management and environmental externalities [51-60].

This multiplicity of scales and fields of application implies a multiplicity of stakeholders: R&D offices, entrepreneurs, small and large companies, households, public authorities, energy utilities, etc. These stakeholders offer their specific expertise to identify and quantify energy efficiency potentials. These expertises can be complementary (e.g., R&D offices and companies need to work together to identify technologies that are not only feasible, but also profitable in the marketplace), but also competing. This is particularly the case for the engineering perspective on vs. the economic view of energy efficiency potentials. While engineering-based studies regularly emphasize important potentials for efficiency gains (e.g., McKinsey & Co. 2009), economists have long questioned these works by noting that if such potentials did exist, economic agents would spontaneously exploit them. These contrasted views translate into a "bottom-up" vs. "top-down" dichotomy in assessment models (Sorrell 2004a; W. J. Hausman and Neufeld 2006; Gerarden, Newell, and 1 An illustration of the engineering stance, making economists sceptical, can be found in (Fickett, Gellings, and Lovins 1990,7), when they famously write that energy efficiency potentials are "not a free lunch; it is a lunch you are paid to eat".(Stavins 2017), or between "technologist" vs. "economic" approaches (Huntington, Schipper, and Sanstad 1994; Sorrell 2004a; 2004b). This points to more general controversies about the relationship between engineering and economics. Already examined in the context of technological change (Rosenberg 1975), these controversies are now an emerging area of research in the field of history of economic thought (Duarte and Giraud 2018).

As for energy efficiency, although they mention the opposition, existing reviews do not fully explore the reasons and conditions for the persistent contrast between economic and technical views. Nor do they offer a long perspective on the history of these controversies, going back at best to the 1970s - and those who mobilize recent history focus primarily on policies and programs, rather than on the ideas surrounding them (Rosenfeld 1999; Gibbons and Gwin 2004). A thorough historical investigation, in line with Turnbull (2017), is likely to uncover older episodes, where economists already built discourses on energy efficiency that were different from that of engineers. It can also help detect the permanence and evolution of the positioning of economic analysis in contrast to the technical expertise on energy efficiency, in order to identify obstacles and opportunities for deeper cooperation between researchers and practitioners in the future. This book provides such a historical account, through three controversial subjects across the last two centuries - the rebound-effect for the 1860s-1930s, the energy efficiency gap for the 1980s-1990s, and green nudges for the most recent period. The rebound effect refers to situations where energy savings are less than proportional to efficiency gains. The energy efficiency gap refers to suboptimal investment in energy efficiency, compared to a normative reference to be specified. Green nudges refer to policy intervention encouraging conservation in both the recipients and society's interest. In each case, we show how economists have built an expertise different from that of engineers. We conclude that most recent developments related to behavioural approaches are likely to reconcile both camps, albeit shifting controversies to new demarcation lines.

The Rebound Effect (1860s-1930s)

The rebound effect, defined above as energy savings that are less than proportional to energy efficiency improvements, can take three major forms (Linares and Labandeira 2010): the direct rebound effect, which consists of less-than-proportional savings in the use of the very service that was subject to efficiency improvements; the indirect rebound effect, coming from the income effect created by the savings, leading to an increased consumption of other energy services; and the general-equilibrium rebound effect, resulting from changes in relative prices that stimulate energy-intensive sectors. In addition to this typology, an important question is the magnitude of the rebound, which can be very different from one situation to another. It can simply consist of savings slightly smaller than efficiency gains, but it can also produce a somewhat counter-intuitive situation, in which energy consumption actually increases - generally referred to as backfire effect.

From a theoretical perspective, the rebound effect can be easily conceived and explained: in the production process, efficiency gains are translated into cost reductions, and price mechanisms adjust to a new equilibrium in which savings are lower than in standard expectations. Empirical evidence of rebound effects is less obvious, as it is regularly argued in the literature (Sorrell 2009; Linares and Labandeira 2010). They are context-dependent and do not always cover the whole typology mentioned above: Herring Greening et al. (2000) add a fourth category of rebound, yet the distinction between direct and indirect effects remains central to their categorization.(2006) reports that the direct rebound effect usually remains quite small (20%), while the indirect and general-equilibrium forms face methodological challenges that prevent them from being thoroughly measured. These methodological limitations should nonetheless not undermine the importance of rebound mechanisms in many sectors in which unitary improvements scarcely result in significant savings, such as home heating and vehicle fuel consumption.

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The modern understanding of the rebound effect dates back to the late 1970s and early 1980s, when Len Brookes (1979) and Daniel Khazzoom (1980) emphasized the low impact of efficiency programmes because of savings clearly less than proportional to energy efficiency improvements. The contemporary literature acknowledges Brookes's and Khazzoom's pioneering inspiration (Alcott 2008; Sorrell 2009). It is well known, however, that the very origin of the conceptualization of the rebound effect is to be found in the ancient writings of W. Stanley Jevons, in his 1865 (2nd ed. 1866) book The Coal Question (Robine 1990; Alcott 2005; 2008; Sorrell 2009; Missemer 2012; Turnbull 2017). After collecting data on coal consumption over decades, confronting them to major innovations in the efficiency of steam engines, Jevons concludes: "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth." (W. S. Jevons 1866, 123)

Interestingly, he not only mentions the direct rebound effect, but also indirect forms, as soon as economic sectors are interrelated: "But no one must suppose that coal thus saved is spared - it is only saved from one use to be employed in others, and the profits gained soon lead to extended employment in many new forms. The several branches of industry are closely interdependent, and the progress of any one leads to the progress of nearly all." (W. S. Jevons 1866, 136) although the rebound effect only constitutes a small part of Jevons's argument on coal depletion - the book covers a wider range of issues (Missemer 2012), it remains a key Sieferle (2001) reports that Sedgwick would have provided a preliminary version of the rebound mechanism before Jevons. Alcott (2008) reviews the economic writings before Jevons sketching rebound effects, but for goods and services outside the energy sector. Argument in peripheral, less-known contributions produced after The Coal Question, in the late 1860s. On January 16, 1867, at Carpenters' Hall in Manchester, Jevons explained: "Some people say we shall [...] economize our coal, use it more carefully, and get more power out of it in the steam engine. The fact is, we are doing that now. Iron is now made by much less coal than it used to be, yet we use more coal than ever. [...] The fact is that coal is a thing of such value to us that we cannot help spending it - there is more temptation than we can resist. It is such a useful substance that we find wealth in it more and more every year." (W. S. Jevons 1867, 26) a similar statement was formulated at the Royal Institution, on March 13, 1868: "Economy, it may be pointed out, does not tend to reduce the industrial consumption of coal, but acts in the opposite direction: by increasing the profitableness of coallabour, it extends its use. Almost every improvement in the engine for the last century and a half has been directed to economizing the consumption of coal; and yet the use of the engine and the quantities of coal consumed advanced pari passu with its economic performance." (W. S. Jevons 1868, 31) Jevons wrote this in a context surrounded by intense debates on the future of British coal reserves (White 1991a; 1991b; Madureira 2012; Mathis 2018; Albritton Jonsson 2019). He was particularly influenced by William Armstrong's warning address at the 1863 Newcastle conference of the British Association for the Advancement of Science (White 2004). Sieferle (2001) reports that many engineers and geologists, from the late 18th century, had formulated estimations about the future of British coal reserves. Most of them considered that there was enough fuel for several centuries. Jevons provided a contrasted view, by forecasting an exponential increase of fuel demand putting rapid pressure on cheap-coal reserves. One reason for this view was the presence of rebound mechanisms in his estimates, turning any efficiency improvement into a poison rather than a remedy. Retrospectively, Jevons's argument and pessimistic scenario can be interpreted as a move in the coal-depletion debate meant to distinguish himself from other parties (Missemer 2017, chp.1; 2018). While many observers considered technical progress and fuel efficiency gains as promising ways to reduce coal consumption (Alcott 2008, 7-8), Jevons used the rebound mechanism to envision a completely different future. In other words, the rebound effect led Jevons to propose an economic discourse on coal depletion emancipated from engineers' view, usually enthusiastic about the opportunities created by technology. Jevons's innovation mainly consisted in including demand and price mechanisms, so far neglected by engineers, into the energy-sector dynamics.

