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Mitigation of Climate Change: The Breakthrough to Come from Northeast Asia

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Acronyms and Abbreviations

BAU – business as usual
CCS – carbon capture and storage
CCUS – carbon capture, utilization, and storage
CHP – combined heat and power
CO_2 – carbon dioxide
COP21 – the 21st Conference of the Parties to UNFCCC
DDPP – Deep Decarbonization Pathways Project
DPRK – Democratic People's Republic of Korea
EJ – Exajoule (10^{18} joules)
FEC – final energy consumption
GDP – gross domestic product
GHG – greenhouse gases
Gt – gigatonne
GW – gigawatt
IEA – International Energy Agency
INDCs – Intended Nationally Determined Contributions
IPCC – Intergovernmental Panel on Climate Change
kW – kilowatt
LULUCF – land use, land-use change and forestry
Mt – million tonnes
Mtoe – million tonnes of oil equivalent
MW – megawatt
NEA – Northeast Asia(n)
OECD – Organization of Economic Cooperation and Development
pkm – passenger-kilometer
PPP – purchasing power parity
PV – photovoltaic
R&D – research and development
RGGI – Regional Greenhouse Gas Initiative of the Northeast and Mid-Atlantic States of the US
ROK – Republic of Korea
TPES – total primary energy supply
TWh – terawatt-hour
UN – United Nations
UNFCCC – United Nations Framework Convention on Climate Change

Introduction

Global warming is recognized as one of the most urgent challenges for human society in the 21st century. The international community has agreed to undertake necessary actions to prevent dangerous anthropogenic impacts on the climatic system. Based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014), the UNFCCC Parties adopted the Paris Agreement aimed at limiting the global mean surface temperature rise by "well below 2 degrees Celsius".

Such an ambitious "climatic" target requires unprecedented efforts to reduce carbon emissions to almost zero worldwide this century. Moreover, in order to keep the warming below 1.5°C, the global total emissions must be reduced by 50% or more by 2050 (compared to current levels) and reach net-zero levels afterwards. In practical terms, it means that most of the countries should deeply decarbonize their economies, energy systems, industries, transport, buildings, products and services, while continuing growth of GDP and the standard of living of the population.

The developed countries agreed to take the lead in climate change mitigation under the UNFCCC; however, the largest developing countries and emerging economies have started playing substantial roles in carbon emissions nowadays. In this decade, China became the world No.1 CO_2 emitter overcoming the United States.

The Northeast Asian (NEA) region, including China, Japan, Mongolia, the Democratic People's Republic of Korea, the Republic of Korea, and the Russian Federation, is responsible for annual emissions of over 12.4 billion tonnes of CO_2 or approximately 40% of global energy-related CO_2 emissions. These countries are huge contributors to global warming today and may increase their share further. The traditional way of combusting the huge fossil fuels reserves (coal, gas, and oil) available in the Northeast Asian region would emit greenhouse gases substantially exceeding the amounts that would warm the planet by 2°C.

On the other hand, plentiful sources of renewable energy (solar, wind, hydro, tidal, and biomass, etc.) in combination with advanced technologies, investments, and land infrastructure developments can transform the Northeast Asian countries into decarbonized, climate- and environment-friendly economies with sustainable growth and development, fully consistent with the goals and commitments under the Paris Climate Agreement. Delays with the deep decarbonization of the Northeast Asian economies will impose higher risks for communities and life-supporting ecosystems, more losses and stranded assets for businesses, and slower technological progress worldwide.

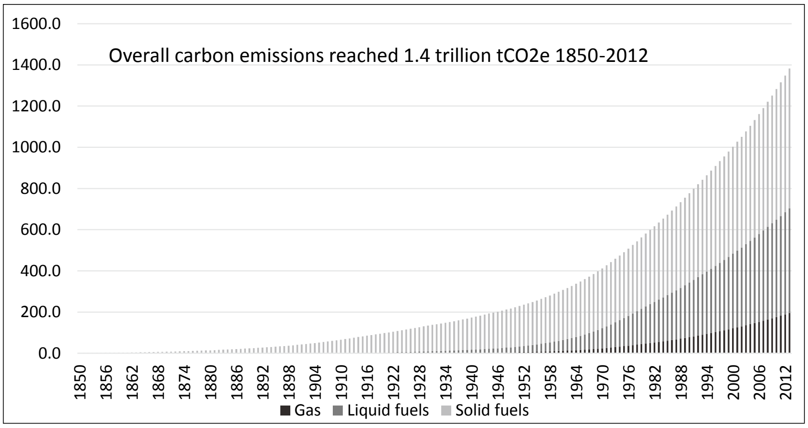
The analysis of challenges and opportunities in deep decarbonization pathways for the Northeast Asian region as a whole is presented in this publication. We raise many questions, and yet have not so many answers. By publishing this text, we want to invite all interested and concerned parties to start thinking about and debating these new, but very up-to-date issues of deep transformation of our economies, industries, consumer behavior, and ways of living in climate-neutral patterns, in order that we can urgently meet the need to save our planet and keep it in good shape for the generations to come.

Chapter 1. The Climate Challenge and Global Climate Treaties

1.1. The world's carbon dilemma

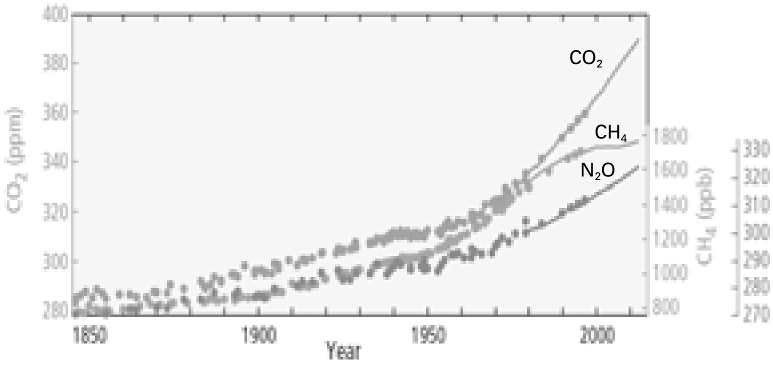
The global climate has always varied naturally for numerous reasons, such as changes in solar radiation, volcanic activity, geological transformation, and many others. However, the recent observations of climate change are, with the widely accepted consensus of scientists, caused primarily by a new phenomenon, namely the rapid growth of anthropogenic emissions of "greenhouse gases" (GHG) in the Earth's atmosphere. Since the beginning of the industrial revolution in the 1850s, human society has dramatically changed its economy, energy systems, transport, infrastructure, and consumer behavior, so that fossil fuels (coal, oil, and gas) became the major source of energy supply and, as the scientists confirm, the cause of the unprecedented growth of the concentration of greenhouse gases (Figures 1 and 2).

Figure 1. Global Cumulative CO_2 Emissions from Fuel Combustion, Billion tCO_2



Source: Carbon Dioxide Information Analysis Center database, http://cdiac.ornl.gov/

Figure 2. The Dynamics of the Global Average Concentration of Greenhouse Gases in the Atmosphere



Source: IPCC, 2014a

The extensive scientific research into climatic processes in the 1970s and 1980s, with the engagement of leading scientific organizations from the United States, Russia (the Soviet Union), European countries, Japan and others, and the evidence of a serious risk of global warming impacts, resulted in the adoption of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. The Intergovernmental Panel on Climate Change (IPCC) was established to provide up-to-date scientific data on the topic, gathering information from thousands of researchers worldwide.

The latest Fifth Assessment Report (IPCC, 2014b) repeatedly warned that the planet is warming much faster than previously thought and that the anthropogenic impacts (carbon emissions, and deforestation, etc.) play a predominant role in it. If we do nothing, the global average temperature will rise by 4–6°C by 2100, meaning the climate will change in extreme fashion from the historically accepted normal patterns. A group of economists headed by Sir Nicolas Stern issued a special report on the Economics of Climate Change (Stern, 2006), in which they estimated the damage from climate change impacts in a “no mitigation” scenario to be as much as 5–20% of global GDP in the 21st century.

Although the global annual average temperature has risen by only 0.8°C we can already observe climate change impacts, sometimes very extreme, such as cold waves (as in Mongolia in 2010, when millions of livestock died from the extreme cold) and heat waves (as in Europe in 2002, with over 30,000 premature deaths in people, or Russia in 2010 with many thousands suffering or dying), droughts and floods, forest fires and storms everywhere, enhanced desertification, drinking water shortages, expansion of insect-borne diseases (malaria, and encephalitis, etc.) and many more.

As approved at the 21st Conference of the Parties to the UNFCCC in Paris in December 2015, the new climate agreement will aim at limiting global warming to much below 2°C via global efforts “to reach the global peaking of greenhouse gas emissions as soon as possible… and to undertake rapid reductions thereafter … to achieve a balance between anthropogenic emissions by source and removal by sinks of greenhouse gases in the second half of this century”.[1]

Not all countries agree with the “2°C” target, especially the most vulnerable ones, such as the small island states, suffering from sea-level rise, and precipitation overload, etc. They insist on a much stronger goal of “1.5°C” and greatly enhanced action by the developed countries. The climatic goals can, with some uncertainties, be transformed into a specific and very understandable target: the CO_2 concentration in the atmosphere must be stabilized at a level not exceeding 450 ppm, about 60% above the pre-industrial level of 280 ppm (IPCC, 2014a). Recent records show we had already exceeded 400 ppm in 2015 (Biello, 2015).

In its 2014 “CO_2 Emissions from Fuel Combustion” report, the IEA noted: “Given the long lifetime of CO_2 in the atmosphere, stabilizing concentrations of greenhouse gases at any level would require a large reduction of global CO_2 emissions from current levels”. Thus, we face the dual challenge of economic growth and preserving the environment and climate at the same time.

For the Northeast Asian countries the climate change mitigation challenge can be considered from the following two practical perspectives: (1) what to do with the huge

[1] UNFCCC, Paris Climate Agreement (2015), Art. 4.

amounts of fossil fuels available in these countries?; and (2) how to utilize the large potential of non-carbon energy sources available domestically or through regional cooperation interlinkages?

