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CONVERGING ENVIRONMENTAL NECESSITIES AND ENERGY REQUIREMENTS: PRODUCING RENEWABLE ENERGY AND HYDROGEN FOR ECONOMIC REVITALIZATION AND GROWTH IN THE POST-COVID-19 PANDEMIC

Hooman Peimani

Affiliated Fellow. The Geopolitical Economy of BRI and Its Reflection Programme. International Institute for Asian Studies (IIAS) and Energy Programme Asia, Leiden University, The Netherlands. E-mail: peimanih@gmail.com

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Abstract: The COVID-19 pandemic has surely damaged the global economy by pushing it into a period of contraction and recession after a decade of poor performance, by and large. Just like rest of the world, it has also affected Asia, which is the world's largest economic and energy consuming region. Similarly, accounting for a major part of this continent and its population, the CAREC region has not been spared by the pandemic.

Its nature is such that it eventually results in social and economic destruction which will last for a significant period of time even after its full containment, the pandemic has signified the danger of the worsening global warming and climate change and the urgency of shifting from the current carbon-intensive economy to a low-carbon and eventually, zero-carbon one. This is especially signified in the CAREC region as a large energy consumer housing China, the world's single largest energy consumer.

As a global necessity, the mentioned shift in the CAREC region demands replacing oil, gas and coal as the main source of energy with sustainable alternatives. In addition to nuclear energy, developing the region's renewable energy sector is not only a necessity for reducing its greenhouse gas (GHG) emissions, but also an available means for revitalizing its economy. Efforts to develop the CAREC region's production of environmentally clean renewable energy (wind, solar, geothermal, hydro and small hydro) can certainly boast the regional economy damaged heavily by the pandemic. Such efforts, if wisely made, will involve a wide range of industries from mining to manufacturing for the required raw material and parts for the mentioned power generators and also for the electricity-based emerging industries such as electric vehicle producers. Added to their existing large manufacturing units, the availability of such necessities in large-scale could also provide the

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possibility for setting up small-scale and, thus, low capital-intensive manufacturing units for the mentioned generators and vehicles all over the CAREC region.

Parallel to this, producing hydrogen for fuel cells, not through methane steaming, but from electrolyzing of wastewater after removing its solid waste could be another feasible and necessary project for expanding the regional countries' range of alternatives to fossil energy. The resulting hydrogen could be especially, but not exclusively, used for public transportation (e.g., city buses) and land transportation of goods (trucks) to help the CAREC region decrease its GHG emissions substantially, while satisfying its essential needs.

As feasible and plausible projects, developing and expanding the CAREC region's renewable energy sector and hydrogen production capacity and their respective bus/truck engines and electric vehicles could not only help the region to stop and eventually reverse global warming as an environmental and economic imperative, but also help revitalize and potentially expand its economy after a period of the pandemic-imposed contraction. As well, these projects could potentially help the CAREC region establish itself as a leading global supplier of renewable and hydrogen technologies with its obvious economic benefits.

Against this background, this study aims at discussing the current energy situation of the CAREC region as a prelude to explain as to why efforts must be made systematically and purposefully to achieve net zero-carbon economies for the regional countries in the shortest period time to avoid a phenomenal increase in the global temperature. Towards this end, their fossil fuel-dominated and, thus, GHG-emitting energy mixes must be replaced with environmentally sustainable ones. Given the region's need for sustainable development, the study argues as to the merit of combing the mentioned necessary energy switch with the required economic revitalization program to offset the extensive negative impact of the COVID-19 pandemic on the CAREC countries' economies. Within this context, the various widely-available clean energy options for these combined purposes (i.e., renewable and nuclear energy) are identified, in addition to "green hydrogen" as an emerging environmentally-clean type of fuel. As well, this study makes certain policy recommendations to facilitate the CAREC countries' embarking on these two projects and help them maximise their environmental and economic gains.

The adopted methodology for this policy study is based on the objective analysis of the relevant secondary sources. Special efforts have been made to use a wide-range of credible and unbiased sources produced by the internationally-known entities concerned with energy, environment and sustainable development. To secure the study's objectivity as well as relevance to the specific situation and needs of the CAREC countries , the pros and cons of the available energy options are accurately identified. Equally, the necessity of regional cooperation to achieve both the needed energy switch and the economic boast is discussed, given the differences between and among the CAREC countries in terms of energy and economic options and level of technological and industrial capabilities.

I. INTRODUCTION

The COVID-19 pandemic has surely damaged the global economy by pushing it into a period of contraction and recession after a decade of poor performance, by and large. In particular, it has negatively affected Asia, which is the world's largest economy and energy consumer. Accounting for a major part of this continent and its population, the CAREC region has not been spared by the pandemic.

Despite its apparent social and economic destructive nature to last for a significant period of time even after its full containment, the pandemic has signified the danger of the worsening global warming and climate change and the urgency of shifting from the current carbon-intensive economy to a low-carbon and eventually, zero-carbon one. This is especially signified in the CAREC region as a large energy consumer housing China, the world single largest energy consumer.

As a global necessity, the mentioned shift in the CAREC region demands replacing oil, gas and coal as the main source of energy with sustainable alternatives. In addition to nuclear energy, developing the region's renewable energy sector is not only a necessity for reducing its greenhouse gas (GHG) emissions, but also an available means for revitalizing its economy.

Efforts to develop the CAREC region's production of environmentally clean renewable energy (wind, solar, geothermal, hydro and small hydro) as distinct from GHG-emitting renewable energy (e.g., wood, charcoal and biofuel) can certainly boast the regional economy damaged heavily by the pandemic. Such efforts, if wisely made, will involve a wide range of industries from mining to manufacturing for the required raw material and parts for the mentioned power generators and also for the electricity-based emerging industries such as electric vehicle producers. Added to their existing large manufacturing units, the availability of such necessities in large-scale could also provide the possibility for setting up small-scale and, thus, low capital-intensive manufacturing units for the mentioned generators and vehicles all over the CAREC region.