The debate between economic views and engineering views over the impact of technical improvements in the coal sector continued in the late 19th century. In 1878, Anthony J. Mundella gave a talk at the Statistical Society, expressing his trust in the capacity of engineering to circumvent exhaustion issues. Jevons, and a few other participants in the meeting, in turn expressed their scepticism on the matter. In the same year, John Marshall (1878, 325-28), professor at Yorkshire College, reformulated the opposition between economists and engineers on fuel efficiency, explaining that the economic rationale is rarely directed towards savings. In France, economist Yves Guyot (1881, 90-91) confirmed the position of his corporation, noting that despite major improvements in fuel efficiency, production processes use considerably more fuel than before. In the 1890s, in the US, some engineers such as the former president of the American Institute of Mining Engineers, John Birkinbine, still refused to take into account the economic expertise - and rebound mechanisms - in their fuel forecasts (Kent 1895, 324), which is a sign of persistent disagreements.

Studies mentioning Jevons's pioneering research on fuel efficiency rarely show any interest in these little known subsequent episodes, just as they rarely mention the role of the rebound effect in debates between economists and engineers in the early 20th century. A historical inquiry however provides insightful results on the matter. In 1915, Hebert S. Jevons, W. Stanley's son, wrote an extensive book on the British Coal Trade. In his essay, he depicted many aspects of fuel activity, including

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the role of technical improvements (Missemer 2015; Turnbull 2017). Referring to his father's book, he explained that the energy efficiency gains of the late 19th century did not permit a reduction of coal consumption, even per capita (H. S. Jevons 1915, 746-47). He put forward an alternative explanation rooted in the existence of the rebound effect. H. S. Jevons's book has not left a strong mark on the history of economics, but it was recognized as an important contribution at the time, as Alfred Marshall's mention in Industry and Trade (1923, 586f) reveals.

Marshall was One of the First to Call for Empirical Tests of the Rebound Effect

In the US, the early 20th century was the time of the First Conservation Movement, under T. Roosevelt's administration. In politics, this meant an increasing role assigned to experts and engineers in the design of public policies, including environmental and resource management. Gifford Pinchot's doctrine was to merge technical efficiency and political regulation to promote a sound use of natural resources for present and future generations (Pinchot 1910). When economists such as Lewis C. Gray (1913; 1914) and Richard T. Ely (1918) came to participate in conservation debates and provide economic principles underlying the new doctrine (Smith 1982; Crabbé 1983; Gorostiza 2003; Missemer 2017; Turnbull 2017), they were confronted to the question of technological improvements for fuel efficiency. Engineers still considered that conservation was primarily a matter of engineering (Drinker 1919, 30). In contrast, while establishing his optimal extraction principles, Gray (1913) shed light on the role of demand and the need for regulating it as much as supply. Even if he did not refer to the rebound effect, he thus highlighted the role, neglected by engineers, of demand and prices in the fuel sector, in the lineage of Jevons. The energy debates that took place in the US in the 1920s confirmed both the persistent controversies between engineers and economists, and the permanence of the rebound-effect argument, half a century after The Coal Question. It was then finally agreed that engineers and economists should work together to elaborate sound resource management programs (Hammar 1931). In the late 1920s, the Brookings Institution launched a research project on the role of energy in economic development, involving both engineers and economists (Missemer and Nadaud 2019). The participants in this project suggested that the field of mineral economics should be defined as the intersection between economics, geology and engineering (Moulton 1932; Tryon and Berquist 1932). Yet working together does not necessarily imply sharing the same views and values. Within the Brookings project, engineers and economists joined forces in the writing of a common book, Mineral Economics (Tryon and Eckel 1932), but through separate contributions (Pogue 1933). While engineers focused on particular sectors (copper, petroleum, etc.), economists tried to provide more general pictures (e.g., Tryon 1927; Tryon and Rogers 1930; Tryon and Berquist 1932). Doing so, they notably focused their attention on fuel efficiency. The Great War was the occasion of important efforts on the matter (Tryon and Rogers 1930,358), but in the same way that past unitary gains resulted in global increases in consumption, the last improvements are certainly promised to lead to what we now call less-than-proportional savings (Tryon and Rogers 1930, 361). This reference to the rebound effect is not a coincidence; it directly comes from Jevons's old research. Tryon and Rogers cite The Coal Question on several occasions which is not the case for engineering contributors to the Brookings project, and they especially quote Jevons for the rebound effect in its backfire version:

"The ultimate effect of the advance in efficiency may be to increase the consumption of fuel. As Jevons pointed out in 1865, "As a rule, new modes of economy will lead to an increase of consumption, according to a principle recognized in many parallel instances [...]"." (Tryon and Rogers 1930, 364f) This episode shows that the history of the rebound effect is not just the reigniting of Jevons's pioneering contribution by Brookes and Khazzoom in the late 1970s and early 1980s. From Jevons to the first decades of the 20th century, the rebound effect was discussed, commented and regularly emphasized to characterize the economic discourse on fuel efficiency in contrast to the engineering optimism towards technological improvement. Every time in this early history, what was at stake was an underestimation of demand and price mechanisms in engineers' views, and a clear reaction against it by economists. The focus of engineers on the supply side was not specific to energy issues. Knowles (1952) has shown that the same could be observed for other markets, such as for labour: most of the time, engineers built relevant estimates for producers' reactions to shocks or public regulations, but they neglected market mechanisms, in particular demand feedback. When it came to technology, they appeared more optimistic than economists about substitution and efficiency mechanisms - the long-term dynamics of the economy can seem to prove them right - but for the short and medium term, their partial view of market mechanisms caused estimation errors, or disappointment regarding the effectiveness of incentives. On the contrary, by insisting on market mechanisms, economists such as W. S. Jevons, Y. Guyot, H. S. Jevons, F. G. Tryon and H. O. Rogers built a contrasted discourse on energy efficiency. Interestingly, this historical demarcation line was also the one chosen by Len Brookes in the late 1970s to constitute an autonomous economic expertise on energy efficiency. His 1979 contribution was in fact a book review of a bottom-up, engineering contribution (Leach et al. 1979) reporting the insufficient results of the energy efficiency programs conducted in the 1970s in the UK. With the rebound effect, Brookes thus positioned the economic analysis of fuel efficiency at odds with the engineering expertise, in the same way as Jevons and his other predecessors.

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In the late 20th century, the economics of energy efficiency was the heir to this long history of differentiation towards engineering, through the consideration of market mechanisms, in particular the role of demand and prices. With the increasing complexity of energy issues in the broader context of sustainable development, new controversies over fuel efficiency appeared between engineers and economists, creating new demarcations lines.