The known reserves of conventional and non-conventional fossil fuels in the Northeast Asian countries, including coal, natural gas, crude oil, shale oil and gas, and methane hydrates, are enormous: over 1.7 trillion tonnes of oil equivalent (Table 1, Figures 3–5). Even if we do not have economically viable technologies for the extraction and use of all these resources currently, scientific and technological progress may help in utilizing them within the coming 1–2 decades. We can already see it in shale oil and gas extraction (the so called "shale revolution" in the United States increased shale gas production from 2.1 billion cubic feet (bcf)/day in 2000 to 44.1 bcf/day in 2016, accounting for about 40% of current total gas production[2]), and the continuation of efforts to use methane hydrates in Japan (with the first successful project implemented in 2014 and plans to commercialize this energy source by 2023).[3]

Table 1. The Estimates of Reserves of Conventional and Non-Conventional Fossil Fuels in Northeast Asian Countries.

	Coal	Crude Oil	Natural Gas	Shale Oil	Shale Gas	Methane Hydrates
Reserves of Fuels, billion toe						
China	79.8	2.6	2.9	90.2	94.9	100.0
Russia (Siberia and Far East)	121.8	14.4	27.1	174.0	0.3	913.0
Mongolia	70	*N/A*	*N/A*	11.9	0.05	*N/A*
ROK	0.1	*N/A*	*N/A*	*N/A*	*N/A*	1.2
DPRK	3.2	0.1	*N/A*	*N/A*	*N/A*	*N/A*
Japan	0.2	*N/A*	*N/A*	*N/A*	*N/A*	16.6
Total Reserves, billion toe	275.1	>17.1	>30.0	>276.1	>95.2	>1,030.8
Carbon Content of Fuels, billion tCO_2e	**1,089.6**	**>52.5**	**>76.3**	**>847.7**	**>223.9**	**>2,421.1**

Sources: Authors' estimates based on data from IEA, and the EIA, US

[2] Source: the US Energy Information Administration database.

[3] Japan's Methane Hydrate R&D Program was established in 2001, under which the industry–government–academia consortium MH21 undertakes extensive scientific research. The first practical results were reported in the "Japan Times", 25 December 2014.

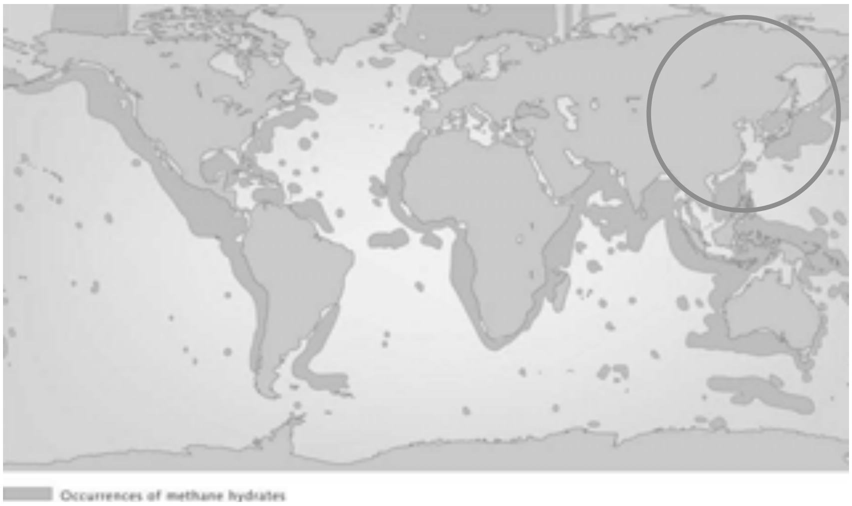
Figure 3. Map of Global Coal Reserves.

Source: Maps of the world,
http://www.mapsofworld.com/business/industries/coal-energy/world-coal-deposits.html

Figure 4. Map of Global Shale Oil and Gas Reserves

Source: EIA, http://www.eia.gov/analysis/studies/worldshalegas/

Figure 5. Map of Global Methane Hydrate Occurrence



Source: World Ocean Review, http://worldoceanreview.com/en/wor-1/energy/methane-hydrates/

The overall "2°C" carbon budget[4] is limited, to roughly 1 trillion tonnes of carbon, over a half of which has already been used. The rest would be "consumed" in the 2040s, if the current trend in GHG emissions continues. This means that combating global warming would require keeping most of the carbon contained in the fossil fuel reserves underground or underwater. And this is absolutely opposite to what we can expect from the current economic development and corporate behavior patterns, where the fossil fuel resources are considered as very valuable assets.

The terrifying news is that the combustion of all Northeast Asian fossil fuels in the traditional way (e.g. without carbon capture and storage) would lead to emissions of 4.7 trillion tCO_2e. In other words, the Northeast Asian region alone can emit an amount of greenhouse gases that is almost three times more than the globe can afford to stop at 2°C of warming.[5]

1.2. Paris Climate Agreement: From science to business

The 21st Conference of the Parties to the UNFCCC in Paris (December 2015) adopted a new international climate agreement, which will replace the Kyoto Protocol from 2020 onwards. One of the main goals of the treaty is "to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (Art. 2, Paris Agreement).

Such a "climatic" goal has very challenging practical implications for socioeconomic

[4] The carbon budget is often associated with the amount of greenhouse gases that could be emitted into the atmosphere to reach a certain level of global warming. The overall carbon budget may also be considered as distributed among individual countries or groups of countries.

[5] The estimated amount of GHG emissions that would lead to "below 2°C" warming is approximately 1.5 trillion tCO_2e. Source: IPCC Fifth Assessment Synthesis Report, Figure 3.2.

development, technologies, finance, regulation, and international cooperation. Long-term carbon emissions should decrease no less than 50% from the current level by 2050 and reach a net-zero level (accounting for carbon sinks in forests and land use) in the second half of this century.

Unlike the Kyoto Protocol, the Paris Agreement is based on a bottom-up approach, where the overall emission targets are determined by the contributions of individual countries (or groups of countries, as for the EU). Over 160 countries provided their Intended Nationally Determined Contributions (INDCs) with the targets for carbon emission reduction/limitation by 2030. However, according to the estimates by the UNFCCC Secretariat, the overall INDC pledges demonstrate substantial growth of emissions by 2030, not a decline (Figure 6): if all mitigation efforts proposed by the countries were implemented emissions would rise by 51% above the 1990 level by 2030, while the IPCC warns that total emissions must decline by at least 50% by 2050 in order to move toward the "below 2°C" target.

An increasing gap between the envisaged levels of GHG emissions and the required climatic target means a higher risk of its non-achievement and much more effort and costs of mitigation will be needed after 2030. That is, the current policy makers would just transfer the burden of decarbonization of their economies to future generations.

While the negotiators at the UNFCCC sessions continue to debate the scientific grounds and affordable climatic goals (e.g. "1.5°C" or "2°C" and their environmental consequences, and the role of anthropogenic factors, etc.), the economic and investment processes have started reflecting the risk of carbon regulation, the need for technological transformation, and the growing awareness and concern of consumers (as well as producers) about the carbon footprint of products and industrial processes. Many international experts concluded that the new paradigm of an "environmentally clean" and "climate friendly" economy is a substantial part of the fourth (post-)industrial or technological revolution (Schwab, 2016).

All previous industrial revolutions led to a massive increase in productivity, a boost in economic growth, and technological modernization on a global scale. That was the case for the First Industrial Revolution using water and steam power to mechanize production, the Second using electric power for mass production, and the Third using electronics and information technology in automating industrial production and many other spheres of human life. The coming Fourth Industrial Revolution has already started leading the world economy to a cyber-physical, environmentally and climatically sound future, based on sustainable development principles, amongst others things.

The need for upgrading technology, production processes, and infrastructure, and changing consumer behavior patterns in favor of climate-friendly options will stimulate GDP growth, create new markets and reformat existing markets (e.g. fossil fuels, transportation, and basic materials, etc.), and change the international competitiveness of countries (especially those which fail to adjust to the new circumstances). These economic processes can already be observed in many spheres: divestments from carbon-intensive industries, a ban on new coal projects by international organizations, the decarbonization of the portfolios of institutional investors, the rocketing renewable energy markets, and the boost in hybrid and electric automobile production, etc.

However, the economic sense of a "below 2°C" goal is still underestimated: reaching this ambitious but very necessary target for human beings means much deeper transformation processes than those which have been observed to date. The world should gradually switch to an 80–100% lower carbon intensive economy this century, and there is no other feasible option now if we seriously want to leave the planet safe for future generations.

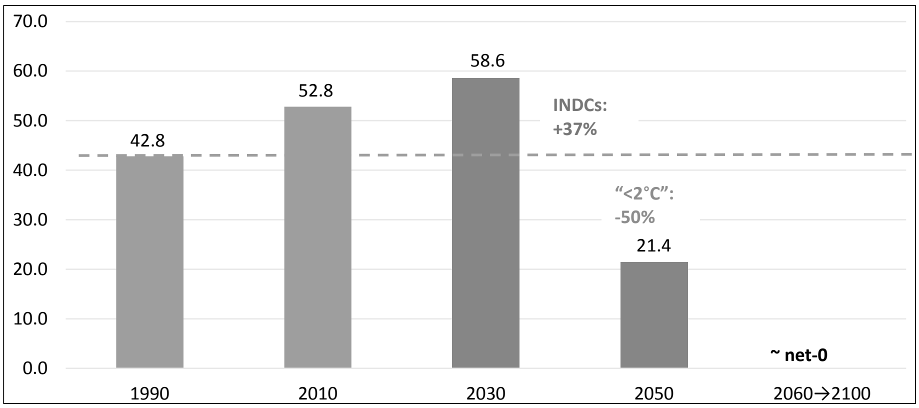
Northeast Asian countries provided their pledges on GHG emission reductions/limitations under the UNFCCC negotiations for 2020 (under the post-Kyoto commitments) and 2030 (as INDCs). It is hard to quantify the overall target for the region, as the nationally determined contributions vary by type and include: absolute targets, indicators per unit of GDP, emission reductions compared to the business as usual (BAU) scenario, the percentage shares of renewables in the energy mix, and the targets including/excluding carbon removals, etc. (Table 2).

For instance, China declared the following very ambitious targets to 2030:

- Reduction of CO_2 per unit of GDP by 60% to 65% below the 2005 level;
- Increase in the share of non-fossil fuels in primary energy consumption from 11% to 20%;
- Increase the forest growing stock volume from 2.2 to 4.5 billion cubic meters.