Parallel to this, producing hydrogen for fuel cells, not through GHG-emitting methane steaming, but from electrolyzing of wastewater after removing its solid waste could be another feasible and necessary project for expanding the regional countries' range of alternatives to fossil energy. The resulting hydrogen could be especially, but not exclusively, used for public transportation (e.g., city buses), land transportation (e.g., by trucks) and sea transportation (e.g., cargo ships) of goods to help the CAREC region decrease its GHG emissions substantially, while satisfying its essential energy-related needs.

As feasible and plausible projects, developing and expanding the CAREC region's renewable energy sector and hydrogen production capacity and their respective bus/truck engines and electric vehicles could not only help the region to stop and eventually reverse global warming as an environmental and economic imperative, but also help revitalize and potentially expand its economy after a period of the pandemic-imposed contraction. As well, these projects could potentially help the CAREC region establish itself as a leading global supplier of renewable and hydrogen technologies with its obvious economic benefits.

II. LITERATURE REVIEW

There has been a large number of studies on various issues pertaining to the main components of this study with regional or Asia-wide geographic focuses. They include green energy and the necessity of replacing the fossil energy-dominated Asian energy mix with an environmentally sustainable one, economic development and the role of small and medium-sized enterprises (SMEs), the impact of the COVID-19 pandemic on Asia's economy and the importance of using Asia's required switch to a sustainable energy mix as a drive for revitalizing its pandemic-affected economies.

Thus, the necessity of the mentioned switch and various financial and technological barriers to the required expansion of Asia's renewable energy sectors, including those of the CAREC countries, and the long-term imperative of that expansion for the Asian countries' energy security have recently been discussed in detail by this author elsewhere (Peimani, 2020, Peimani, 2018 and Peimani and Taghizadeh-Hesary, 2019). Other recent studies on this topic include that by Volz, et al. (2020).

Likewise, the severe impact of the pandemic on the Asian economies and the necessity of having clear economic policies for their recovery through different economic, industrial and technological means have been discussed to a varying extent in different studies. As a most recent example, the Asian Development Bank (2021) deals with the Asian countries' individual and collective response to the pandemic-created economic crisis by "leveraging rapid technological progress and digitalization as well as increasing services trade to reconnect and recover", for example. Broader recovery policies have been argued in various studies such as that of Bernie (2020). Other studies have focused on the importance of technology and innovation as a means for economic revitalization in some of the Asian regions such as Central Asia (UNDP, 2020a) as well as the socio-economic impacts of the pandemic on this region and measures to deal with them (UNDP, 2020b).

UNESCAP has elaborated on combing sustainable development goals with the pandemic-necessitated economic revitalization plans in the Asia-Pacific region with an emphasis on the role of SMEs (UNESCAP, 2020). Morgan has argued on the contribution of SMEs to Central Asia Regional Economic Cooperation countries' economic development "by helping to diversify the[ir] production base, create employment opportunities, alleviate poverty, and increase regional food security" (Morgan, 2021).

OECD has explored the critical importance of "timely policy responses in health and labour markets, combined with appropriate monetary and fiscal policies" as well as "the use of digitalisation and further strengthening regional co operation" as means to meet the short and medium-term challenges posed by the pandemic (OECD, 2020).

Finally, some aspects of combing the promotion of green energy and economic recovery strategies of the COVID-19 pandemic-affected countries have been considered in a few recent studies. Examples include a joint study of the ASEAN Catalytic Green Finance Facility (ACGF)) and the Asian Development bank (ADB) focused on Southeast Asia, which is also applicable to the CAREC region (ACGF and ADB, 2020). However, Um's elaboration on "Recovery through Rejuvenation and Resilience" is similar to the main argument of this study, as it "rests on the following interrelated four pillars" as necessities for "reinvigorated development efforts": 1. Enhancing sustainable energy services; 2. Improving energy sector resilience and security; 3. Accelerating energy access to the poor and vulnerable; and 4.Using advanced technology (Um, 2020).

III. WORSENING GLOBAL WARMING AND CLIMATE CHANGE

The COVID-19 pandemic has signified the danger of the worsening global warming and climate change and the urgency of shifting from the current carbon-intensive economy to a low-carbon and eventually, zero-carbon one. The 196 countries attending the Paris Conference of Parties (COP) on global warming and climate change in 2015 agreed on the urgency of the shift as the necessary step towards achieving zero-emission objective within the next few decades only to **"limit global warming** to well below 2 degrees, **preferably to 1.5 degrees, Celsius**, compared to pre-industrial levels" (UNFCC, 2016). The adopted agreement by the 196 Parties represented at COP 21 on 12 December 2015 "entered into force on 4 November 2016" (UNFCC, 2016).

The significant reduction in greenhouse gas (GHG) emissions as a result of wide-spread lockdowns imposed because of the COVID-19 pandemic in 2020 and the resulting decrease in all kinds of activities, including industrial ones, created hopes for slowing down global warming. However, the United Nations Environment Programme (UNEP) Emission Gap Report 2020 suggests otherwise. Accordingly, "a brief dip in carbon dioxide emissions caused by the COVID-19 pandemic will make no significant difference to long-term climate change. The world is still heading for a catastrophic temperature rise in excess of 3°C this century – far beyond the Paris Agreement goals of limiting global warming to well below 2°C and pursuing 1.5°C" (UNEP, 2020).

Hence, it is an absolute necessity that all countries, including the CAREC ones, to increase their efforts for reducing their emissions by expanding the share of non-pollutive renewable and nuclear energy of their energy mix dominated by GHG-emitting fossil energy. This objective has, of course, a major economic benefit as efforts towards manufacturing, installing and using various types of renewable energy generators (e.g., solar panels, wind turbines and hydropower dams) as well as nuclear power generators also serve as a major economic stimulus to help revitalize the CAREC countries' economies damaged by the pandemic, as is the case in all other regions.