The Energy Efficiency Gap (1980s-1990s)

The concept of energy efficiency gap developed in the late 1970s and 1980s and reached maturity in the early 1990s. Broadly speaking, the energy efficiency gap refers to the notion that investment in energy efficiency is, by some measure, suboptimal. The problem can equally affect the extensive and intensive margins of investment; that is, produce too few and/or too small investments. The crux of the concept is that the reference taken for optimality differs in engineers' and economists' views, with important consequences for any conclusion as to the magnitude of the gap. As we will see below, the concept creates a new demarcation line between engineers and economists which superimposes on, and to some extent even encompasses, the one associated with the rebound effect. The reflection about the optimal level of energy efficiency was initiated in the United States by the first assessments of the energy efficiency policies implemented in response to the oil crisis of the 1970s. So-called Demand-side management (DSM) programs were rolled out between 1975 and 1978 in many States. In a context of growing concerns about dependence on foreign energy sources, local pollution associated with coal-powered electricity generation plants and nuclear risk, DSM programs were meant to leverage the knowledge electric and gas utilities have of energy end-uses in order to reap the social benefits of energy savings. Practically, DSM gave rise to a number of programs involving subsidies, information provision, etc., at the local level. In the first economic assessment of these programs, Joskow and Marron (1992) pointed to a 'negawatt-hour cost -the cost of saving one unit of energy-substantially higher than that suggested by engineers. Led at the time by Amory Lovins from the Rocky Mountain Institute, the community of engineers was referred to by economists as one of 'efficiency advocates.' Joskow and Marron based their estimates on data self-reported by electric utilities. They attributed the discrepancy to a number of issues, including failure to account for all relevant costs, reliance on projections rather than actual measurement of savings, and failure to account for non-additional participants in subsidy programs, often referred to as 'free riders.' This seminal contribution ignited a methodological dispute that continues to this day [61-70].

While Joskow and Marron's evaluation was the first to address the multiple programs that a utility would rollout within its overarching DSM policy, the economic evaluation of individual programs had started earlier on and identified two phenomenon - abnormally high implicit discount rates and a gap between predicted and realized energy savings. From an economic perspective, implicit discount rates are those that rationalize observed investment choices. They are estimated as the unknown variable that equates the net present value of investment to zero. An implicit discount rate is deemed abnormal if it exceeds conventional values, usually aligned with the returns households can enjoy in financial markets - typically 5-7%. A 'normal' discount rate is a notion of optimality that appeals to both engineers and economists. While it postulates a model of choice, it is the smallest common denominator in that regard that speaks to both engineers and economists. Moreover, it is not too demanding in terms of data requirements, as it can be assessed for each individual choice, without relying on some elasticity estimated at the market level. Hausman (1979) was the first to provide evidence of abnormally high implicit discount rates in relation to energy efficiency investment. The research effort inspired many others, which would soon be reviewed by Train (1985). The most recent developments include Loughran and Kulick (2004), Auffhammer, Blumstein, and Fowlie (2008) and Arimura et al. (2012). From a methodological perspective, narratives of underinvestment collected in surveys formed a third type of evidence (e.g., Blumstein et al. 1980).

These are however less systematic and thus not examined here lower-than-predicted, or missing, energy savings - was a prefiguration of the finding Joskow and Marron reached at a more systematic scale. Though the problem was first noted by Hirst and Goeltz (1985), it was not until Metcalf and Hassett (1999) that it became widely recognized. Interestingly, it has recently attracted renewed interest with the publication by Fowlie, Greenstone and Wolfram (2018) of a study finding virtually no savings in a heavily-subsidized weatherization programme. Compared to abnormal discount rates, the identification of missing savings does not rely on any preconception of a model of choice. Still, engineering predictions embed normative assumptions that are not always clearly elicited. Both abnormal discount rates and missing savings can be seen as manifestations of a gap between reality and some notion of optimality - respectively conventional market returns and engineering projections. The identification of these gaps raised a number of questions, including:

3. **What problems are at the source of these gaps?**

Are they economically important? If so, should they be addressed by policy intervention?

These were the starting point of the elaboration of a conceptual framework known as the 'energy efficiency gap' and meant to list, characterize and assess the significance of various sources of the gap. This reflection was the result of a collective effort coordinated by the Energy Modeling Forum (EMF) in the early 1990s. Convened by Stanford University, the EMF gathers an interdisciplinary community interested in energy modelling and involving both economists and engineers. The reflection resulted

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in the publication in 1994 of a special issue in Energy Policy on the energy efficiency gap. We find here many analogies with the 1932 book Mineral Economics published as part of the Brookings program and mentioned above. Although the integration of engineering and economic perspectives was certainly more advanced in the EMF than it was at the Brookings Institution, the special issue in Energy Policy featured the same segmentation as in Mineral Economics, with separate papers for each view.

To put these contributions in perspective, the citation count of these references in the Web of Science if 8 for Hirst and Goeltz (1985), 84 for Metcalf and Hassett (1999) and 12 for Fowlie, Greenstone and Wolfram (2018), as of August 23, 2019. Fowlie, Greenstone and Wolfram's study is the most cited among a broader set of references reaching the same finding, including Davis, Fuchs and Gertler (2014), Graff Zivin and Novan (2016) and Giraudet, Bourgeois and Quirion (2018). Among the papers in the issue, that of Jaffe and Stavins (1994c) turned out to be the most impactful. By proposing an original conceptual framework, it laid down a whole new research agenda. The most essential feature of the framework was a distinction between market barriers and market failures. Market barriers are considered as normal components of markets (e.g., risk, heterogeneity in consumer preferences). In contrast, market failures occur when the basic assumptions of well-functioning markets - perfect competition, perfect information and well-defined property rights - are violated. While both may prevent adoption of energy efficiency technologies from being widespread, only the latter justify policy intervention. Borrowed from public economics, this dichotomy provides a framework to think about conflicts between engineering and economist views. In essence, while market failures might be a concern for both economists and engineers, market barriers only worry the latter. In this regard, the rebound effect can be seen as a market barrier: a pure economic mechanism that nevertheless prevents maximization of energy savings. Likewise, the problems pointed out by Joskow and Marron (1992) -who personify the economist stance- are essentially market barriers, which lead the authors to seriously question the economic rationale for DSM programs. One can see in the success of Jaffe and Stavins' paper a victory of the economist view taken by the authors. This however casts shadow on the fact that the framework developed in the special issue was remarkably consensual, in particular by being validated by contributions from several researchers from the Berkeley Lab (Alan Sanstad, Richard Howarth), a prominent institution in the field of integrated energy-economy modelling. In contrast, somewhat extreme economist views developed in parallel without gaining significant traction (Sutherland 1996; Wirl 1997).

The 'energy efficiency gap' was both a framework to think of the engineer vs. economist dichotomy and, perhaps more importantly, a research program. Much effort remained to be done to give it substance by identifying, characterizing, and quantifying the problem. For instance, a problem frequently pointed out in relation to energy efficiency is credit constraints. How important is it? Is it simply a market barrier -after all, economic decisions are all about maximizing outcomes under credit constraints- or is there. The authors made their point in several references, including in Energy Policy (Jaffe and Stavins 1994c), Resource and Energy Economics (Jaffe and Stavins 1994b) and the Energy Journal (Jaffe and Stavins 1994a). They kept refining their diagram until the definitive version was published in the Encyclopedia of Energy (Jaffe, Newell, and Stavins 2004), with Richard Newell as a co-author. Something more specific to it (e.g., information asymmetries) in the context of energy efficiency that makes it a market failure? To a large extent, the energy efficiency gap research program was not followed up by serious investigation. This changed in the early 2000s, when concerns over anthropogenic global warming gained prominence. Carbon dioxide externalities associated with energy use were recognized as the greatest market failure humanity had ever faced (Stern 2006). Attention was drawn to energy efficiency by engineering studies portraying it as the most cost-effective way of reducing carbon dioxide emissions. In the most impactful of these studies, McKinsey & Co (2009) suggested that most energy efficiency technologies were socially profitable not only for modest values of the social cost of carbon - indicating that they should be prioritized to reduce emissions - but also for negative values - indicating that they should be prioritized anyway. While the first argument remained uncontroversial, economists objected to the second that if it were true, energy efficiency would be everywhere, which was not the case. This was clearly a reminiscence of the by now old debate between economists and engineers, only occurring in a new context."