Figure 7 illustrates the quantifiable GHG emission targets in selected Northeast Asian countries. Russia's INDC includes an emission reduction level of 30% below that of 1990 by 2030, which is comparable to the current level of emissions (29% below the 1990 level in 2014). A significant additional reduction has not been proposed. Furthermore, the INDC provides that a full accounting of forest carbon removals should be applied, which were 611 million tCO_2 per year in 2014 (22% of total national GHG emissions). The target of Japan looks the most ambitious among the Northeast Asian countries, aiming at a rather significant reduction of GHG emissions: 26% below the 2013 level by 2030. The ROK's INDC aims at a 21% reduction of emissions from the current level, while Mongolia's quantitative target is to increase the absolute emission level by 2030. Relevant data for the DPRK are not available.

Figure 6. Global GHG Emissions: 1990–2010 Levels, 2030 Targets for INDCs and the Long-Term "<2°C" Target for 2050, billion tCO_2e



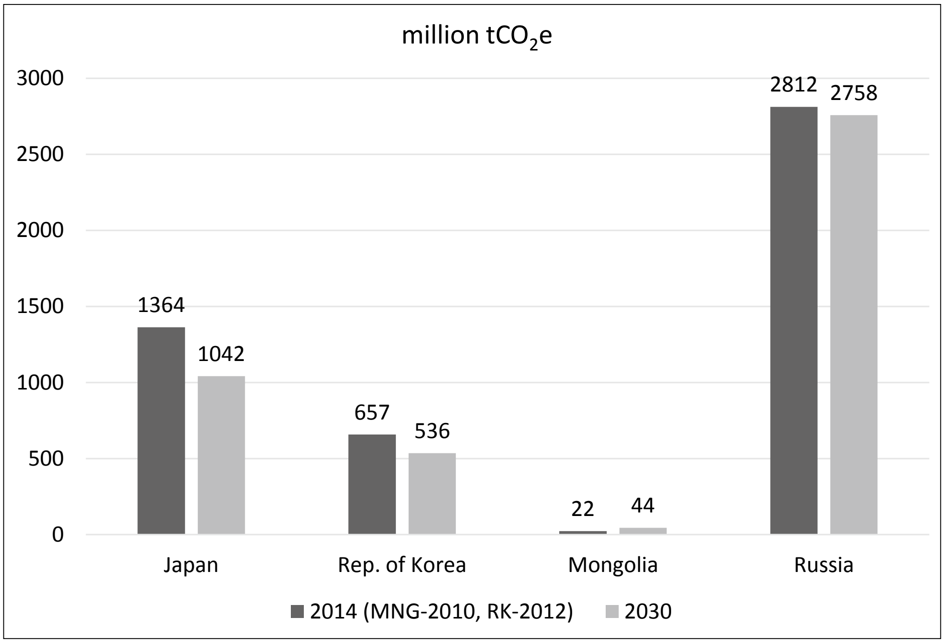
Sources: UNFCCC database, and authors' calculations

Table 2. GHG Emission Targets for 2020 and 2030 by Northeast Asian Country

Country	Quantified Economy-Wide Targets for 2020	INDC Targets for 2030
Japan	3.8% reduction in 2020 compared to the 2005 level	26% reduction by FY2030 compared to the FY2013 level
Russia	Nationally determined commitment is set at 25% below 1990 level by 2020	25–30% reduction by 2030 compared to 1990 level, full accounting of forest carbon removals
ROK	Reduction by 30% from "business as usual (BAU)" emissions in 2020	37% reduction of BAU emissions by 2030
China	Reduction of CO_2 emissions per unit of GDP by 40–45% by 2020, compared to the 2005 level	Peak by 2030, reduction of CO_2 emissions per unit of GDP by 60–65% by 2030 from the 2005 level
Mongolia	Non-quantified emission reduction measures	14% reduction by 2030 compared to BAU (excluding LULUCF)
DPRK	N/A	N/A

Source: Authors' overview based on the national INDCs submitted to the UNFCCC

Figure 7. The National Targets for GHG Emission Reduction/Limitation of Selected Northeast Asian Countries under the Paris Climate Agreement.



Source: Authors' estimates based on UNFCCC data

Chapter 2. Economic Development in Northeast Asia: "Business as Usual"

2.1. Historical pathways and trends

The subregion of Northeast Asia plays an increasingly important role in global economic development: it represents 1.7 billion of the global population and 1 billion of the labor force, one-quarter of the world's GDP, over US$6.6 trillion of its industrial production, and approximately 40% of total anthropogenic CO_2 emissions. In addition, it has vast reserves of fossil fuels as well as renewable energy sources that can be utilized through the combination of the technologies and investment resources available in the region.

In the last 25 years the Northeast Asian countries have changed dramatically, speeding up their economic growth and strengthening their positions in the globalizing world. While world GDP (in terms of PPP[6]) increased 2.16 times, the GDP of Northeast Asian countries tripled in the period 1990–2015. The overall share of the regional economy within global GDP increased from 18% in 1990 to approximately 25% in 2015. The population increased from 1,477 to 1,708 million, with a substantial rise in the share of the urban population associated with the industrialization and urbanization processes in these countries (Table 3).

Of course, the development pathways were very different by country, and it is important to characterize briefly the individual country pathways since the year 1990, which we will herein consider a reference year for our purposes.

Due to its fast economic growth (measured in GDP PPP), China overtook Japan, the number-two economy in the world, in 1999, and then the US economy in 2014.[7] The unprecedented GDP PPP growth rate of 14.6% on average in the period 1990–2015 allowed China to increase GDP 3.5-fold in terms of PPP and more than a 9-fold rise in US$ equivalence at the current exchange rate. The standard of living of the population has also substantially increased: GDP (PPP) per capita increased from US$980 in 1990 to US$14,239 in 2015. The country experienced a radical transformation of its labor force profile: the share of the urban population rapidly increased from 26.4% in 1990 to 55.6% in 2015. In the 2000s China became a global leader in industrial production, manufacturing and exports worldwide. Its energy use per capita tripled: from 0.767 toe in 1990 to 2.230 toe in 2015. At the same time the total primary energy supply grew from 871 to over 3,000 Mtoe per year, overtaking the world leader, the United States, in 2009.

In contrast to China, Japan had relatively low economic growth in the period 1990–2015: national GDP was growing at slightly less than 1% per year. The GDP (PPP) per capita increased almost two-fold from US$19,230 in 1990 to US$37,322 in 2015. The population increased by 3% and reached 127.3 million. Japan's energy use per capita increased from 3.560 toe in 1990 to a historical high of 4.090 toe in 2004 and then declined to 3.470 toe in 2015. The total primary energy supply increased from 440 Mtoe in 1990 to a peak of 522 Mtoe in 2004 and then declined to 455 Mtoe in 2015.

[6] PPP stands for purchasing power parity.

[7] Sources: IEA/OECD (2015) for 1999; the Financial Times for 2014 (http://www.businessinsider.com/china-overtakes-us-as-worlds-largest-economy-2014-10, retrieved on 20 September 2016)

Table 3. The Roles of Northeast Asian Countries in the World Economy

	1990	2000	2015
GDP using current exchange rates, US$ billion			
World	22,563.0	33,321.0	73,434.0
NEA total	~4,306.2	~6,786.4	~17,733.1
China	359.0	1,205.3	10,866.4
Japan	3,103.7	4,731.2	4,123.3
Russian Federation	516.8	259.7	1,326.0
Mongolia	2.6	1.1	11.8
ROK	284.8	561.6	1,377.9
DPRK (in 2005 US$)*	39.4	27.5	27.8
Share of NEA in global GDP	~19.1%	~20.4%	~24.1%
GDP using purchasing power parity, billion (current international US$)			
World	28,600.0	48,213.0	113,613.0
NEA total	~5,045.2	~8,830.7	~29,627.3
China	1,112.5	3,681.1	19,524.3
Japan	2,375.6	3,290.1	4,738.3
Russian Federation	1,188.2	1,000.6	3,579.8
Mongolia	7.2	8.8	36.1
ROK	361.7	850.1	1,748.8
DPRK (in PPP 2005 US$)*	148.0	103.2	104.3
Share of NEA in global GDP (PPP)	~17.6%	~18.3%	~26.1%
Population, millions			
World	5,278.0	6,090.0	7,118.0
NEA total	1,476.9	1,606.1	1,708.3
China	1,140.0	1,260.0	1,360.0
Japan	123.6	126.8	127.3
Russian Federation	148.0	147.0	143.0
Mongolia	2.2	2.4	2.8
ROK	42.9	47.0	50.2
DPRK	20.2	22.8	24.9
Share of NEA in world population	28%	26%	24%

* Data for the DPRK are very limited and not consistent, and are provided here for indicative purposes.
Source: IEA/OECD (2015); World Bank (2016)

The collapse of the USSR and the deep economic transformations in the early 1990s led to a 42% drop in Russia's GDP from US$843 billion in 1990 to US$485 billion in 1998, with a subsequent gradual recovery to approximately US$1 trillion in 2015. The GDP (PPP) per capita also showed a decline from US$7,850 in 1990 to US$5,460 in 1998, and fast growth to US$24,451 in 2015. Russia's population gradually declined from 148 million in 1990 to 143 million in 2015. The energy use per capita dropped from 5.929 toe in 1990 to a low of 3.982 toe in 1998, and then rapidly increased to 5.093 toe in 2015, despite industrial modernization and the active energy efficiency policies adopted since 2008. The total primary energy supply declined from 879 Mtoe in 1990 to a low of 588 Mtoe in 1998, and then grew to approximately 740 Mtoe in 2015. A significant amount of fuel is exported from Russia, reaching 67% of total merchandise exports in 2015.

Mongolia faced a sharp drop in GDP after the beginning of political and economic reforms in the 1990s. GDP at current exchange rates fell from US$2.561 billion in 1990 to US$0.768 billion in 1993, followed by a slight increase and then stagnation at around US$1.1–1.4 billion up to 2004, followed by rapid growth to US$12.582 billion in 2013. By 2015 GDP decreased to US$11.758 billion. The GDP (PPP) per capita gradually increased from US$3,311 in 1990 to US$12,189 in 2015, practically following China's path. The population of Mongolia increased from 2.4 million in 1990 to 2.8 million in 2015. The energy use per capita dropped sharply from 1.560 toe in 1990 to a low of 0.944 toe in 1999, and then rapidly increased to 1.826 toe in 2013. The total primary energy supply increased from 3.4 Mtoe in 1990 to 5.2 Mtoe in 2013. The country pursued a policy of the expansion of mineral production industries, but in the last 3–4 years has faced a decline in international prices and the demand for its products, which has led to a slowing-down of economic growth. In addition, the country's external debt has substantially increased.