As a result, combing efforts towards zero-emission objective with economic revitalization initiatives to offset the negative impact of the pandemic on the CAREC countries' economy could help them achieve both objective simultaneously and obviously at the lower cost. This point is well taken by UNEP as follows:

> *But hopes lies in a* ***green recovery [bolded by this author]*** *from the COVID-19 pandemic, which could help put the world close to the pathway to 2p C, and growing commitments to net-zero emissions by 2050 -although more work would be required to reach 1.5p C goal (UNEP, 2020).*

This economic benefit is potentially quite significant in the CAREC region since it is a large energy consumer housing China, the world single largest energy consumer, and thus a major GHG emitter as reflected in Table 1

Table 1: Greenhouse Gas Emissions in the CAREC Countries 2019 (Million Tons)

Country	*Greenhouse Gas Emissions in Million Tons*
Afghanistan	11.0
Azerbaijan	36.0
China	11,535.2
Georgia	13.5
Kazakhstan	277.4
Kyrgyz Republic	11.9
Mongolia	35.9
Pakistan	223.6
Tajikistan	8.9
Turkmenistan	90.5
Uzbekistan	95.0
Total	12,338.9

Source: Author's creation based on the data provided in: Kenoma. 2021. "CO2 Emissions (million tonnes)." World Data Atlas: Ranking: Environment. https://knoema.com/atlas/ranks/CO2-emissions containing the most-recent available data on all the CAREC countries' GHG emissions.

Based on the most-recent available data on the global GHG emissions, the world's total CO_2 emissions in 2019 was estimated to be 35,515.3 million tons (Kenoma, 2021). As a result, the CAREC region with 12,338.9 million tons of GHG emissions as per above table accounted for 34.74% of the total global emissions in that year. The reason for such large emission is the region's heavy reliance on GHG-emitting fossil energy, especially coal, the most pollutive type of such energy, as apparent in its energy mix (Table 2). However, the regional countries' shares of such emissions vary from one country to another with China as the largest emitter and Tajikistan as the smallest one due to their consuming different amounts of fossil energy as justified by their energy-consuming economic and non-economic activities.

IV. ENERGY MIX OF THE CAREC REGION

The CAREC region is a large energy-consuming region thanks to its large and growing population with improving living standards and its enlarging economies. Like all other regions, this region's energy mix is dominated by fossil energy (oil, gas and coal) as detailed in the following Table 2 based on the most recent available data (2019) on the regional energy consumption.

Table 2: Energy Mix of the CAREC Region in 2019 in Exajoules

Country	*Oil*	*Gas*	*Coal*	*Nuclear*	*Hydropower*	*Other Renew-ables*	*Share of Non-Fossil energy**	*Total*
Afghanistan								
Azerbaijan	0.21	0.42		0.00	0.01	+	1.5%	0.66
China	27.91	11.06	81.67	3.11	11.32	6.63	14.92%	141.07
Georgia								
Kazakhstan	0.69	0.64	1.67	0.00	0.09	0.01	3.22%	3.10
Kyrgyz Republic								
Mongolia								
Pakistan	0.90	1.64	0.55	0.08	0.32	0.06	12.92%	3.56
Tajikistan								
Turkmenistan	0.31	1.14	0.00	0.00	+	+	#0%	1.45
Uzbekistan	0.09	1.56	0.07	0.00	0.06	+	3.37%	1.78

Source: Author's creation based on the data provided in: BP. *Statistical Review of World Energy 2020*. London: BP, June 2020, p. 9. https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

+ Less than 0.005

*Calculated by the author.

+Data unavailable.

The share of non-fossil energy of the regional countries' energy mix is very insignificant or none in almost all the cases with a few exemptions, namely China and Pakistan, as evident in the above table. Yet, this share even in the latter two cases is way below what is needed to deal with the expanding global warming and climate change, which demand sharp reduction of the current heavy consumption of CO_2-emitting oil, gas and coal. Consequently, it is necessary that the CAREC countries make major efforts to expand their non-fossil energy sectors to prevent the global environmental catastrophe, as all other countries must do. Various financial and technological barriers to the expansion of Asia's renewable energy sectors, including those of the CAREC countries, and the necessity of their expansion for the Asian countries' energy security have recently been discussed in detail by this author elsewhere (Peimani, 2020, Peimani, 2018 and Peimani and Taghizadeh-Hesary, 2019).

V. NECESSITY OF REALIZING A NET-ZERO CARBON ECONOMY

As is the case in the overwhelming majority of other countries, none of the CAREC countries has a plan for a net-zero carbon economy by 2050 or earlier enshrined in its law or economic and/or energy planning. However, some of them are aiming to reach there, primarily China, before 2060 (China Plus, 2020), while at least one of them, Kazakhstan, has a plan for achieving a low-carbon, but not zero-carbon economy. Thus, in December 2012, then Kazakh President Nursultan Nazarbayev launched "*Strategy Kazakhstan-2050: A New Political Course of the Established State*, which aims to place the country within the top 30 most developed nations in the world" (WNA, 2021a). Thus, "[in] line with the strategy's aim to 'move swiftly towards a low-carbon economy,' the May 2013 decree #557 on the *Concept for the Transition of the Republic of Kazakhstan to Green Economy* outlines a target for the power sector to achieve a 50% share of alternative and renewable energy by 2050, including 1.5 GWe of nuclear capacity by 2030 and 2.0 GWe by 2050" (WNA, 2021). However, despite differences, all the regional countries have taken steps of a varying significance to expand their use of non-fossil energy, that is renewable in all cases, while China and Pakistan have additional vibrant nuclear energy sectors and Kazakhstan has a plan to build one. The following Table 3 details the electricity mix of the CAREC countries indicating their installed renewable and non-renewable energy capacity as of 2019, the most recent year for which comparable data for all the CAREC countries exists. Table 3 also reveals these countries' reported plans for expanding their renewable energy capacity in the future, as reported by the International Renewable Energy Agency (IRENA).