Altogether, the state of the art of the economics of energy efficiency had settled as follows by the 2000s: market barriers were deemed significant, and it was considered the engineers' duty to improve their projections; market failures were also deemed important, but chiefly in energy market, e.g., energy-use externalities; in contrast, market failures in energy efficiency markets, if anything, remain to be elicited. This was summarized in important reviews, including Sorrell (2004b), Gillingham, Newell and Palmer (2009) and Linares and Labandeira (2010). Importantly, we saw the energy efficiency gap was a broader conceptual framework than the rebound effect in that the former encompassed the latter and deployed the same fault lines in a more systematic way. We will see now that an even broader framework is now developing, building on somewhat new divides. It was also a reminiscence of the notions of no-regret potential for, and co-benefits of, carbon dioxide emission reductions, which both gained popularity in the IPCC community.

Green Nudges (Since 2000s)

The energy efficiency gap essentially is a neo-classical economic concept, in the sense that, by drawing a line between market failures and non-market failures, it provides a framework

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to think of energy efficiency investment in situations where the fundamental assumptions of well-functioning markets - perfect competition, perfect information and well-defined property rights - are violated. The framework also has a practical appeal in that it provides clear guidance for policy-making: for any market failure proved significant, there is a policy remedy to implement.

Evidence is growing, however, that energy efficiency decisions are subject to new economic problems which the energy efficiency gap framework is not well-suited to accommodate: behavioral anomalies. Behavioral anomalies occur when perfect rationality, the essential assumption of the neo-classical economic framework, is violated. These include context-dependent preferences, inconsistencies in time and risk preferences, and the use of heuristics in lieu of proper optimization. 10 To put it simply, behavioral anomalies result in people making mistakes in the sense that they make decisions that do not satisfy them ex post. Put still another way, they create a gap between decisions, or ex ante utility and experienced, or ex post utility. Economic research into irrationality and behavioral anomalies reached full recognition with the Nobel Prizes awarded to Herbert Simon in 1978, Daniel Kahneman in 2002 and Richard Thaler in 2017. What has come to be known as behavioral economics is now part of most standard frameworks in economic analysis. 11 Unlike with market failures, the policy implications of behavioral anomalies are ambiguous. Whenever there is a market failure, some agent in the economy benefits from a rent -competitive, informational, and legal -at the expense of another agent; in this context, it has been uncontroversial that the Government should intervene to level the playing field. In contrast, intervening to address behavioral anomalies would be equivalent for the Government to helping people reconcile with themselves. This kind of intervention, coined 'nudge' by Thaler and Sustein (2008) in their eponymous best-seller, is more controversial.

10 Before the 2000s, behavioral anomalies were sometimes tackled in the energy efficiency literature through the concepts of behavioral obstacles or bias (e.g., Eyre 1997). However, they were neither central nor empirically tested at the time. 11 On the disputed integration of behavioral economics into neoclassical economics, see Angner (2019). If someone is having issues figuring out her decision utility, how can the Government do better without somehow substituting its own norms for that person's? Nudges are indeed akin to 'libertarian paternalism' in that they impose social norms without being legally binding (Salvat 2014; Schubert 2017).

Throughout the emergence of behavioral economics, energy demand has proved a highly favored setting for seeking evidence of irrational behavior and experimenting with nudges. In particular, feedback experiments in which people are given information as to how their energy consumption compares to that of relevant others (usually their neighbors) were set up early (for a review, see Fischer 2008). These have been more recently deployed on much a broader scale, which improved the statistical power and credibility of the approach, allowing some researchers to publish in major economic journals (e.g., Allcott and Rogers 2014). In such experimental settings, average behavior can be seen as a social norm which people seek to conform to. Accordingly, energy users are found to adjust their consumption by regressing to the mean, even when their consumption is below average. This is not the case if additional structure is imposed on social norms, for instance by adding smileys to consumption feedback. Then, consumers using less energy than average receive positive smileys, to which they respond by keeping their consumption low; meanwhile, those using more than average receive negative smileys and reduce their consumption. Albeit seen as a successful nudge - low-cost, highly effective - harnessing context-dependent preferences, feedback interventions illustrate an important issue, namely the intricacies between behavioral anomalies and the market barriers and failures that define the energy efficiency gap. In particular, electricity billing is typically not given in real time, nor is it detailed for specific usages. In other words, the price people pay for different energy services typically is incomplete information. One can therefore expect people to respond in a suboptimal way to energy bills, even if they do not include feedback. This pre-existing distortion is important to take into account when one seeks to assess the impact of feedback interventions.

Taking stock, behavioral economics adds a new fault line between decision and experienced utility that is found to be highly relevant to energy efficiency decisions. This new fault line is a form of reconciliation between engineers and economists. Economists now start to recognize the point made by engineers that people do not behave rationally. As a result, behavioral economics now concentrates most of the research effort that is put in energy efficiency. This focus however leaves aside important blind spots, in particular in the way behavioral anomalies interact with both the market barriers and market failures making up the energy efficiency gap.

A Synthetic Framework

Our historical journey has revealed demarcation lines between engineers and economists that first emerged in the context of energy efficiency through the rebound effect. In the late 20th century, divergences on the role of market feedbacks were supplemented by contrasted views of decision-making mechanisms. Most recently, the acknowledgement of behavioral barriers has been an opportunity to reconcile the economic and the engineering perspectives over energy efficiency. Both camps consider these barriers as central, legitimizing policy measures for energy improvements. Yet behavioral analysis led to a new fault line - one between nudge advocates and a more sceptical community - about the effectiveness of nudges, which might be strongly driven by pre-existing market failures. Not only does this new fault line not clearly separate out economists and engineers - there are advocates of both positions in both camps - it does not

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either fit into the conceptual framework that prevailed up to now; indeed, it is seemingly orthogonal to the usual demarcation lines structuring the debate over the energy efficiency gap. Against this background, we propose a revised version of the Jaffe-Stavins (1994) and Jaffe-Newell-Stavins (2004) diagram, extended to accommodate behavioral anomalies. Because behavioral analysis brings a new dimension to our understanding of energy efficiency, the diagram is in 3D, distinguishing a space 'decision utility' (DU) and a space 'experienced utility' (EU). This diagram is more complex than the original one, reflecting the enriched analytical framework currently at stake in the economics of energy efficiency. It is both the result of our historical investigation, which has shown the increasing widening of the debate, and a starting-point to help identify the areas of discussion over barriers and failures to be addressed in the design of energy efficiency policies.

Investigating the history of the economics of energy efficiency is a new challenge both from a contemporary perspective - existing reviews scarcely go back beyond the 1970s -and from a history- of -economic-thought perspective- this little studied subject provides a bright illustration of the controversies between economists and engineers throughout history. We have researched the permanencies and evolutions of the relationships between economics and engineering on the subject of energy efficiency, and have obtained the following results. First, the origins of the controversies are not limited to W. S. Jevons's ancient intuition on the rebound effect. Market mechanisms and demand feedbacks had been arguments used by economists for several decades, at least until the 1930s, to build up expertise distinct from that of engineers. This means that already at the time, disagreements were difficult to overcome and when joint research programs were carried out (e.g., at the Brookings Institution), the different participants had difficulty understanding each other and working together.

Second, the long history of the economics of energy efficiency is one of iterative diversification and redefinition of the demarcation lines between economists and engineers. After the divergences on market mechanisms, the debates over the energy efficiency gap gave birth to new disagreements, on the decision-making of agents and on the distinction between barriers and failures. The 1990s reconfigured controversies, to the point of integrating the rebound effect into the discussion on the energy efficiency gap. Research cooperation between engineers and economists continued to pose difficulties, in similar ways to what we had highlighted for the 1920s.