The Republic of Korea is widely considered a fast growing economy. Its GDP rose 5.5-fold, from US$248.8 billion in 1990 to US$1,378.0 billion in 2015. The national GDP (PPP) per capita grew four-fold, from US$8,436 in 1990 to US$35,349 in 2015. The country is among the world leaders in industrial production, electronics, transport vehicles, and ship production. The country's population increased from 42.9 million in 1990 to 50.6 million in 2015. The energy use per capita rose almost linearly from 2.167 toe in 1990 to 5.262 toe in 2015. The total primary energy supply increased from 93 Mtoe in 1990 to 264 Mtoe in 2015. Eighty-two percent of the energy resources consumed in the country are imported.

The DPRK has demonstrated continuing economic decline since 1990. The national GDP (PPP, US$2,005) dropped approximately 30%: from US$148 million in 1990 to US$104 million in 2013. GDP (PPP) per capita decreased by almost half: from US$7,329 in 1990 to US$4,190 in 2013. The population increased from 20.2 million in 1990 to 24.9 million in 2013. The country's TPES dropped down by 56%: from 33.2 Mtoe in 1990 to 14.5 Mtoe in 2013. The country continues to be under UN sanctions, which affect its economic performance and the standard of living of the population, limiting its industrial development. The country has close economic ties with the neighboring Northeast Asian countries, including China, Mongolia, Russia, and the ROK.

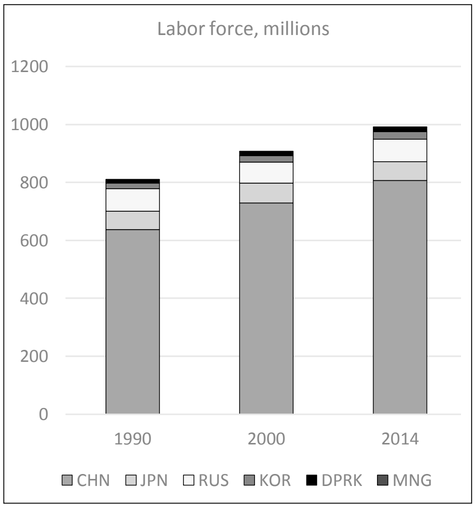
Overall the labor force in the Northeast Asian countries increased from 810 million in 1990 to 992 million in 2014, mostly due to China (27% growth). In Japan and Russia the labor force growth was nearly zero in that period, while it grew by 38% in the ROK, by 26% in the DPRK, and by 78% in Mongolia (Figure 8).

Industrial production substantially transformed during 1990–2015. Overall it increased in real terms 2.6 times (Figure 9). The major industrial producer Japan had rather stable output and was overtaken by China in the mid-2000s, whose output rose 15.5-fold compared to the 1990 level. Russia's output significantly declined in the 1990s, but recovered and reached 83% of the 1990 level by 2015. Production in the ROK increased 3.7 times and in Mongolia 3 times.

The overall final energy consumption in the region grew intensively, primarily due to China, whose energy use increased more than 3.5-fold in 1990–2013. Russia's domestic energy use decreased in the 1990s by 30% and subsequently gradually increased to 83% of the 1990 level. Japan's energy consumption slightly increased by the mid-2000s, and is currently comparable with the 1990 level. The ROK's energy use has almost tripled since 1990. The DPRK's energy consumption dropped by 56%. Mongolia's energy use increased by 59% (Figure 10).

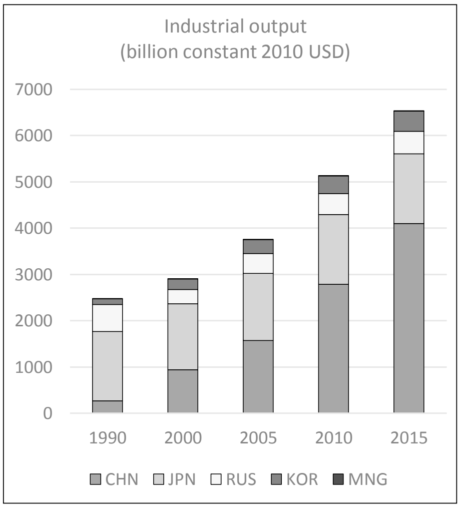
A similar dynamic can be seen in fossil fuel energy consumption. The rapidly growing economy of China increased fuel use (mainly coal) 4-fold, and the ROK almost tripled its fossil fuel use, Mongolia's rose 55%, while Japan's fossil fuel energy consumption increased by 15%. Russia's domestic fossil fuel use declined 19%, and the DPRK's fell 60% (Figure 11).

Figure 8. Labor Force in NEA Countries



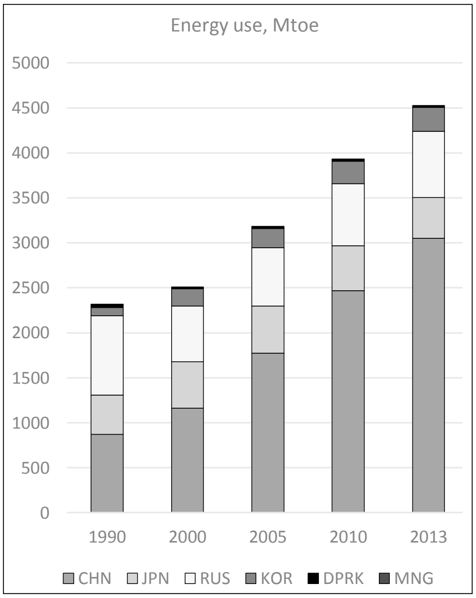
Source: World Bank (2016)

Figure 9. Industrial Value Added in NEA Countries



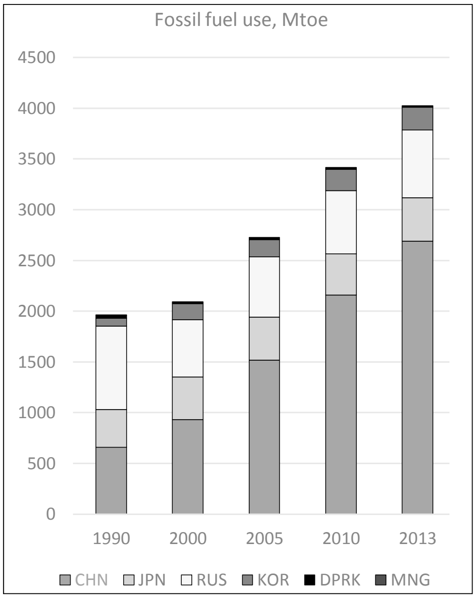
Source: World Bank (2016)

Figure 10. Energy Use in NEA countries



Source: IEA/OECD (2015)

Figure 11. Fossil Fuel Use in NEA Countries



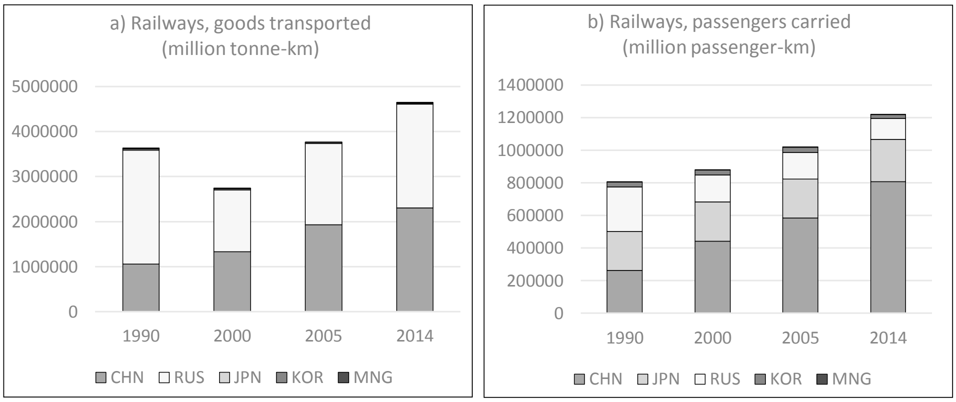
Source: IEA/OECD (2015)

The highly important transportation sector in Northeast Asian countries demonstrated significant changes as well. The leading countries in goods transportation via the extensive railway networks are Russia and China. Since 1990, a 2.3-fold growth in goods transportation by rail was observed in China, while in Russia the amount of goods transported declined by almost 50% in the 1990s and then recovered to 90% of the 1990 level by 2014. However, the passenger railway transportation in leading Northeast Asian countries is quite different: in China the number of passenger-kilometers per year tripled, in Japan it increased 9.5%, and in Russia it decreased 53% (Figures 12a, b).

Air transportation has also been changing dramatically. The market newcomers (and current regional leaders) China and the ROK increased their freight transportation 24 times and 4.6 times, respectively. Japan increased air freight transportation by 70%, and Russia 5.6-fold. In the passenger transportation sector, China became the obvious leader, with 436 million passengers carried in 2015. Japan and the ROK increased passenger transportation by 1.5 and 4.2 times, respectively. Russia experienced a sharp drop in transportation (80%) in the 1990s, and by 2015 recovered to 60% of the 1990 level (Figures 13a, b).

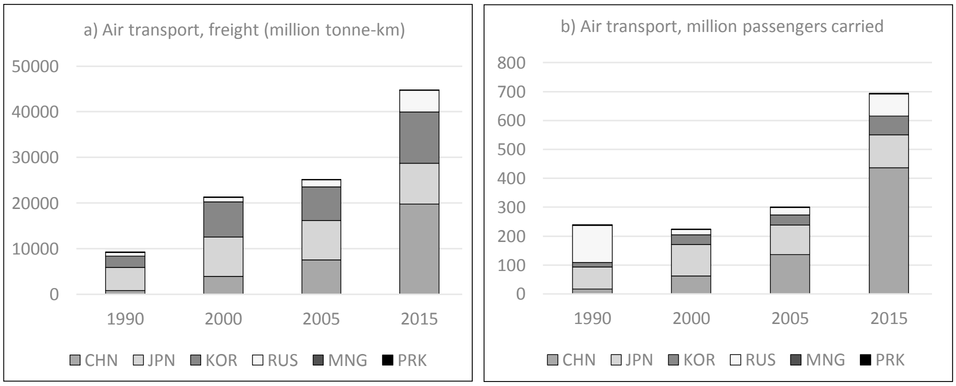
The automotive sector has been booming in all Northeast Asian countries from 1990 on. Today the overall number of vehicles registered in the region exceeds 420 million (Figure 14) and continues expanding. The structure of the vehicle fleet has been changing in recent years toward an increase in the number of hybrid, gas-using electric vehicles, and even hydrogen fuel-cell cars (the mass production of a hydrogen-driven Toyota Mirai was started in 2014).