Table 3: Electricity Mix of the CAREC Countries and Their Shares (%) 2019 & Planned

Country	*Capacity in MW &*	*% Share*	*Planned Increase in Renewable Energy*
Afghanistan	Non-renewable: 237	39%	4500 MW in 2032
	Renewable: 365	61%	
	Hydro/marine: 333	55%	
	Solar: 32 5%Wind:0	0%	
	Bioenergy: 0 0%		
	Geothermal:0	0%	
	Total: 602	100%	
Azerbaijan	Non-renewable: 6,961	84%	
	Renewable: 1, 279	16%	
	Hydro/marine: 1, 131	14%	
	Solar: 37	0%	
	Wind: 66	1%	
	Bioenergy: 45	1%	
	Geothermal: 0	0%	
	Total: 8, 240	100%	
China	Non-renewable: 1,253.043	62%	
	Renewable: 758, 626	38%	
	Hydro/marine: 326,118	16%	
	Solar: 205,493	10%	
	Wind: 210,478	10%	
	Bioenergy: 16,537	1%	
	Geothermal: 0	0%	
	Total: 2,011, 669	100%	
Georgia	Non-renewable: 1,154	26%	
	Renewable: 3, 354	74%	
	Hydro/marine: 3,332	74%	
	Solar: 1 0%Wind: 21	0%	
	Bioenergy: 0	0%	
	Geothermal: 0	0%	
	Total: 4, 508	100%	
Kazakhstan	Non-renewable: 21,902	85%	
	Renewable: 3, 887	15%	
	Hydro/marine: 2,778	11%	
	Solar: 823	3%	
	Wind: 284	1%	
	Bioenergy: 2	0%	
	Geothermal: 0	0%	
	Total: 25,789	100%	
Kyrgyz Republic	Non-renewable: 633	15%	
	Renewable: 3, 673	85%	
	Hydro/marine: 3,673	85%	
	Solar: 0	0%	
	Wind: 0	0%	
	Bioenergy: 0	0%	
	Geothermal: 0	0%	

Country	*Capacity in MW &*	*% Share*	*Planned Increase in Renewable Energy*
	Total: 4, 306	100%	
Mongolia	Non-renewable: 1,200	81%	100% Renewable by 2050
	Renewable: 276	19%	
	Hydro/marine: 31	2%	
	Solar: 89	6%	
	Wind: 156	11%	
	Bioenergy: 0	0%	
	Geothermal: 0	0%	
	Total: 1,476	100%	
Pakistan	Non-renewable: 27 022	68%	
	Renewable: 12,896	32%	
	Hydro/marine: 9,900	25%	
	Solar: 1,329	3%	
	Wind: 1,236	3%	
	Bioenergy: 432	1%	
	Geothermal: 0	0%	
	Total: 39, 918	100%	
Tajikistan	Non-renewable: 718	12%	
	Renewable: 5,273	88%	
	Hydro/marine: 5,273	88%	
	Solar: 0	0%	
	Wind: 0	0%	
	Bioenergy: 0	0%	
	Geothermal: 0	0%	
	Total: 5, 991	100%	
Turkmenistan	Non-renewable: 7,006#	100%	
	Renewable: 1	0%	
	Hydro/marine: 1	0%	
	Solar: 0	0%	
	Wind: 0	0%	
	Bioenergy: 0	0%	
	Geothermal: 0	0%	
	Total: 7, 008	100%	
Uzbekistan	Non-renewable: 12,277	86%	20% Renewable by 2025
	Renewable: 1,943	14%	
	Hydro/marine:1,939	14%	
	Solar: 4	0%	
	Wind: 1	0%	
	Bioenergy: 0	0%	
	Geothermal: 0	0%	
	Total:14, 220	100%	

Source: Author's creation based on the data provided in: IRENA. "Energy Capacity and Generation: Capacity in 2019." *Energy Profile: Afghanistan*. 2021. p.2. Available at: https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Afghanistan_Asia_RE_SP.pdf; IRENA. "Targets, Policies and Measures: Most Immediate clean energy targets & NDCs." *Energy Profile: Afghanistan*. 2021. p.3. Available at: https:/

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IRENA. "Energy Capacity and Generation: Capacity in 2019." *Energy Profile: Mongolia*. 2021. p. 2. Available at: https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Mongolia_Asia_RE_SP.pdf;IRENA. "Targets, Policies and Measures: Most Immediate clean energy targets & NDCs." *Energy Profile: Mongolia*. 2021. p.3. Available at: https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Mongolia_Asia_RE_SP.pdf; IRENA. "Energy Capacity and Generation: Capacity in 2019." *Energy Profile: Pakistan*. 2021. p. 2. Available at: https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Pakistan_Asia_RE_SP.pdf; IRENA. "Targets, Policies and Measures: Most Immediate clean energy targets & NDCs." *Energy Profile: Pakistan*. p.3. Available at: https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Pakistan_Asia_RE_SP.pdf; IRENA. "Energy Capacity and Generation: Capacity in 2019." *Energy Profile: Tajikistan*. 2021. p. 2. Available at: https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Tajikistan_Asia_RE_SP.pdf; IRENA. "Energy Capacity and Generation: Capacity in 2019." *Energy Profile: Turkmenistan*. 2021. p. 2. Available at: https://www.irena.org/IRENADocuments/Statistical_Profiles/Asia/Turkmenistan_Asia_RE_SP.pdf

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Non-fossil energy is mainly used for electricity generation in the CAREC region. Yet, the share of such energy of this mix varies from practically 0% (Turkmenistan) to 88% (Tajikistan), which seems very significant. However, the total amount of such energy could be very small despite its large share, as evident in the case of Tajikistan as apparent in the above Table 3.

Hence, to remove any doubt as to the required amount of efforts to make the mentioned shift to the zero-emission economy objective, it should be kept in mind that the actual share of renewable energy, and, in general, non-fossil energy, of the regional countries' energy mix is very small, though varying from one country to another. The energy mix covers the entire energy requirements of the region, including for electricity generation, e.g., sea and land transportation, residential, commercial, industrial and agricultural energy demands. This reality is clearly indicated in Table 2, which shows the shares of the regional countries' installed non-fossil energy consisting of renewable and nuclear energy of their energy mix. It ranges from 0% in the case of Turkmenistan to 14.92% in the case of China.

Renewable energy is a necessity for shifting to a carbon-free economy, but not enough for such objective due to its limits as intermittent sources of energy in most cases, except hydropower and geothermal. In the CAREC region, hydro, wind and solar energy are the dominant types of renewable energy as evident in Table 3, but they are not enough to fully replace fossil energy as the source of electricity generation in the regional countries to meet their current needs, let alone generating enough electricity to replace fossil energy in their main fossil-energy consuming sectors such as transportation, industrial and residential. Innovations in batteries to provide for large-scale and affordable storage of electricity to address the mentioned intermittency has created hopes for turning renewable energy into a fully-fledged alternative to fossil energy. Briefly, various lithium-ion batteries with pros and cons offering options for storing electricity generated by intermittent sources such as solar and wind to be used once electricity cannot be generated because of their total absence or inadequacy (e.g., when sun beams are totally or adequately unavailable at night and cloudy days, respectively), as discussed by many experts such as Cheryl Katz, 2021.