Third, the acknowledgement of behavioral barriers to optimal investment in energy efficiency offered an opportunity for the reconciliation of economists and engineers. It seems however that a new fault line appeared, between those accepting green nudges and those more sceptical about their legitimacy, both in ethical and economic terms. Interestingly, this new dividing line does not separate economists from engineers, but more heterogeneous constellations of researchers and experts. This could be a historically unprecedented reconfiguration, made possible by behavioral approaches. To synthetize these findings and to make the link between our historical inquiry and future research in the economics of energy efficiency, we proposed an update of the famous Jaffe-Newell-Stavins diagram, showing the orthogonal character of the behavioral perspective with respect to the historical oppositions in the field. This makes it possible to highlight research avenues for the future, by pointing out the areas where we need further work to articulate market and behavioral mechanisms, and distinguish barriers from failures, to design legitimate policy measures.

Renewable Energy

Renewable energy is energy that is collected from renewable resources that are naturally replenished on a human timescale. It includes sources such as sunlight, wind, rain, tides, waves, and geothermal heat. Renewable energy stands in contrast to fossil fuels, which are being used far more quickly than they are being replenished. Although most renewable energy sources are sustainable, some are not. For example, some biomass sources are considered unsustainable at current rates of exploitation. Renewable energy often provides energy in four important areas: electricity generation, air and water heating/cooling, transportation, and rural (off-grid) energy services. About 20% of humans' global energy consumption is renewables, including almost 30% of electricity. About 8% of energy consumption is traditional biomass, but this is declining. Over 4% of energy consumption is heat energy from modern renewables, such as solar water heating, and over 6% electricity. Globally there are over 10 million jobs associated with the renewable energy industries, with solar photovoltaics being the largest renewable employer. Renewable energy systems are rapidly becoming more efficient and cheaper and their share of total energy consumption is increasing, with a large majority of worldwide newly installed electricity capacity being renewable. In most countries, photovoltaic solar or onshore wind are the cheapest new-build electricity.

Many nations around the world already have renewable energy contributing more than 20% of their energy supply. And many nations around the world already generate over half their electricity from renewables. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond. A few countries generate all their electricity using renewable energy. Renewable energy resources exist over wide geographical areas, in contrast to fossil fuels, which are concentrated in a limited number of countries. Deployment of renewable energy and energy efficiency technologies is resulting in significant energy security, climate change mitigation, and economic benefits. However renewables are being hindered by hundreds of billions of dollars of fossil fuel subsidies. In international public opinion surveys there is strong support for

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promoting renewable sources such as solar power and wind power.

While many renewable energy projects are large-scale, renewable technologies are also suited to rural and remote areas and developing countries, where energy is often crucial in human development. As most of renewable energy technologies provide electricity, renewable energy is often deployed together with further electrification, which has several benefits: electricity can be converted to heat, can be converted into mechanical energy with high efficiency, and is clean at the point of consumption. In addition, electrification with renewable energy is more efficient and therefore leads to significant reductions in primary energy requirements. In 2021 China accounted for almost half of the increase in renewable electricity. Renewable energy flows involve natural phenomena such as sunlight, wind, tides, plant growth, and geothermal heat, as the International Energy Agency explains: Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources.

Renewable energy resources and significant opportunities for energy efficiency exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency, and technological diversification of energy sources, would result in significant energy security and economic benefits. It would also reduce environmental pollution such as air pollution caused by burning of fossil fuels and improve public health, reduce premature mortalities due to pollution and save associated health costs that could amount to trillions of dollars annually. Multiple analyses of decarbonization strategies have found that quantified health benefits can significantly offset the costs of implementing these strategies. Renewable energy sources, that derive their energy from the sun, either directly or indirectly, such as hydro and wind, are expected to be capable of supplying humanity energy for almost another 1 billion years, at which point the predicted increase in heat from the Sun is expected to make the surface of the Earth too hot for liquid water to exist [71-80].

Climate change and global warming concerns, coupled with the continuing fall in the costs of some renewable energy equipment, such as wind turbines and solar panels, are driving increased use of renewables. New government spending, regulation and policies helped the industry weather the global financial crisis better than many other sectors. As of 2019, however, according to the International Renewable Energy Agency, renewables overall share in the energy mix (including power, heat and transport) needs to grow six times faster, in order to keep the rise in average global temperatures "well below" 2.0 °C (3.6 °F) during the present century, compared to pre-industrial levels. As of 2011, small solar PV systems provide electricity to a few million households, and micro-hydro configured into mini-grids serves many more. Over 44 million households use biogas made in household-scale digesters for lighting and/or cooking, and more than 166 million households rely on a new generation of more-efficient biomass cook stoves. United Nations' eighth Secretary-General Ban Ki-moon has said that renewable energy has the ability to lift the poorest nations to new levels of prosperity. At the national level, at least 30 nations around the world already have renewable energy contributing more than 20% of energy supply. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond, and some 120 countries have various policy targets for longer-term shares of renewable energy, including a 20% target of all electricity generated for the European Union by 2020. Some countries have much higher long-term policy targets of up to 100% renewables. Outside Europe, a diverse group of 20 or more other countries targets renewable energy shares in the 2020-2030 time frame that range from 10% to 50%. Renewable energy often displaces conventional fuels in four areas: electricity generation, hot water/space heating, transportation, and rural (off-grid) energy services:

- **Power Generation**

By 2040, renewable energy is projected to equal coal and natural gas electricity generation. Several jurisdictions, including Denmark, Germany, the state of South Australia and some US states have achieved high integration of variable renewables. For example, in 2015 wind power met 42% of electricity demand in Denmark, 23.2% in Portugal and 15.5% in Uruguay. Interconnectors enable countries to balance electricity systems by allowing the import and export of renewable energy. Innovative hybrid systems have emerged between countries and regions.

- **Heating**

Solar water heating makes an important contribution to renewable heat in many countries, most notably in China, which now has 70% of the global total (180GWth). Most of these systems are installed on multi-family apartment buildings and meet a portion of the hot water needs of an estimated 50-60 million households in China. Worldwide, total installed solar water heating systems meet a portion of the water heating needs of over 70 million households. The use of biomass for heating continues to grow as well. In Sweden, national use of biomass energy has surpassed that of oil. Direct geothermal for heating is also growing rapidly. The newest addition to heating is from geothermal heat pumps which provide both heating and cooling, and also flatten the electric demand curve and are thus an increasing national priority.

- **Transportation**

Bioethanol is an alcohol made by fermentation, mostly from carbohydrates produced in sugar or starch crops such as corn, sugarcane, or sweet sorghum. Cellulosic biomass, derived from non-food sources such as trees and grasses is also being developed as a feedstock for ethanol production. Ethanol can

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be used as a fuel for vehicles in its pure form, but it is usually used as a gasoline additive to increase octane and improve vehicle emissions. Bioethanol is widely used in the USA and in Brazil. Biodiesel can be used as a fuel for vehicles in its pure form, but it is usually used as a diesel additive to reduce levels of particulates, carbon monoxide, and hydrocarbons from diesel-powered vehicles. Biodiesel is produced from oils or fats using transesterification and is the most common biofuel in Europe. A solar vehicle is an electric vehicle powered completely or significantly by direct solar energy. Usually, photovoltaic (PV) cells contained in solar panels convert the sun's energy directly into electric energy. The term "solar vehicle" usually implies that solar energy is used to power all or part of a vehicle's propulsion. Solar power may be also used to provide power for communications or controls or other auxiliary functions. Solar vehicles are not sold as practical day-to-day transportation devices at present but are primarily demonstration vehicles and engineering exercises, often sponsored by government agencies. High-profile examples include Planet Solar and Solar Impulse. However, indirectly solar-charged vehicles are widespread and solar boats are available commercially.