Figure 12. Transportation by Railway in NEA Countries



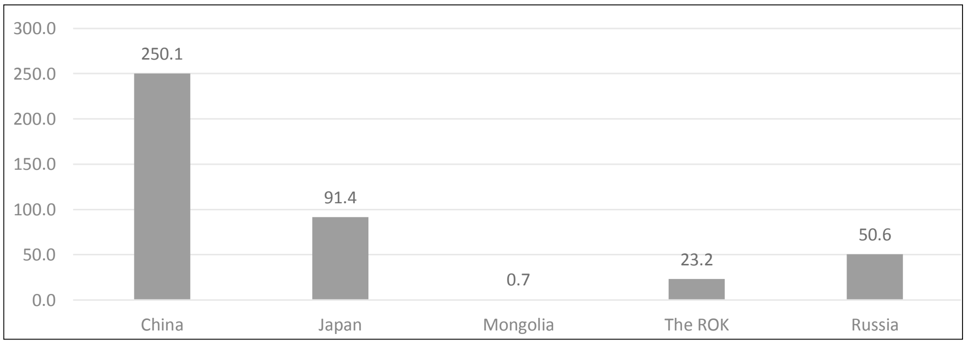
Source: World Bank (2016)

Figure 13. Transportation by Air in NEA countries



Source: World Bank (2016)

Figure 14. Number of Registered Automobile Vehicles, million (2013)



Source: World Bank (2016)

2.2. The Prospects for socioeconomic development

The forecasts for socioeconomic development are usually limited to 10–20 years, and therefore it is very difficult to get appropriate data for longer term horizons, such as to 2050. However, based on fairly reasonable assumptions (projections), we can get an understanding of the macro-level picture of the envisaged changes in the regional economies.

First of all, UN forecasts illustrate an approximate 2% rise in the total population of Northeast Asian countries by 2030 with a subsequent decline to 3% below the current level by 2050. China, Russia, and Japan are expected to have somewhat lower populations, while in the DRPK and Mongolia the population will increase and in the ROK it will stay relatively stable (Table 4).

At the same time, the economic growth in leading Northeast Asian countries is expected to be rather high. During 2014–2050, the GDP by PPP may rise 3.5 times in China, 1.7 times in Japan, 2.1 times in Russia, and 2.3 times in the ROK (PwC, 2015). This corresponds to an approximate 3% annual average rate of GDP growth for these countries (Table 5).

The standard of living of the population is also expected to rise: by 2050, GDP by PPP per capita may rise 3.4 times in China, 1.9 times in Japan, 2.2 times in Russia and 2.5 times in the ROK. In a scenario by PwC (2015) the ROK will overtake Japan in GDP PPP per capita from 2030 onwards, while Russia will be able to reach practically the current level of GDP PPP per capita of Japan in 2030 and continue an approximate 2-fold rise by 2050.

The long-term socioeconomic development strategies and programs in Northeast Asian countries are numerous: the five-year plans in China; the energy strategies to 2030 and 2035 in Russia; the green development and energy policies to 2030 in Mongolia; the ROK green growth strategy; Japan's New Growth Strategy and Strategic Energy Plan with targets up to 2020 and 2030; and many more. For our purposes, the most important policy targets are related to energy, freight and passenger transportation, industries (cement, metals, and some others), residential and commercial buildings, agriculture and forestry, and environmental management (waste treatment, and methane emission regulation, etc.). Table 6 provides a summary of selected indicators up to 2050 (as projected by the national modeling teams under the DDPP), which we consider useful for further analysis of the low-carbon development strategies and policy options.

Table 4. Population Forecast up to 2050 (thousands)

Country	2015	2030	2050	2050/2015
China	1,376,049	1,415,545	1,348,056	98%
Russia	143,457	138,652	128,599	90%
Japan	126,573	120,127	107,411	85%
The ROK	50,293	52,519	50,593	101%
The DPRK	25,155	26,701	26,907	107%
Mongolia	2,959	3,519	4,028	136%
Total in NEA	1,724,486	1,757,063	1,665,594	97%

Source: UN, 2015

Table 5. Projections of Economic Development up to 2050

Country	2014-Fact	2030-Projection	2050-Projection	2050/2014
GDP at PPP (2014 US$ billion)				
China	17,632	36,112	61,079	346%
Japan	4,788	6,006	7,914	165%
Russia	3,559	4,854	7,575	213%
The ROK	1,790	2,818	4,142	231%
GDP at PPP (2014 US$ billion) per capita				
China	12,885	24,872	43,528	338%
Japan	37,620	49,207	72,245	192%
The ROK	36,728	54,347	80,579	219%
Russia	24,811	35,792	61,727	249%

Source: PwC, 2015

Table 6. Summary of Selected Development Indicators in NEA Economies up to 2050

Country	2010-Fact	2050-Projection	2050/2010
China			
Primary energy, EJ	101	178	176%
Final energy consumption, EJ	74	122	165%
Freight transport, trillion tonne-km	2.7	9.8	363%
Passenger transport, trillion passenger-km	2.1	13.2	629%
Japan			
Primary energy, EJ	16.5	8	53%
Final energy consumption, EJ	14	7	50%
Freight transport, trillion tonne-km	0.4	0.2	128%
Passenger transport, trillion passenger-km	1.3	1.1	90%
Russia			
Primary energy, EJ	28.13	17.95	64%
Final energy consumption, EJ	22.94	15.35	67%
Freight transport, trillion tonne-km	2.4	4.2	178%
Passenger transport, trillion passenger-km	0.9	2.1	221%
The ROK			
Final energy consumption, EJ	7.98	5.01	63%
Industry, share in GDP	27.2%	35.3%	130%
Passenger transport, pkm/person	13,400	26,300	196%

Source: DDPP project: http://deepdecarbonization.org/; Kainuma, M., Akashi, O., 2016

Chapter 3. Carbon Emission Trends and Drivers

3.1. Trends

The greenhouse gas (GHG) emission data are not available for some years for the Northeast Asian countries, but according to our rough estimates, the regional GHG emissions (excluding land use and forestry) grew by 66%, from 9 billion tCO_2e in 1990 to 15 billion tCO_2e in 2014.[8] More precise data from the IEA show that CO_2 emissions from the energy sector in Northeast Asian countries increased more than twofold, from 5.8 to 12.4 billion tCO_2 in 1990–2013 (Figure 15).[9] The countries performed differently in increasing (+) or decreasing (–) their CO_2 emissions from fossil fuel use (2013 compared to 1990):

China	+311%
ROK	+147%
Mongolia	+45%
Japan	+18%
Russia	–29%
DPRK	–59%

Currently the leader in carbon emissions in Northeast Asia is China, accounting for 72% of total regional emissions. Russia is responsible for 12% of emissions, Japan for 10%, the ROK for 5%, and the DPRK and Mongolia for less than 1%. The structure of GHG emissions is different by country, but the energy sector is predominant in all of them (Figure 16). Mongolia can be distinguished from its other Northeast Asian neighbors for the large share of emissions from the agricultural sector, and is comparable to energy sector emissions.

Since 1990, CO_2 emissions per GDP (PPP) from the energy sector in most Northeast Asian countries have declined, with the exception of the DPRK and Russia in the turbulent 1990s. The dynamics of such a decline have been different by country, but most often the reduction of CO_2 emissions per GDP (PPP) was associated with the increase of GDP per capita (PPP) as shown in Figure 17. Japan demonstrated a very modest reduction of emissions per GDP with increasing GDP per capita. Meanwhile in the ROK emissions per GDP dropped dramatically with the increase of GDP per capita (to a level comparable with Japan in 2013–2014). China's CO_2 emissions per GDP declined more than half with rising GDP per capita. Mongolia increased its GDP per capita with a slight decline in CO_2 emissions per GDP. Russia slightly increased CO_2 emissions per GDP due to the dramatic decline of GDP per capita in the 1990s, but later on substantially reduced it (about 40%) with growing GDP per capita. The DPRK demonstrated a decline in both GDP per capita and CO_2 emissions per GDP.

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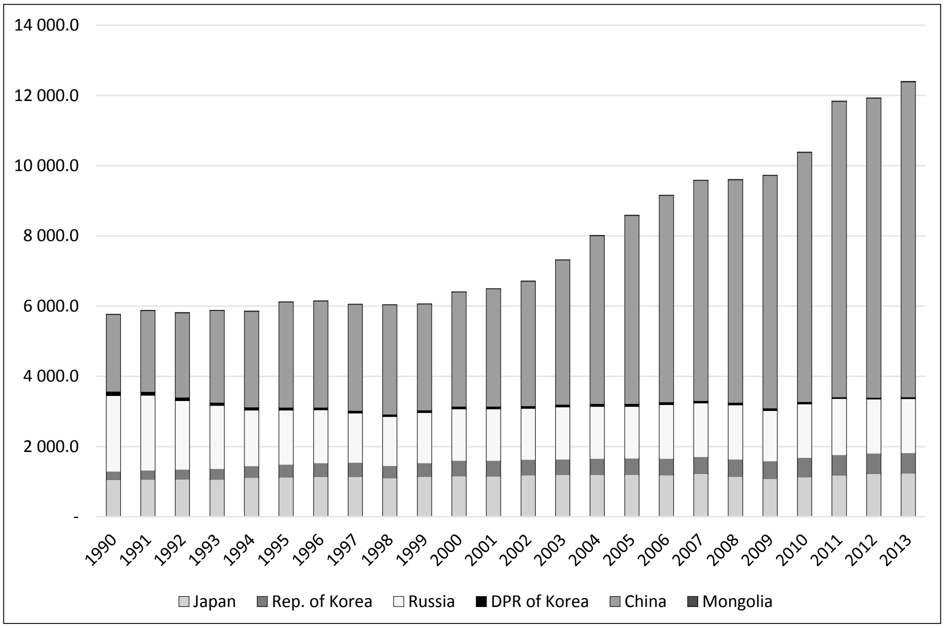
[8] The authors' estimate based on the UNFCCC reporting data for the latest inventories by country (subject to relatively high uncertainty).