However, charging batteries requires extensive and growing renewable sector to generate a phenomenal amount of electricity beyond the immediate demand of the CAREC countries when wind and solar beams are adequately available to provide for storing the excessive generated electricity. Consequently, in most cases in the CAREC region as is the case elsewhere, other sources of environmentally-clean energy and, therefore, non-GHG-emitting types of energy, must be used. Hydropower is an option in many CAREC countries with substantial water resources, including China, Georgia and Kyrgyz Republic, but to a limit as this type of renewable energy is currently used at a large-scale to leave a limited room for expansion.

As a result, nuclear energy is another necessity for large-scale electricity generation, at least, for some of the regional countries with large and growing electricity demand such as China and Pakistan. In fact, currently, three countries in the CAREC region (Armenia, China and Pakistan) have nuclear energy sectors of various scales while another country, Kazakhstan, has plans for one in an uncertain future. As reflected in Table 4, China has the largest regional nuclear sector with major ongoing, planned and proposed nuclear power projects to expand its sector phenomenally. Actually, China has been the main arena for nuclear power expansion not just in the CAREC region or even Asia, but in the world, for about the last two decades.

Table 4: Nuclear Power Sector in the CAREC Region: Current, Under-Construction, Planned and Proposed Capacities

Country	*Installed Capacity in 2021 (MW)*	*Under-Construction with Expected Grid Connection In 2020s (MW)*	*Planned (MW)*	*Proposed*
Armenia	375		1060	
China	47,498	17,253	43,085	106,500
Kazakhstan	0.0	0.0	1800*	
Pakistan	1,318	2,322	1,161	

Source: Author's creation based on the data provided in: World Nuclear Association. 2022. *Country Profiles: Nuclear Power in Armenia*. Available at: https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/armenia.aspx; World Nuclear Association. 2021. *Country Profiles: Nuclear Power in China*. Available at: https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx; Available at: World Nuclear Association. 2021. *Country Profiles: Nuclear Power in Kazakhstan*.https://www.world-nuclear.org/information-library/country-profiles/countries-g-n/kazakhstan.aspx; World Nuclear Association. 2021. *Country Profiles: Nuclear Power in Pakistan*. Available at: https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/pakistan.aspx

* The date for the actual construction of potentially two 300 MW and one 1200 MW reactors are yet to be determined.

It is noteworthy that the operating nuclear reactor of Armenia is a potential source of concern for the CAREC region, given the country is geologically prone to earthquakes. While Armenia is not a CAREC country, it borders with two CAREC countries (Azerbaijan and Georgia) and thus any serious damage to its Metsamor Reactor could have implications for these countries. In fact, its close proximity to Turkey (being located about 16 kilometers from the Turkish border) and its closeness to the European Economic Area (EEA) have made both Turkey and the European Union (EU) concerned about the potential of a significant release of radioactive material in case of a major earthquake. Such concern prompted the EU to reach an agreement with Armenia in 1999 by which Yerevan agreed to close the reactor "before the end of its design lifetime, provided that alternative replacement capacity is available" (WNA, 2021b).

The Metsamor reactor is the only operating reactor of the two reactors (each 407.5 MW gross) built in Metsamor, which went online in 1976 and

1980 respectively. Although the December 1988 earthquake, which resulted in the deaths of over 25,000 Armenians, did not damage the reactors, they were both shut down in 1989 "due to safety concerns regarding seismic vulnerability" (WNA, 2021b). While Unit 1 is now being decommissioned, Unit 2 was restarted in 1995 due to Armenia's need for electricity and the International Atomic Energy Agency has since been " participating in safety improvements at the plant" (WNA, 2021b). Armenia decided to increase its operating life to 2040 in July 2018 (WNA, 2021b). Towards this end, the plant will" undergo extensive work during a 140-day outage" in 2021 involving "annealing the pressure vessel and modernising the emergency core cooling and power supply systems" (WNA, 2021b).

As it stands, the Metsamor Reactor is not an immediate source of concern for the CAREC countries, given it is under the IAEA safeguards regime and undergoing the mentioned work meant to prepare the reactor to avoid a total core meltdown and its subsequent release of radioactive material to potentially ended up in Azerbaijan and Armenia by natural means such as wind, while extending its operational life. However, the reactor's safety and that of any other reactor built in Armenia must be guaranteed by keeping Armenia obliged to abide by its responsibilities in this regards through the IAEA safeguard regime.

VI. HYDROGEN AS A CLEAN SOURCE OF ENERGY: MYTH AND REALITY

In search for alternatives to pollutive fossil energy, hydrogen has become attractive as a solution, in addition to nuclear energy. It can be mixed with natural gas in gas pipelines to reduce its GHG emissions when it is consumed as some countries in the Asia-Pacific region such as Australia and New Zealand has considered, tested or started such use (Future Bridge, 2020). However, it has its own challenges such as hydrogen's energy density is "about 33 of that of natural gas" with the effect of making end users' greater consumption of the mixture to meet their energy needs (Future Bridge, 2020).

Hydrogen can also be used as a non-pollutive fuel on its own to generate electricity once it is mixed with oxygen in fuel cells of electric engines. Such application has been used at a limited scale in a growing number of countries in Asia, Europe and the Americas, especially for heavy vehicles such as buses and trucks. As well, it is now considered as a fuel for industries using coal or gas. For example, as reported by the Nikkei newspaper in December 2020, "Japan will aim to make hydrogen a power source viable enough to produce the output of more than 30 nuclear reactors by 2030" as an alternative to coal or gas for power generation (Energy World.com, 2020).

Yet, while hydrogen is a clean fuel since it does not emit GHG, the bulk of global production of hydrogen is in "grey hydrogen". Briefly, hydrogen can be produced in three ways with the effect of determining whether it can be used as an environmentally-friendly alternative to oil, gas and coal or not. It can be produced with electricity to decompose water,that is electrolysis, which requires only pure water and electricity, to produce hydrogen and oxygen (GasTerra, 2018). Provided the source of the required electricity is non-pollutive such as solar and wind energy, electrolysis produces CO_2-neutral and, therefore, environmentally-friendly hydrogen called "green hydrogen" (GasTerra, 2018).