Demand

In July 2014, WWF and the World Resources Institute convened a discussion among a number of major US companies who had declared their intention to increase their use of renewable energy. These discussions identified a number of "principles" which companies seeking greater access to renewable energy considered important market deliverables. These principles included choice (between suppliers and between products), cost competitiveness, longer term fixed price supplies, access to third-party financing vehicles, and collaboration. UK statistics released in September 2020 noted that "the proportion of demand met from renewables varies from a low of 3.4 per cent (for transport, mainly from biofuels) to highs of over 20 per cent for 'other final users', which is largely the service and commercial sectors that consume relatively large quantities of electricity, and industry". In some locations, individual households can opt to purchase renewable energy through a consumer green energy program.

4. Trends for Individual Technologies

Hydroelectricity

In 2017 the world renewable hydropower capacity was 1,154 GW. Only a quarter of the worlds estimated hydroelectric potential of 14,000 TWh/year has been developed, the regional potentials for the growth of hydropower around the world are, 71% Europe, 75% North America, 79% South America, 95% Africa, 95% Middle East, 82% Asia Pacific. New hydropower projects face opposition from local communities due to their large impact, including relocation of communities and flooding of wildlife habitats and farming land. High cost and lead times from permission process, including environmental and risk assessments, with lack of environmental and social acceptance are therefore the primary challenges for new developments. In addition, economic limitations in the third world and the lack of a transmission system in undeveloped areas result in the possibility of developing 25% of the remaining potential before 2050, with the bulk of that being in the Asia Pacific area. There is slow growth taking place in Western counties, but not in the conventional dam and reservoir style of the past. New projects take the form of run-of-the-river and small hydro, neither using large reservoirs. It is popular to repower old dams thereby increasing their efficiency and capacity as well as quicker responsiveness on the grid. Where circumstances permit existing dams such as the Russell Dam built in 1985 may be updated with "pump back" facilities for pumped-storage which is useful for peak loads or to support intermittent wind and solar power. Countries with large hydroelectric developments such as Canada and Norway are spending billions to expand their grids to trade with neighboring countries having limited hydro.

Wind Power Development

Wind power is widely used in Europe, China, and the United States. From 2004 to 2017, worldwide installed capacity of wind power has been growing from 47 GW to 514 GW, a more than tenfold increase within 13 years as of the end of 2014, China, the United States and Germany combined accounted for half of total global capacity. Several other countries have achieved relatively high levels of wind power penetration, such as 21% of stationary electricity production in Denmark, 18% in Portugal, 16% in Spain, and 14% in Ireland in 2010 and have since continued to expand their installed capacity. More than 80 countries around the world are using wind power on a commercial basis. Wind turbines are increasing in power with some commercially deployed models generating over 8MW per turbine.

Solar Thermal

Solar thermal energy capacity has increased from 1.3 GW in 2012 to 5.0 GW in 2017. Spain is the world leader in solar thermal power deployment with 2.3 GW deployed. The United States has 1.8 GW, most of it in California where 1.4 GW of solar thermal power projects are operational. Several power plants have been constructed in the Mojave Desert, Southwestern United States. As of 2017 only 4 other countries have deployments above 100 MW: South Africa (300 MW) India (229 MW) Morocco (180 MW) and United Arab Emirates (100 MW). The United States conducted much early research in photovoltaics and concentrated solar power. The U.S. is among the top countries in the world in electricity generated by the Sun and several of the world's largest utility-scale installations are located in the desert Southwest.

The oldest solar thermal power plant in the world is the 354 megawatt (MW) SEGS thermal power plant, in California. The

Ivanpah Solar Electric Generating System is a solar thermal power project in the California Mojave Desert, 40 miles (64 km) southwest of Las Vegas, with a gross capacity of 377 MW. The 280 MW Solana Generating Station is a solar power plant near Gila Bend, Arizona, about 70 miles (110 km) southwest of Phoenix, completed in 2013. When commissioned it was the largest parabolic trough plant in the world and the first U.S. solar plant with molten salt thermal energy storage. In developing countries, three World Bank projects for integrated solar thermal/combined-cycle gas-turbine power plants in Egypt, Mexico, and Morocco have been approved.

Photovoltaic Development

Photovoltaics (PV) is rapidly-growing with global capacity increasing from 177 GW at the end of 2014 to 385 GW in 2017. PV uses solar cells assembled into solar panels to convert sunlight into electricity. PV systems range from small, residential and commercial rooftop or building integrated installations, to large utility-scale photovoltaic power station. The predominant PV technology is crystalline silicon, while thin-film solar cell technology accounts for about 10 percent of global photovoltaic deployment. In recent years, PV technology has improved its electricity generating efficiency, reduced the installation cost per watt as well as its energy payback time, and reached grid parity in at least 30 different markets by 2014. Building-integrated photovoltaics or “onsite” PV systems use existing land and structures and generate power close to where it is consumed.

Photovoltaics grew fastest in China, followed by Japan and the United States. Solar power is forecasted to become the world’s largest source of electricity by 2050, with solar photovoltaics and concentrated solar power contributing 16% and 11%, respectively. This requires an increase of installed PV capacity to 4,600 GW, of which more than half is expected to be deployed in China and India. Commercial concentrated solar power plants were first developed in the 1980s. As the cost of solar electricity has fallen, the number of grid-connected solar PV systems has grown into the millions and utility-scale solar power stations with hundreds of megawatts are being built. Many solar photovoltaic power stations have been built, mainly in Europe, China and the United States. The 1.5 GW Tengger Desert Solar Park, in China is the world’s largest PV power station. Many of these plants are integrated with agriculture and some use tracking systems that follow the sun’s daily path across the sky to generate more electricity than fixed-mounted systems.

Biofuel Development

Brazil produces bioethanol made from sugarcane available throughout the country. A typical gas station with dual fuel service is marked “A” for alcohol (ethanol) and “G” for gasoline. Bioenergy global capacity in 2017 was 109 GW. Biofuels provided 3% of the world’s transport fuel in 2017. Mandates for blending biofuels exist in 31 countries at the national level and in 29 states/provinces. According to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by 2050. Since the 1970s, Brazil has had an ethanol fuel program which has allowed the country to become the world’s second largest producer of ethanol (after the United States) and the world’s largest exporter. Brazil’s ethanol fuel program uses modern equipment and cheap sugarcane as feedstock, and the residual cane-waste (bagasse) is used to produce heat and power. There are no longer light vehicles in Brazil running on pure gasoline. By the end of 2008 there were 35,000 filling stations throughout Brazil with at least one ethanol pump. Unfortunately, Operation Car Wash has seriously eroded public trust in oil companies and has implicated several high ranking Brazilian officials. Nearly all the gasoline sold in the United States today is mixed with 10% ethanol, and motor vehicle manufacturers already produce vehicles designed to run on much higher ethanol blends. Ford, Daimler AG, and GM are among the automobile companies that sell “flexible-fuel” cars, trucks, and minivans that can use gasoline and ethanol blends ranging from pure gasoline up to 85% ethanol. By mid-2006, there were approximately 6 million ethanol compatible vehicles on U.S. roads.

Geothermal Development

Global geothermal capacity in 2017 was 12.9 GW. Geothermal power is cost effective, reliable, sustainable, and environmentally friendly, but has historically been limited to areas near tectonic plate boundaries. Recent technological advances have expanded the range and size of viable resources, especially for applications such as home heating, opening a potential for widespread exploitation. Geothermal wells release greenhouse gases trapped deep within the earth, but these emissions are usually much lower per energy unit than those of fossil fuels. As a result, geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels. In 2017, the United States led the world in geothermal electricity production with 12.9 GW of installed capacity. The largest group of geothermal power plants in the world is located at The Geysers, a geothermal field in California. The Philippines follows the US as the second highest producer of geothermal power in the world, with 1.9 GW of capacity online [81-90].