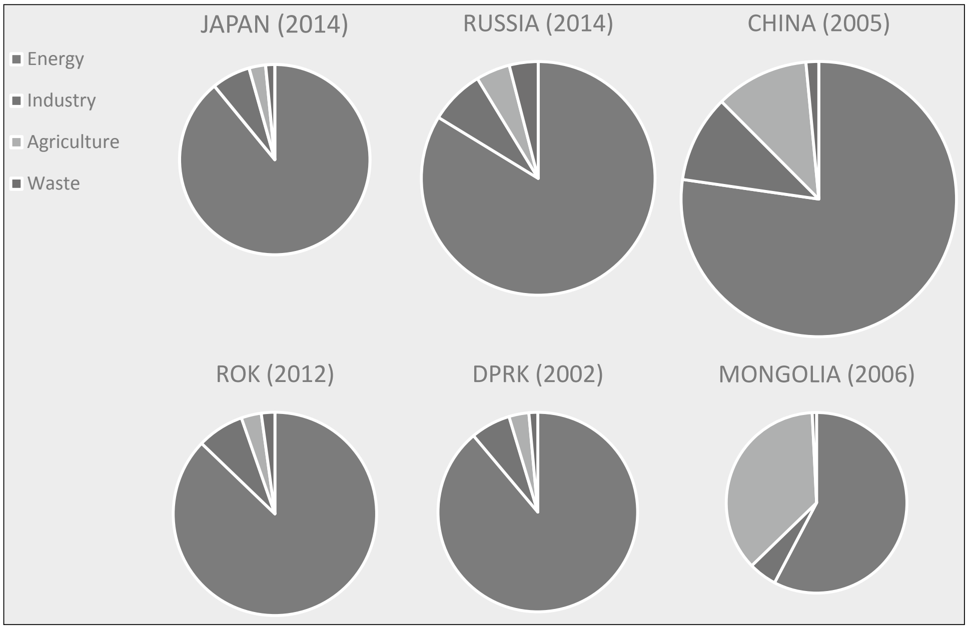
[9] IEA database: CO_2 Highlights 2015.

Figure 15. CO_2 Emissions by Northeast Asian Country, million tCO_2



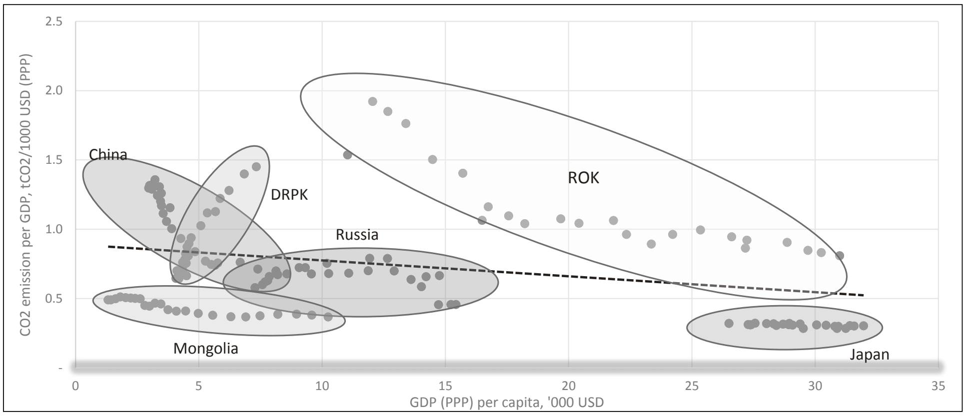
Source: Authors' estimates based on IEA data

Figure 16. Breakdown of GHG Emissions in Northeast Asian Countries by Sector



Source: UNFCCC database

Figure 17. CO_2 Emissions and GDP per Capita in Northeast Asia, 1990–2014



Source: Authors' estimates based on IEA data

3.2. Drivers

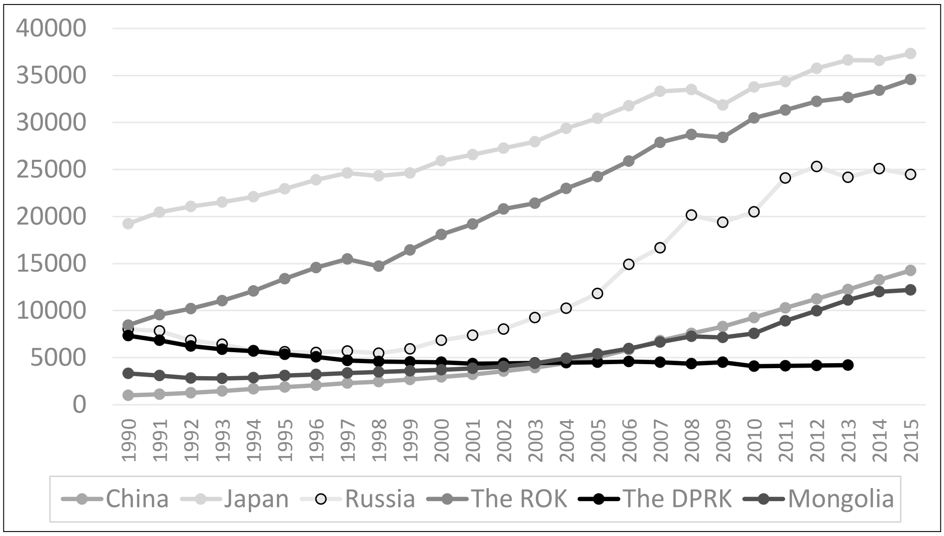
The Northeast Asian countries demonstrated substantial changes in 1990–2015: the population increased by 17% from 1.47 to 1.72 billion people; overall GDP increased by 142% from US$7.2 to US$17.4 trillion (at market prices, constant 2010 US$); and CO_2 emissions increased 4-fold from 3.2 to 12.7 billion tCO_2 per year.

At the same time, the economic development pathways of these countries were diverse, experiencing different scales of impacts from economic reforms, the global financial and economic crises of 1998 and 2008, and world fuel and metal price drops in 2013–2016.

Overall in the period 1990–2015, the standard of living of the population was rising in most of the countries: GDP per capita (measured in purchasing power parity, PPP) in the Republic of Korea (ROK) almost reached the level of Japan in 2015, while in Mongolia it practically followed China's path (Figure 18). In Russia it tripled compared to 1990 to approximately US$25,000 (PPP) per capita in 2015. In the Democratic People's Republic of Korea (DPRK), GDP per capita declined to approximately half since 1990, primarily due to the sanctions regime, the recession of the economy and continuing population growth.

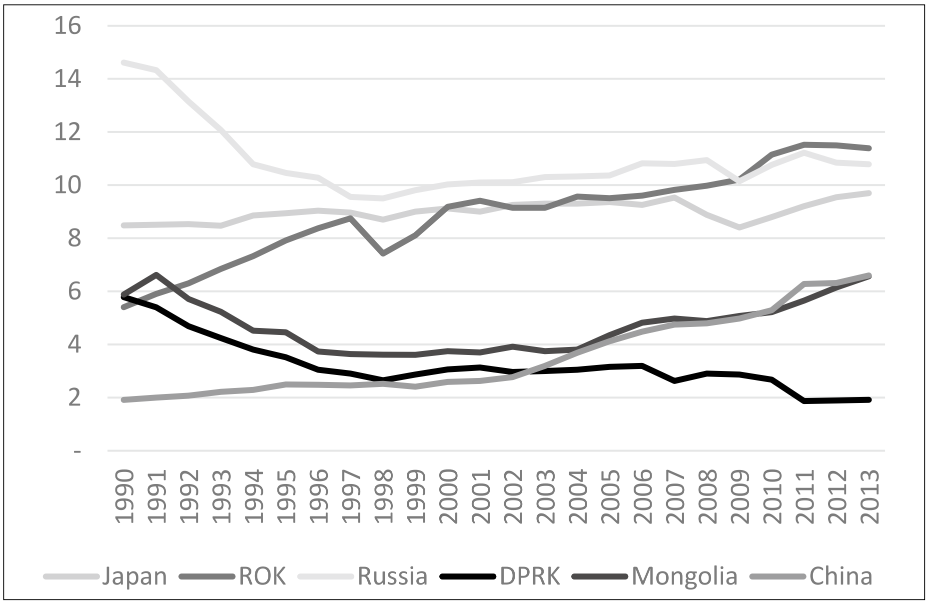
Since 1990, the energy-related CO_2 emissions per capita (Figure 19) decreased in Russia by 30%, in the DPRK by 60%, and increased in Japan by 15%, in the ROK by 100%, and in China by 250%, while in Mongolia they declined by 30% and then returned to the 1991 level.