However, fossil energy is primarily used for the production of hydrogen mainly through methane steaming known as "grey hydrogen", which emits CO_2 (GasTerra, 2018). If such CO_2 is not released in the air, rather captured and stored (i.e., through carbon capture and storage, CCS) the resulting hydrogen is called "blue hydrogen" for being CO_2 -neutral (GasTerra, 2018). Given the production of the required methane is pollutive as all other types of fossil energy are added to the mentioned CO_2 generated but captured and stored, "blue hydrogen" is not a real environmentally-friendly alternative to fossil energy. Using electricity generated by fossil fuels for electrolysis also practically results in producing "grey hydrogen", although the involved electrolysis is not CO_2-emitting in itself.

Unfortunately, the bulk of the global production of hydrogen is not an environmentally-clean and sustainable source of energy. It is either grey or blue not green to make the available hydrogen not a clean energy on par with wind, solar and nuclear energy, although the hydrogen itself does not emit GHG once it is used as a fuel. Among others, the cost of generating green hydrogen is a major barrier to its expansion, given "the electrolysis process is still very expensive - today, it is 40 times as expensive as oil - and requires enormous amounts of renewable electricity," with the effect of making blue hydrogen more attractive as an affordable choice to prompt the oil and gas industry to opt for blue hydrogen (Dupont-Nivet and Maggiore, 2020).

As a result, "green hydrogen" is still at the stage of infancy and is challenging as generating green electricity for the required water electrolysis adds a heavy burden to the growing demand for green electricity for daily consumptions. Hence, green hydrogen-generating facilities must have their own sources of green electricity, which are emerging in Asia and Europe still at a small scale to ensure the dominance of blue and grey hydrogen for more years. According to IRENA (International Renewable Energy Agency) concerned with expanding renewable energy globally, there is a "widespread support for green hydrogen as the long-term, sustainable solution. Amongst countries that support only one technological pathway, there is also more supporting only green hydrogen than only blue. As recently as 2020, eight jurisdictions around the world announced hydrogen strategies and at least ten more are expected in 2021" (IRENA, 2020).

In reality, green hydrogen production is more suitable for those countries with an abundance of wind, sunshine and rivers with extensive and growing renewable energy sectors. These natural sources of energy can feed their wind and solar panel farms and hydropower dams, respectively, to generate enough amount of electricity for the required electrolysis of water without damaging their respective countries' plans for replacing fossil fuels for electricity generation with renewable energy. It also makes sense that the generated green hydrogen be used as fuel for heavy vehicles (e.g., buses and trucks) and vessels (e.g., cargo ships) to reduce and eventually end the consumption of liquid fossil fuel for land and sea transportation, which are a main and, in cases, the single largest source of GHG emissions. According to IRENA, the current trend for the use of hydrogen is for fuel cells of electric cars and their required refueling stations (IRENA, 2020). However, this trend is "set to change in the coming years as focus changes to sectors with existing hydrogen demand (industry) and replacement of fossil-based hydrogen" (IRENA, 2020).

VII. GREEN HYDROGEN IN THE CAREC REGION

In the CAREC region, interest in green hydrogen is emerging as a new potential source of emission-free fuel to meet part of their growing energy demand now mainly met with pollutive fossil energy. At a varying scale and scope and stage of development, it is gaining attention in those countries with abundant renewable energy resources (e.g., wind, sunshine and water) and thus the potential for generating large-scale clean electricity necessary for the required electrolysis.

The main protagonist in this field is China in search of reducing its phenomenal GHG emissions while meeting its gigantic and expanding energy requirements. Currently, the country is the only producer of hydrogen at a large scale, in general, and, in fact, the world's largest producer of hydrogen. Its annual hydrogen production is 20 million tons "accounting for around one-third of global production, enough to cover one-tenth of its massive energy needs" (Casey, 2021). However, as is the case in other regions, much of China's production is "tied to fossil fuel-reliant" hydrogen, namely "grey hydrogen" (Casey, 2021). Reportedly, methane steaming (Steam Methane Reforming) accounts for 85% of its hydrogen production (Yue and Wang, 2021). It means that coal is used for the bulk of China's hydrogen production and "electrolysis contributed just 3% of the total hydrogen supply" (Yue and Wang, 2020).

Reportedly, China's hydrogen production, which is enough to satisfy about 10% of China's energy needs, is mainly used for industrial and chemical processes, such as "for producing ammonia as agricultural fertilizer" (Yue and Wang, 2020). However, China is now accelerating its efforts to expand the use of hydrogen for other purpose, including for land transportation, which is a major source of CO_2 emissions. Thus, by January 2020, "China had 61 hydrogen refueling stations, compared with 81 in Germany and 116 in Japan to power fuel cell electric vehicles" (Yue and Wang, 2020).

Appreciating the importance of green hydrogen as a sustainable alternative to fossil energy, China, which has active plans to reduce its GHG emissions as the world's largest emitter, is looking into green hydrogen at a large-scale. As a matter of fact, it is so far the only country with significant research and development plan for green hydrogen and also the only producer of electrolysers necessary for producing green hydrogen (IRENA, 2020).

Being the only producer of green hydrogen in the CAREC region, China is also the only regional country with official plans for such production. This is part of its plan to replace liquid fossil fuels with a sustainable one for its land transportation, involving the manufacturing of electric vehicles with fuel cells using hydrogen to generate emission-free electricity when mixed with oxygen. In September 2020, for example, four major Chinese cities announced their official plans to develop hydrogen fuel cell industry in the next decade as per the following summary report:

- Beijing: a "mainstream" plan with emphasis on fuel cell vehicle employment. The plan envisions 10,000 FCV [Full Cell Vehicle] on the road by 2025.
- Zhoushan: a new focus on applying hydrogen with the shipping industry; another city emphasizing low-carbon hydrogen production (natural gas and wind)
- Liu'an: a similar target is set to use fuel cell technology in the shipping sector, the plan envisions to launch 100 fuel cell ship demos by 2030.
- Wuhai: the traditional coal-to-chemical city is aiming to support the energy transition of its coal, chemical, and rare-earth mining sectors by combing them with hydrogen (Yuki, 14 September 2020).