Developing Countries

Renewable energy technology has sometimes been seen as a costly luxury item by critics, and affordable only in the affluent developed world. This erroneous view has persisted for many years, however between 2016 and 2017, investments in renewable energy were higher in developing countries than in developed countries, with China leading global investment with a record 126.6 billion dollars. Many Latin American and African countries increased their investments significantly as well. Renewable energy can be particularly suitable for developing countries. In rural and remote areas, transmission and distribution of energy generated from fossil fuels can be difficult and expensive.

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Producing renewable energy locally can offer a viable alternative.

Technology advances are opening up a huge new market for solar power: the approximately 1.3 Billion people around the world who do not have access to grid electricity. Even though they are typically very poor, these people have to pay far more for lighting than people in rich countries because they use inefficient kerosene lamps. Solar power costs half as much as lighting with kerosene. As of 2010, an estimated 3 million households get power from small solar PV systems. Kenya is the world leader in the number of solar power systems installed per capita. More than 30,000 very small solar panels, each producing 12 to 30 watts, are sold in Kenya annually. Some Small Island Developing States (SIDS) are also turning to solar power to reduce their costs and increase their sustainability.

Micro-hydro configured into mini-grids also provide power. Over 44 million households use biogas made in household-scale digesters for lighting and/or cooking, and more than 166 million households rely on a new generation of more-efficient biomass cook stoves. Clean liquid fuel sourced from renewable feed stocks are used for cooking and lighting in energy-poor areas of the developing world. Alcohol fuels (ethanol and methanol) can be produced sustainably from non-food sugary, starchy, and cellulosic feedstocks. Project Gaia, Inc. and Clean Star Mozambique are implementing clean cooking programs with liquid ethanol stoves in Ethiopia, Kenya, Nigeria and Mozambique. Renewable energy projects in many developing countries have demonstrated that renewable energy can directly contribute to poverty reduction by providing the energy needed for creating businesses and employment. Renewable energy technologies can also make indirect contributions to alleviating poverty by providing energy for cooking, space heating, and lighting. Renewable energy can also contribute to education, by providing electricity to schools.

Renewable Energy Growth Depends on A Circular Economy for Batteries

The renewable energy sector is growing at an exponential rate. In 2020, for the first time, renewables have generated more electricity in the U.K. than fossil fuels and according to the International Energy Agency, solar energy is the "cheapest electricity in history." Yet while the capacity of the renewable energy sector is strengthening, renewables still only account for 11 percent of the world's primary energy. This is just twice the proportion provided by renewables more than 50 years ago, and with the United Nations expecting an overshoot of the Paris Agreement 2030 targets -nearing 32 billion metric tons of CO2 emissions- the pace of the transition to renewables needs to be accelerated.

Overcoming Barriers to Renewable Energy

There have been many barriers to the renewable energy transition. Over the years, economic obstacles have included subsidies for non-renewable energy, low oil prices that have limited investment in renewables, and the cost of infrastructure development. Social barriers also have limited progress, including public reservations about changes to local landscapes and disruptions to established ways of life. While these barriers are persistent, international pressure and awareness of the negative impacts of fossil fuel-based energy are catalyzing government action to decarbonize the energy sector. The EU's European Green Deal, for example, sets out a plan for net-zero greenhouse gas emissions by 2050, and China is taking steps to achieve carbon neutrality by 2060. With policymakers setting a course for change, renewables are receiving new investment. In October, the Financial Times reported that stocks in hydrogen energy equipment manufacturer ITM Power had risen by 220 percent while Dutch energy storage company Alfen jumped more than 230 percent. Meanwhile, multinational oil and gas corporation ExxonMobil, which once had the world's biggest equity value, has been overtaken by Florida-based "clean energy" provider Next Era Energy in terms of stock market value.

Investments in renewables are also being made by some Big Oil companies. Total has committed to a significant solar project in Qatar while ENI SpA has pledged to lower its greenhouse gas emissions by 80 percent by 2050. Swiss commodity trader Mercuria is also investing $1.5 billion into renewable energy projects in North America with private equity partners. And BP's decision to write down around $17.5 billion worth of assets on the basis that they are "no longer economic" could be a game changer in the energy sector.

However, despite these big steps forward, a fundamental technical barrier remains: energy storage. As Amrit Chandan, CEO of lithium-ion battery technology company Aceleron, notes: "Renewables are intermittent, meaning that they need the support of batteries to store clean energy for use when the sun isn't shining and the wind isn't blowing. Battery storage is vital."

Battery Development

High-capacity long-life battery development is particularly important for the utility and transport sectors. A key enabler of their success is likely to be the lithium-ion battery most commonly used for small-scale applications such as phone chargers but increasingly being developed for larger-scale applications. Seven European countries already have committed 3.2 billion euros to support research into lithium-ion batteries, and both Tesla and General Motors are investing billions of dollars in manufacturing facilities for the technology. Battery waste is an elephant in the room when it comes to the renewable energy transition. By 2030, there could be 11 million tonnes of lithium-ion battery waste from electric vehicles alone enough to fill London's Wembley Stadium almost 20 times over. Combined with the growth of renewable energy for utilities, as well as other battery-driven devices, this adds up to a large and growing problem that needs to be managed.

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Designing Out Battery Waste

Lithium-ion batteries are designed and sold in ways that mean they are difficult to repair, remanufacture and recycle. As Chandan explains, they are "traditionally welded or glued together, making individual components difficult to replace. If one part fails, the whole battery is usually thrown away often with more than 80 percent of its potential life left unused." Two important issues are raised here: first, batteries with most of their charging capacity remaining are being discarded rather than used; and second, the valuable materials used to make these batteries are being lost from the economy. With a shortage of lithium possible as soon as 2025, this could be a major barrier to the uptake of renewable energy.

Extending Battery Life

To ensure that batteries are used to their full potential and don't become waste, collaboration across industries and between businesses and policymakers, as well as a rethinking of battery ownership, is needed. In the EU, for example, the Waste Framework Directive currently defines reuse of an item as "any operation by which products or components that are not waste are used again for the same purpose for which they were conceived." For batteries, this definition needs to be revisited; while automotive batteries lose 20 to 30 percent of their storage capacity after eight to 10 years and no longer can be used in cars, they can be used, as Chandan notes, "as back-up batteries, for applications in data centers and elsewhere as this doesn't require the same battery capacity." In addition to a review of the definitions of reuse, for it to happen in practice requires effective resale markets to be established or for the manufacturer to retain ownership of the batteries so that they can be passed between multiple users. Manufacturers retaining ownership of batteries is also a model that can increase the likelihood of repair and remanufacturing.

Aceleron's lithium-ion battery has been designed to facilitate the easy replacement of components, extending the life of its batteries. Coupled with advanced analytics that can detect which components need servicing, this means the batteries are expected to function for up to 25 years with appropriate maintenance, more than double the lifespan of traditional lithium-ion batteries. Electric cars such as Renault's also will play a key role in the broader transition to renewable energy by harnessing more of the potential of battery technology. A study by the European Climate Foundation together with representatives of the automotive and electromobility industry, battery makers, the energy sector and French institutions and NGOs found that when an electric vehicle is parked and connected to the grid, it is able to export energy from its battery. Called vehicle-to-grid systems, they can meet peaks in electricity demand, help manage overloads and absorb surplus energy from renewable sources. Developing this relationship between utilities and electric cars has the potential to accelerate the renewable energy transition in both sectors. For example, on the Portuguese island of Porto Santo, Hitachi ABB Power Grids and Renault have partnered to integrate renewable energy into the island's grid by leveraging electric vehicle batteries. Vehicle-to-grid technology is complemented by an aggregation platform to create an energy ecosystem which will see Porto Santo become one of the world's first smart fossil-fuel-free islands.