Figure 18. Dynamics of GDP per Capita in Northeast Asia, GDP (PPP) International US$ per Capita



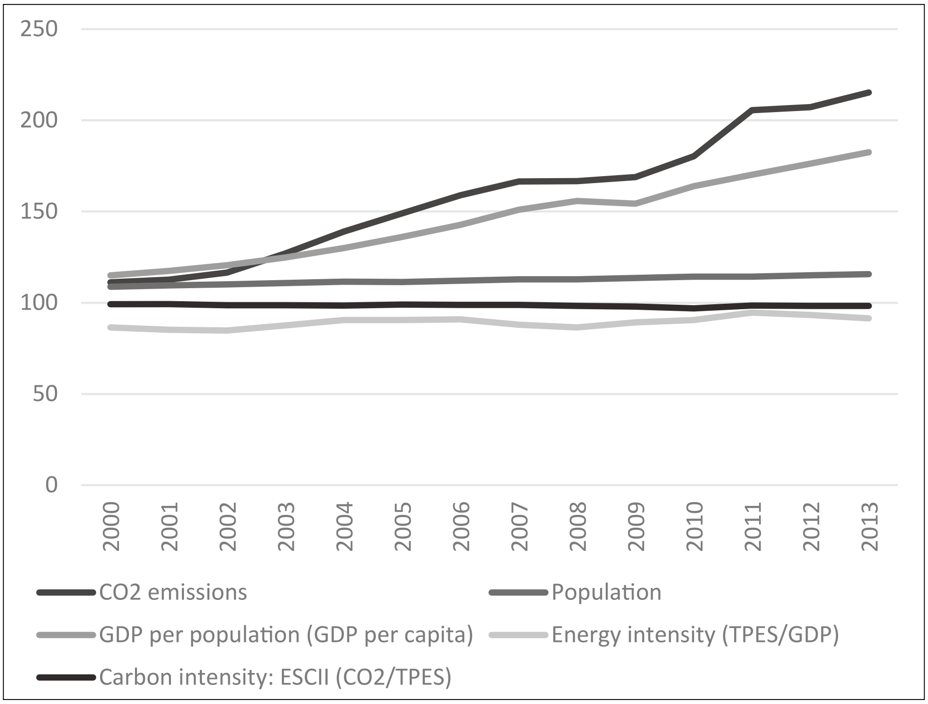
Source: IEA, 2015b

Figure 19. Energy-Related CO_2 emissions per Capita, tCO_2 per capita



Source: IEA, 2015b

Figure 20. Kaya Decomposition for Northeast Asian Economies as a Whole, 2000–2013 (1990 = 100%)



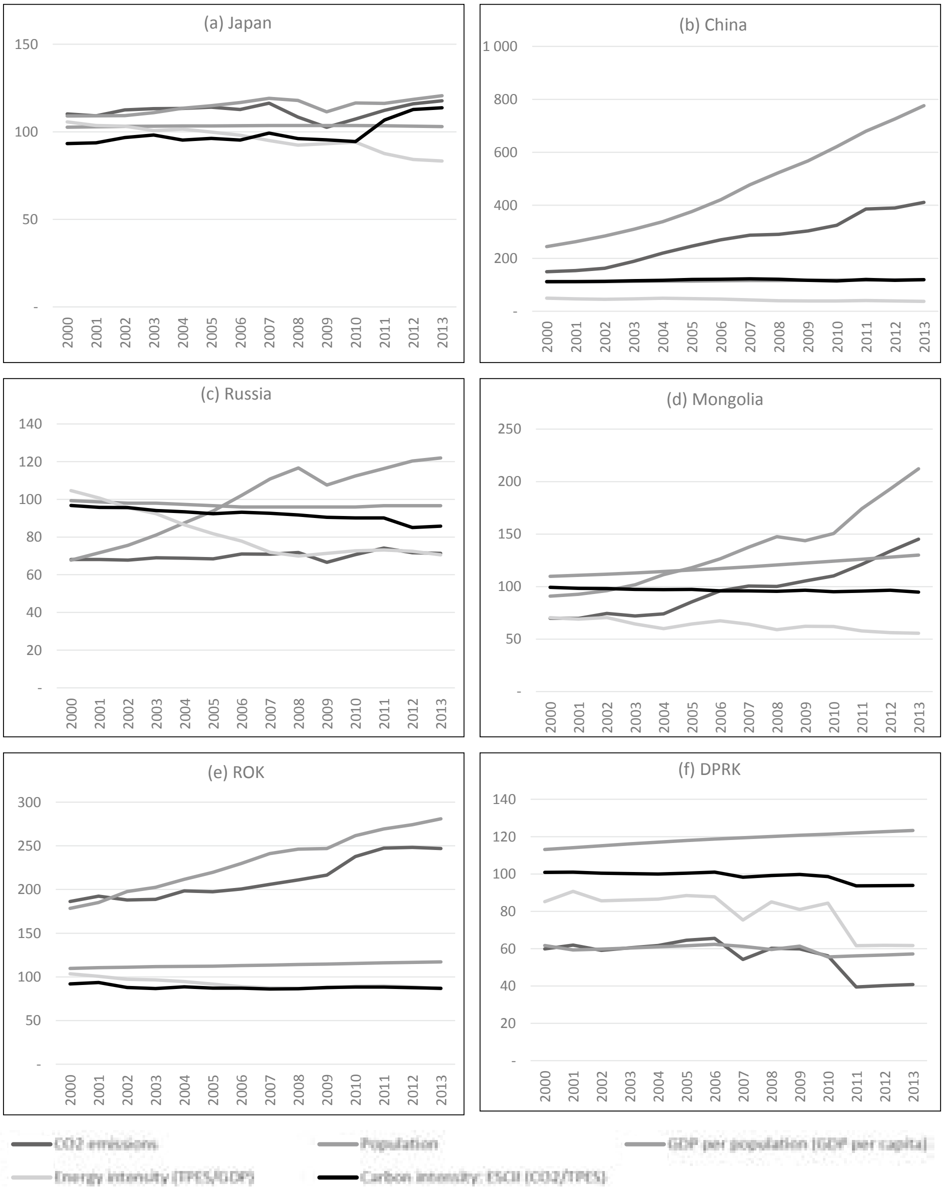
Source: IEA, 2015b

Analysis by Kaya decomposition[10] for the Northeast Asian region allows an identification of the most important drivers of CO_2 emission growth during the last 15 years (Figure 20). The growth of GDP per capita was the key driver of the CO_2 rise, while other factors, such as population growth, energy intensity and the carbon intensity of total primary energy supplies (TPES) were relatively stable and did not substantially affect the dynamics of CO_2 emissions.

However, if the individual country Kaya factor pathways are considered (Figures 21a–f), the importance of these drivers significantly changes: a significant energy intensity reduction was observed in Russia, Japan, Mongolia, and it dropped dramatically by approximately 30% in 2011 in the DPRK. The carbon intensity of TPES gradually declined by 30% in Russia, while in Japan it was relatively stable to 2011 and then increased by approximately 20%. The growth of population was a substantial driver for Mongolia and the DPRK.

[10] The Kaya identity was developed by Japanese energy economist Yoichi Kaya: the total emission level is expressed as the product of four inputs: human population, GDP per capita, energy intensity (per unit of GDP), and carbon intensity (emissions per unit of energy consumed). The Kaya identity plays a core role in the development of future emissions scenarios in the IPCC Reports on Emissions Scenarios.

Figures 21a–f. Kaya Decomposition of CO_2 Emission Drivers in Northeast Asian Economies, 2000–2013 (1990 = 100%)



Source: IEA, 2015b

Chapter 4. Climate-Friendly Growth in Northeast Asia: A mirage or a reality?

4.1. The deep decarbonization concept

Climate change poses global risks with dangerous impacts on economies, infrastructure, the environment, human health, local communities, and the standard of living of the populations. The 5th Assessment Report (IPCC, 2014b) provides a comprehensive review of such impacts as well as the long-term projections by country and region.

Although in the near term some countries may benefit from warmer weather or increased precipitation (e.g. growth of crop productivity), in the mid- and long-term perspectives all countries will lose. And the scale of the overall cost of a "no mitigation and adaptation" policy is up to 5–20% of global GDP per year by the end of this century (Stern, 2006).

The key driver of the dramatically increasing concentration of greenhouse gases in the atmosphere in the last 150 years is the hyperbolic growth in fossil fuel combustion (primarily, coal, oil, and gas) and associated anthropogenic CO_2 emissions, accounting for 1.4 trillion tonnes of CO_2 up to the present. In addition, rapid deforestation leads to both carbon emissions and the decline of carbon sinks, which is especially relevant in the case of tropical forests (50% of which have already been cleared).

Mostly due to these anthropogenic impacts, the CO_2 concentration has grown from 280 ppm in 1850 to over 400 ppm today. Recent measurements at Mauna Loa Observatory showed a record high CO_2 level of 409 ppm (April, 2016). The Earth has not had such a level of CO_2 concentration for the last 400,000 years at the least.

The global average temperature increased by 0.8°C compared to the pre-industrial level. But the regional distribution of warming is quite different. In Siberia and the Far East of Russia the temperature rose 2.5–3.5°C and above, while in Japan it rose 1.15°C (compared to 1900). Unfortunately, the projections for further changes are all pessimistic, with various "tragic" levels: in the "good" scenarios warming will reach 2–3°C, while in the "really bad" ones it exceeds 6°C by 2100 (IPCC, 2014b).

Precipitation will also change dramatically, in some regions by over 50%, so that the hydrologic regimes will never be as they usually were in most of the world regions: more drought and longer dry seasons in some areas, and heavier rains in others. The tragedy of this change can be illustrated as follows: with 2°C of warming 300 million people will suffer from a lack of drinking water, while with 3°C of warming over 3 billion people will face water shortages. In any case, the migration of millions of people may have severe consequences for the global economy and standards of living.

Taking the Northeast Asian region into consideration, the most important impacts of climate change include: drought with enhanced desertification and forest fires; sea level rise with the loss of sandy beaches and land; flooding with damage to infrastructure and residential areas; the spread of insects and diseases northwards (including encephalitis, malaria, and yellow fever); heat and cold waves affecting human health and killing livestock; and many others (IPCC, 2014b; S-8, 2014; Roshydromet, 2014). Some impacts have already been observed, such as the loss of approximately 9 million head of livestock from the cold wave in Mongolia in 2010 (Ikegami, 2016), over 44,000 deaths from the heat waves in Russia (Revich, 2010) and over 1,800 deaths in Japan in 2010 (MOE, 2012), and billions in US dollar terms in damage from the Amur River flooding in China and Russia in 2013, etc.

The new climate agreement, signed at the UNFCCC COP21, set a new global target: "to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels" (Art. 2, Paris Agreement). In order to reach this "climatic" goal, the global greenhouse gas (GHG) emissions should decrease no less than 50% from the current level by 2050 and reach a net-zero level (accounting for carbon sinks in forests and land use) in the second half of this century.

Ratification of the Paris Agreement by the United States and China (jointly responsible for 38% of global carbon emissions) in early September 2016 enabled the global treaty to come into force on 4 November 2016 and the world economy will move toward a low-carbon society. The faster the better for climate and human beings. The question is how?

The first attempt to model a "climate-friendly" world economy by 2050 was undertaken under the Deep Decarbonization Pathways Project, initiated by the UN Secretary General Ban Ki Moon and supported by the Sustainable Development Solution Network and over 30 research teams from 16 countries (those responsible for 75% of global CO_2 emissions).