As well, there is a growing interest in China for producing large-scale green hydrogen. Reportedly, as of November 2020, at least ten Chinese green hydrogen companies had "the most potentials to become the Chinese market leaders" and the likely partners (Yu, 4 Nov 2020) as listed below:

- State Power Investment Corp (SPIC)
- China Petroleum & Chemical Corporation (Sinopec)
- China Huaneng
- China Energy Investment Corp (CEIC)
- China Three Gorges (CTG)
- China Huadian
- China Datang
- China National Offshore Oil Corp (CNOOC)
- China General Nuclear (CGN)
- China National Nuclear Corp (CNNC)

Apparently, China was accelerating its switch to hydrogen in 2021. Three Chinese electricity equipment makers supplying the Chinse electricity-generating companies, namely Dongfang Electric, Shanghai Electric, and Harbin Electric, have announced moving towards hydrogen (Yuki. 10 February 2021). These companies are reportedly the leading manufacturers of equipment for electricity generation, including coal, hydro, nuclear and wind ones (Yuki, 10 February 2021). Their move towards producing the required equipment for hydrogen production indicates the expected growing market for hydrogen.

Apart from China, green hydrogen is appropriate type of clean and renewable energy for those CAREC countries with both abundance of natural resources for rapid expansion of large-scale clean electricity generation needed for electrolysis of water to produce green hydrogen. These are primarily, but not exclusively, Georgia, Kyrgyz Republic, Pakistan and Tajikistan. In reality, two of them (Pakistan and Georgia) have initiated a process towards this end.

Having large and growing energy requirements now mainly satisfied with fossil energy, Pakistan has sought to find alternatives to oil, gas and coal. Apart from renewable and nuclear energy, the Pakistanis are now looking into green hydrogen as a viable option. It is especially an attractive option for the country's land transportation system, first and foremost, for heavy vehicles (e.g., trucks), which are a major source of pollution, particularly, in large cities such as Karachi.

Thanks to its extensive natural resources for generating emission-free electricity, Pakistan has a great potential for large-scale green hydrogen production through electrolysis. Its "abundant potential for wind, solar and hydroelectric power generation" has prompted some energy experts to raise the potential of its 'energy-autonomy' with green hydrogen production (Cockerill, 2021). Accordingly, the country could transit "from being a net energy importer to becoming an exporter of green hydrogen or derivatives such as ammonia or methanol" as well (Cockerill, 2021). Given this potential, hydrogen is reportedly "getting much attention from the power and energy departments within the Government of Pakistan's administration" (Cockerill, 2021). Consequently, in January 2021, *Gas World* reported efforts to initiating green hydrogen production in Pakistan. Thus, "work is well underway in the country as a collaboration of Asian Development Bank (ADB), Pakistan's National Energy Efficiency and Conservation Authority (NEECA), consultant Stephen B. Harrison of sbh4 GmbH and other local organisations work together on a pre-feasibility study and how energy priorities can be turned into projects" (Cockerill, 2021).

Georgia is another CAREC country pursuing the same objective. The mountainous country of the Southern Caucasus has vast water resources enabling it to generate the bulk of its electricity demand with hydropower equal to 74% in 2019 as per Table 3. Having unexhausted water resources to allow for much larger emission-free electricity generation, the Georgian government is now taking steps towards green hydrogen production. According to the European Bank for Reconstruction and Development (ERBD), the government has now asked the EBRD to "explore the country's potential for generating green hydrogen which could then be blended and transported to end-users through [its] existing gas pipelines" (Bennett, 2020). Towards this end, the EBRD and the Georgian government signed a deal in September 2020 "to provide technical cooperation support to assess the investment requirements in Georgia for green hydrogen generation, as well as to upgrade existing assets to transport blended hydrogen to end-users. The technical cooperation will run over the next few years, setting out a timeline for potential investments after that" (Bennett, 2020).

Interestingly enough, the deal was part of a broader deal "between Georgia' GOGC energy company and the EBRD, to lend the company €217 million to help it refinance a corporate Eurobond in the wake of this year's Covid-19 slowdown" (Bennett, 2020). The deal, therefore, revealed the great potential of combing the environmentally imperative switch from the country's heavy reliance on GHG-emitting fossil energy to a sustainable energy mix with Georgia's plan to revitalize its economy suffered from the

COVID-19 slowdown, as is the case in parts of the CAREC region and, in fact, all other regions.

In short, green hydrogen is a clean energy option for the CAREC region. However, its large-scale production to turn it into a meaningful source of clean energy for the regional countries with the mentioned required characteristics is hinged, among others on the availability of capital and clean fresh water.

As discussed, the technology is still expensive to make any major effort for producing green hydrogen highly capital intensive in a region, which is developing rapidly with a growing demand for capital to finance such development. Combing its production with developmental projects aimed at addressing infrastructural deficiencies and generating employment to eradicate unemployment and/or poverty is certainly a viable solution. In such a case, producing green hydrogen, including developing its respective technologies, could replace projects to build new fossil-fuelled power generators and, hence, use their available funds.

Large-scale green hydrogen production demands a huge amount of water for its water electrolysis process. As the most suitable, but not the only, CAREC countries for such production, China, Georgia, Kyrgyz Republic, Pakistan and Tajikistan have substantial freshwater resources. Yet, they equally have a significant and growing water demand for all their sectors (e.g., agriculture, industry, and residential), while facing shortages of water in parts of their countries (e.g., China and Pakistan). Desalination of seawater is a solution for those countries with access to open seas (i.e., China, Georgia and Pakistan). However, being highly electricity-intensive, that would phenomenally increase their green electricity demand when their total green electricity generation cannot keep pace with their growing electricity demand. Using treated sewage water is an environmentally-friendly solution to combine the necessary treatment of wastewater for their respective countries done routinely with securing clean fresh water for electrolysis to meet their steady demand for the latter without exhausting their freshwater resources. This solution also reduces the high cost of green hydrogen production to make green hydrogen a competitive alternative to the existing non-green types of energy while decreasing the required capital.