Recycling Battery Components

While new business models, cross-sector collaboration and battery design can facilitate the reuse and remanufacturing of batteries, a further challenge is posed: recycling their materials. This is crucial to avoid the discharge of toxic metals and materials from discarded batteries into the environment, polluting soil and water. A 2018 study by Google and the Ellen MacArthur Foundation -which assessed the circular economy solutions for both lead-acid and lithium-ion batteries- found technical difficulties associated with recycling lithium-ion batteries and the cost to do so is significant. However, there is a big incentive to recover cobalt, and other materials, from batteries. Large recycling centers have been established in Belgium and Canada for this purpose. Earlier this year, chemical company Solvay and utilities business Veolia announced their partnership to create a circular economy consortium for critical metals used in lithium-ion batteries for electric cars. Veolia already operates a recycling plant in France, Euro-Dieuze Industrie, for electric vehicle batteries, based on an in-house hydrometallurgical process for selective extraction of metals. The partnership with Solvay -which brings expertise to optimize the extraction and purification of critical metals such as cobalt, nickel and lithium- aims to allow the metals to be reused as raw materials to produce new batteries. Ilham Kadri, CEO of Solvay, said of the project: "Solvay's unique know-how combining specialty polymers, composites and mining solutions, together with Veolia's unique experience in waste management, is a fantastic opportunity to build a greener battery ecosystem." Veolia Chairman and CEO Antoine Frérot added: "The recycling of electric vehicle batteries and the management of the pollutants they contain are major ecological and industrial challenges. By partnering, Veolia and Solvay help develop the recycling value chain and the production of strategic raw materials for the production of new batteries."

Enabling Policies

For private sector initiatives such as these to be successfully scaled requires the support of policymakers. The European Commission already has acknowledged that policymakers need to look closely at the opportunities and challenges facing industrial clusters and ecosystems, which go beyond traditional industry sectors to encompass all players operating in a value chain -from SMEs to multinational companies- each bringing their own expertise and innovation skills. A good example is the European Battery Alliance, which brings together more than 120 European and non-European stakeholders representing the entire battery

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value chain. When implementing a circular economy approach, such alliances could be used to help steer efforts and finance large-scale projects, helping to remove barriers to innovation and improve policy coherence in key areas.

The European Commission's Circular Economy Action Plan notes that a new regulatory framework for batteries will be proposed, building on the evaluation of the Batteries Directive, which focuses on battery waste and draws on the work of the European Batteries Alliance. One of its key focuses will be to "ensure the recovery of valuable materials." The evaluation of the Batteries Directive also could lead to necessary changes to waste regulations and the notion of "waste" itself. In the European Waste Catalogue, for example, which provides a list of waste descriptions, there is no entry for lithium batteries. However, because of its flammability, lithium can prove hazardous and therefore needs to be handled appropriately. Through an Innovation Deal on Circular Economy, the European Commission has offered an opportunity for businesses to put forward recommendations to improve the legislative framework for the large-scale use and reuse of electric vehicle batteries, the development of vehicle-to-grid services, and second-life electric vehicle battery applications. Some issues raised by the Innovation Deal members already have informed the consultation on the revision of the EU Battery Directive.

The Potential of A Circular Economy for Batteries

If technical hurdles can be overcome and supportive regulations put in place, establishing a circular economy for batteries could have a huge impact across the world, and particularly in emerging markets. Globally, 840 million people live without access to power and many developing countries are exploring the option of mini-grids as a key enabler of decarbonized energy. Mini-gridsare small, closed-loop energy systems, centered on distributed and renewable energy sources, such as solar panels. With the aim to optimize mini-grids, U.K.-based energy companies, including Aceleron, are undertaking the Energy Catalyst project, and conducting field studies on how maintainable batteries can embed resilience into such energy systems.

Another potential large-scale use for batteries in a circular economy is support for back-up power systems in data centers and telecommunications infrastructure, ultimately supporting the foundations of the internet, connectivity and communications. Many operators are turning to lithium-ion batteries thanks to their ability to operate in this environment without the need for cooling. Battery technology is vital in this industry to provide an uninterrupted power supply that protects networks from unexpected outages and offers greater resilience across digital infrastructure. A circular economy is underpinned by a transition to renewable energy. Two of its principles are to eliminate waste and pollution and to keep products and materials in use. Applying these principles to batteries not only ensures valuable and finite materials such as lithium are circulated in the economy, but also helps make the energy transition, and meeting net zero emissions targets, possible.

The Resource Use and Waste Dimensions of The Clean Energy Transition

Climate change and environmental degradation have become an existential threat to Europe and the world. To overcome these challenges, Europe has a new growth strategy, the European Green Deal that transforms our economy into a modern, resource-efficient, and circular and climate neutral competitive economy. If the EU is to become climate neutral by 2050, it will have to transition to a sustainable, low-carbon energy model. Guided by EU and national targets and policy frameworks, a systemic shift is under way: from the current fossil fuel-based energy infrastructure towards renewable energy sources and greater improvements in energy efficiency.

However, the speed at which these changes need to occur to allow a net 55 % reduction in greenhouse gas emissions by 2050 is a challenge. Within the EU power sector, renewable electricity needs to become the main energy carrier within only one decade. This will require the sector to be almost completely redesigned to accommodate the fastest emerging technologies (e.g., solar photovoltaic (PV) and wind power); supported by widespread deployment of energy storage technologies. The new infrastructure will also need to be maintained during its service life and replaced as technology improves.

This briefing is underpinned by a report commissioned by the EEA to inform action on waste and resource issues arising from this major transformation, through an analysis of emerging waste streams related to the energy transition: Emerging waste streams - Challenges and opportunities. The study identified the key drivers and framework conditions necessary to realise opportunities and solutions for improving the circularity of renewable energy.

This briefing focuses on the waste aspect of three main renewable energy infrastructure types:

- Solar PV cells for electricity production,
- Wind turbines
- Batteries for energy storage.

This briefing describes the nature and scale of the circular economy aspects, the opportunities and challenges that the deployment of these three technologies brings and how policy can help drive the changes to achieve the best environmental outcome.

Circular Economy Opportunities and Challenges

Europe has a significant infrastructure for wind and solar energy production and for energy storage and the use of portable batteries. As this infrastructure is replaced by more modern facilities, and as the maintenance cycle prompts replacement of

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parts, applying circular economy principles is key to untapping the resource potential of the waste generated and minimizing the challenges of managing it. Waste generation, related to emerging streams from the three energy infrastructure types that were studied, is currently rather low, since the installations are relatively new and, generally, have not yet exhausted their useful life span. However, as Figure 1 indicates, waste generation in this sector will undergo a dramatic increase in future and requires immediate attention from policymakers. This increase will be challenging to manage, though there are strong potential benefits because much of the wastes arising either belong to established recycling systems (e.g. steel, glass, aluminum); or are high-value critical raw materials.

Recovering these materials and reintroducing them into production cycles presents challenges such as:

- processing difficulties due to:

  (1) Use of composite materials,

  (2) Presence of hazardous substances

  (3) Low concentrations of more-valuable elements;

- Equipment not designed to facilitate end-of-life/ recyclability aspects;

- Underdeveloped recycling capacity and technologies;

- Market conditions that do not properly price the externalities of using virgin materials versus recycled ones;

- Logistical issues due to the remote locations, size, and safety requirements associated with energy infrastructure.

Implementing innovative circular business models is also impeded because the ecological and climate benefits of using recycled materials are not yet fully accounted for in the costs of the materials. Therefore, suitable secondary materials regularly have to compete on price with primary materials that are often cheaper. Timeframes are also important in developing policies and protocols for dealing with the future wastes generated by this sector. Much of the infrastructure being installed will have a relatively long service life, and as such provisions are required to plan now for the environmental and financial impacts of dealing with these wastes as they arise in future [91-97].

Applying circular economy principles will mitigate the impacts; for this sector, they include:

1. Applying circular business models to maintain producer responsibility.

2. Designing infrastructure in a circular manner to facilitate reuse of components.

3. Supporting the development of recycling to maximize recovery of materials.

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