VIII. CONCLUSION: TURNING CHALLENGES TO OPPORTUNITIES

The CAREC region is facing two challenges at the beginning of the third decade of the 21st Century. The worsening global warming demands ending its consumption of GHG-emitting fossil energy and, therefore, switching to green energy over a short period of time to prevent a global environmental disaster, a task equally urgent for all other regions. The region also needs to come up with a plan to revitalize its economy heavily damaged as a result of the COVID-19 pandemic, which has induced a global recession affecting the regional countries to a varying extent.

These two challenges could well become a blessing in disguise. Quite feasibly, they could put the CAREC region on a sustainable development path, while addressing its share of the global environmental challenge and offsetting the adverse effect of over one year of pandemic-induced economic hardship, which will likely last throughout the entire 2021. Fortunately, all the CAREC countries have all or most of the necessary natural "fuels" adequately to secure a viable and growing renewable energy sector, namely wind, sunshine and rivers, to embark on building or expanding their existing renewable energy sectors, depending on the case.

There is a degree of indigenously-developed renewable energy technologies in some of the regional countries (e.g., Pakistan), which could be expanded, while China is a major developer and manufacturer of various renewable energy technologies and, in fact, the world's leading producer of wind turbines and solar panels. Hence, the CAREC countries could well build and/or expand their renewable energy sectors with the regionally-available technologies. In other words, given the growing friendly and multi-dimensional ties between and among the CAREC countries cooperating with each other on a variety of economic and non-economic projects such as the *Belt and Road Initiative*, the diffusion of the region's available renewable energy technologies from its developers to the others is logical, feasible and beneficial to all of them.

Manufacturing, transporting, installing and operating wind, solar and hydro equipment, for instance, could well be integrated into the existing economic development, infrastructure expansion and environmental restoration programs of the regional countries to reduce their cost while expanding their scientific and industrial sectors, boosting their economies and addressing their challenges and shortcomings.

Without any exception, energy demand is increasing in the regional countries, which must be met in a sustainable manner. Renewable energy has its obvious merits, but also its limits to both justify and necessitate adding other alternative types of emission-free energy to fossil energy to the CAREC countries' energy mixes. Nuclear energy is certainly a viable option for some of them, but not all for various reasons, including its initial high cost of construction, even though developing indigenous technologies as is being done in China and Pakistan could well decrease such cost for the regional countries. Without a doubt, nuclear energy, if used safely, is an indispensable large-scale source of environmentally-friendly energy to provide for a successful transition from the currently-unsustainable fossil energy-dominated regional energy mix to a sustainable one.

Nevertheless, green hydrogen could be a better option for those regional countries lacking the nuclear energy option, provided the availability of its technology and/or ease of its obtaining from other regional countries as well as the availability of ample amount of water. While fresh water is in abundance in some of the regional countries, it is a challenge in others such as Turkmenistan and Uzbekistan. However, the availability of wastewater in all these countries as discussed earlier, which has to be treated before being disposed of or reused, depending on the case, could well address this water challenge at an affordable cost. In this case, the production of green hydrogen could well be combined with wastewater treatment. Briefly, this combination reduces the cost of such production while offering an environmentally-friendly way to deal with the costly wastewater management, which damages the environment if poured into water resources untreated (e.g., seas, lakes and rivers) as the cheapest way or dumped in remote areas to eventually penetrate other water resources such as wells. For encouraging and expanding economic activities, connecting these two activities would certainly act as an economic boaster while securing their individual designated objectives.

In conclusion, combing the necessary switch to sustainable energy to meet the CAREC region's large and growing energy demand with the equally essential economic revitalization program to offset the COVID-19 pandemic's devasting below to the regional countries' economy is feasible and wise option for these countries. Apart from meeting their designated and previously-discussed benefits, this combination could potentially enable the CAREC countries to emerge and/or establish themselves as a major and, quite possibly, a leading supplier of renewable and hydrogen technologies.

VI. RECOMMENDATIONS

- Given the expansion of the CAREC countries' renewable energy sector and the revitalization of their economies are both necessary and individually costly, macro planning with clear milestones and goals must be devised to bring down the total cost of the combined program through planned and systematic full utilization of available resources.
- In devising short, medium and long-term plans for the combined program, priority should be given to those projects capable of supplying essential industrial, agricultural and infrastructural projects once they

are up and running to ensure steady, income-generating, sustainable development.

- Given the abundance of specific natural resources determines the appropriateness of the available renewable energy options to the CAREC countries, they should carefully identify their respective potentials for renewable energy development and opt for the most suitable types of technologies, which may not be the cheapest.
- Given the uneven distribution of indigenous renewable energy technologies in the CAREC region, the regional countries should establish a coordinating entity to provide for the exchange of the available technologies to all of them and create incentive for the growth of their respective industries and joint and/or individual development of new ones by creating economies of scale.
- Given the availability of adequate wind and solar energy in all the CAREC countries, joint and large-scale production of their respective generators should become the focus of the regional attention.
- Given the suitability of vertical-axis wind turbines (AVWTs) for both rural and urban use, standalone functions and microgrids and their low cost and ease of production, transportation, installment and operation compared to the currently widely-used horizontal-axis wind turbines (HAWTs) mostly for large-scale electricity generation, projects for harnessing wind energy should fully utilize both technologies for their respective advantages.
- Given the abundance of rivers in most CAREC countries, special attention should be made to environmentally-friendly and relatively inexpensive and easy to produce and install small hydro/run-of-the-river technologies to speed up the expansion of hydropower as a cheap source of electricity, along with large hydro projects when necessary and justifiable.
- Since production of green hydrogen is green electricity-intensive, the CAREC countries with small renewable power sector should not opt for it for as long as the sector is incapable of meeting their peak load electricity demand now met by fossil fuel-fired generators.
- As green hydrogen production is water-intensive and thus is a suitable option for those CAREC countries with ample amount of easily-renewable water resources, the others should not embark on it for its depleting impact on their limited/scarce water resources.
- Given water and electricity-intensive nature of green hydrogen production and the associated high cost, the interested CAREC countries

should combine their wastewater treatment with their green hydrogen production to decrease the total cost and the required electricity and preserve their water resources.

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