The deep decarbonization concept assumes that global emissions should decline to a level sufficient to limit global average temperature growth by less than 2°C. In economic terms, it means that CO_2 emissions should decline to roughly 1.7 tCO_2 per capita by 2050 or so, and subsequently decline to almost a net-zero.

The "clean" future of the largest economies, including China, the United States, Japan, the EU, Russia, and some others, was modeled using advanced mathematical tools. Surprisingly, a lot of opportunities for decarbonization were found, and the costs were estimated to be in a range of 0.8–1.2% of GDP a year to deeply decarbonize these economies with a time horizon of 2050 (SDSN–IDDRI, 2015).[11] An important impact of cost reduction was identified, first of all, with the declining "learning" curves for key technologies (wind, solar, and electric vehicles, etc.) and an appropriate phasing-out of old and amortizing equipment (coal and gas power plants), being replaced by carbon-free alternatives.

4.2. Northeast Asian decarbonization: a view from the future

The projections of energy-related CO_2 emissions in Northeast Asian countries to 2050 (Table 7), based on modeling of the individual countries' deep decarbonization pathways, show that even with extensive efforts on the national level aimed at decarbonization of

[11] IDDRI and UN SDSN are jointly coordinating the innovative international project Deep Decarbonization Pathways Project (DDPP), which was launched in 2013 and involves 16 of the world's largest economies, including the United States, Japan, China, India, Russia, Germany, France, Britain, and Indonesia, etc. DDPP research teams study decarbonization in their own countries. Each national team defines its own pathways to a low carbon energy system that still provides all the energy services their society needs, taking into account current infrastructure, natural resources, and the stage of socioeconomic development. More can be found at http://deepdecarbonization.org/.

the economy, the overall emissions reduction may reach 50% by 2050. However, the dynamics of cumulative emissions will not allow a reduction of emissions below the 1990 level, and will not allow the following of a "below 2°C target" pathway.[12]

Table 7. Energy-Related CO_2 Emissions in 2010 and Projections for 2050, million tCO_2e

Country	1990[1)]	2010[1)]	2050	2050 / 2010, %	2050 / 1990, %
China[2)]	2,184	8,152	5,201	64%	238%
Russia[3)]	2,163	1,529	200	13%	9%
Japan[4)]	1,049	1,123	180	16%	17%
The ROK[3)]	232	560	82	15%	35%
The DPRK[5)]	117	66	*80*	121%	68%
Mongolia[5)]	13	14	*30*	214%	233%
TOTAL	**5,757**	**11,444**	**5,773**	**50%**	**100%**

Sources: [1)] IEA/OECD, 2015; [2)] Teng, 2015; [3)] SDSN–IDDRI, 2014; [4)] Kainuma, 2015; [5)] authors' estimates

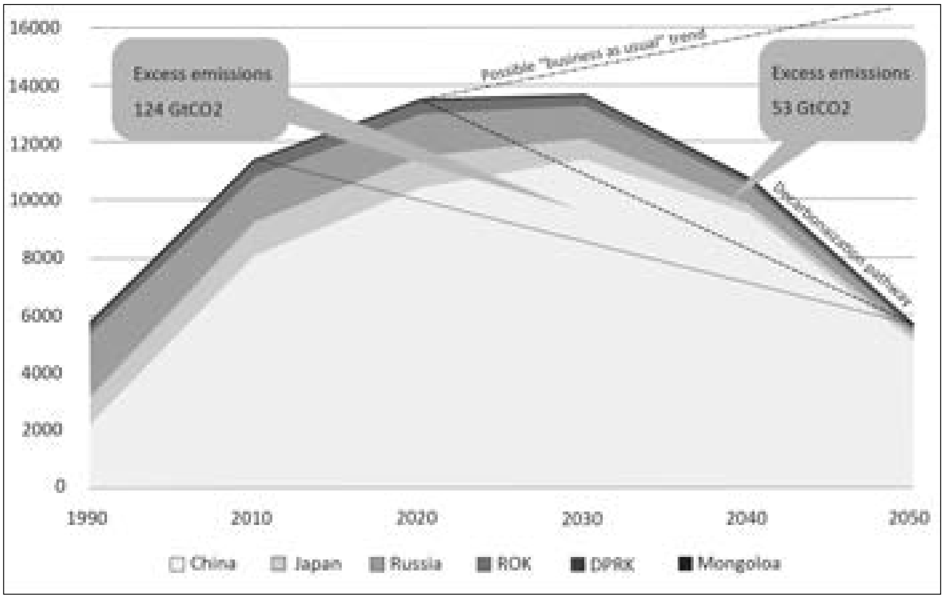
A delay with decarbonization actions will cost much in terms of excess carbon emissions. If the downward linear decline of emissions had started in 2010, it would reduce cumulative emissions by 124 billion tCO_2 from energy use compared to the deep decarbonization scenario, while the beginning of a linear decline in 2020 would reduce excess emissions by 53 billion tCO_2 by 2050 (Figure 22). The emission reductions would be much higher if the business as usual (BAU) scenarios were considered for comparison, because for many countries the BAU pathways would have an increasing or relatively stable level of emissions up to 2050, as would be the case for the ROK, Russia, China, the DPRK and Mongolia. Japan's nationally adopted target of an 80% reduction by 2050 (the base year is still to be determined) was adopted by the Fourth Basic Environment Plan, approved by the government on 27 April 2012 and reconfirmed in the forthcoming formal decisions, e.g., in its INDC submission to the UNFCCC in 2015.

An early start for mitigation actions in Northeast Asia would mean a great deal for the cumulative emission dynamics. As implementation of the Kyoto Protocol showed, the trend in emissions did not shift to a decline in the region in 2008–2012. The efforts of the other countries would definitely be "compensated" for by the growing emissions from the "carbon giant", China, but even without that, almost all the countries of the region demonstrated continuing growth of emissions to date (except the DPRK). Inertia in economic development is likely to force the countries toward carbon-intensive growth at least to 2030, increasing their risk of carbon lock-in, where the long-term investment in fossil-fuel-based assets will sustain high emission levels for the 40–50 year lifetime of

[12] To limit the global temperature rise by 2°C, the concentration of GHGs should be below 450 ppm CO_2 equivalent, which can be achieved by a GHG emission reduction of 41–72% by 2050 and 78–118% by 2100 below the 2010 level (IPCC, 2014). The "1.5°C target" would not be met even in this scenario as a much more ambitious reduction of cumulative carbon emissions would be required. The global "inspirational" target for 2050 first appeared as a political target in the G8 communique released at the L'Aquila summit, stating that G8 will collectively cut emissions by 80% below "1990 or more later years" by 2050, and that the world should be able to cut its emissions by 50% by 2050.

power plants, industries, and transport infrastructure, etc. This risk even has global implications, as the regional economies will likely contribute to a higher share of global carbon emissions to 2030 and beyond (up from the current 40%).

Figure 22. Dynamics of Cumulative Energy-Related CO_2 Emissions in Northeast Asia, $MtCO_2$



Source: Authors' estimates, based on SDSN–IDDRI, 2015

4.3. Different ambitions and opportunities: Country profiles

China

China's economy demonstrated unprecedented growth in the period 1990–2015: the annual real GDP has been increasing by approximately 10% on average, hitting record high levels of 10–14% per year in the early 1990s and mid-2000s. Industry (including construction) was a leading sector in annual growth in the early 1990s (23% growth in 1992), and compatible with the service sector in 1997–2013 (8–16% growth in real terms), and slowing down to around 7% in 2014–2016. Agriculture has been growing at about 3–4% per year on average (in real terms) since 1990. The slower growth rate of GDP (around 7%) is currently considered within the framework of the "New Normal" for China in the longer-term perspective.

Economic growth, the demographic situation, urbanization, the enhanced capacity of the fossil-fuel-fired energy sector, the transportation boom, industrialization, and other factors, substantially affected the national carbon-emission dynamics. In 2006, China became the world leader in energy-related CO_2 emissions (IEA/OECD, 2015), and now emits about 9 billion tCO_2 per year (28% of global CO_2 emissions).

According to China's INDC, its climate change mitigation policy includes the following main targets: to have GHG emissions peak by 2030; to reduce the carbon intensity of GDP by 60%–65% by 2030 compared to the 2005 level; to raise the share of non-fossil fuel primary energy (including nuclear, renewables, and hydro) to about 20% by 2030; and to increase its forest growing stock volume by 4.5 billion cubic meters by 2030 (China, 2015).

Deep decarbonization is considered as a huge challenge for the country, and may conflict with on-going development goals. China's CO_2 emissions per capita have gradually increased from 1.9 to 6.6 tCO_2 in the period 1990–2013 (IEA/OECD, 2015).

The deep decarbonization pathway was modeled with regard to the acceleration of economic structural evolution, the effective control of service demand, the promotion of low-carbon energy development (including natural gas and non-fossil fuels), and the deployment of low-carbon technologies such as carbon capture, utilization, and storage (CCUS), while maintaining economic growth (Teng, 2015).[13]

Primary energy consumption is expected to reach 4,610 Mtoe by 2040 (1.86 times the 2010 level) and stabilize at 4,358 Mtoe by 2050. The industry sector is projected to remain the largest end-use energy consumer over the whole period; its final energy consumption will increase by 39% by 2050 compared to 2010. Transportation and buildings will experience rapid growth in energy demand, with final energy consumption in 2050 increasing by 130% and 92%, respectively, from 2010 levels.

Energy sector. In the deep decarbonization scenario, electricity will gradually become a major energy source with a tripling of electricity consumption to 11,772 TWh by 2050, and the electrification rate reaching 34% in 2050. The electrification rate should rise from 18% in 2010 to 34% in 2050. Non-fossil fuel electricity will predominate due to the continued rapid growth of wind and solar, and the steady growth of nuclear and hydropower. Such targets correspond to the national commitments to reach 15% and 20% in primary energy consumption in 2020 and 2030, respectively, with further acceleration after 2030.

Coal use is projected to reach a maximum of approximately 4.1 billion tonnes around 2020 and to stabilize by 2030, with a further decrease afterwards. The share of non-fossil fuel power in total power generation will rise from 20% in 2010 to 34% in 2020, 43% in 2030, and 72% in 2050. The installed hydropower capacity is projected to reach 500 GW; nuclear capacity is expected to grow to 320 GW; wind power capacity could reach 1,200 GW; and solar power capacity over 1,200 GW in 2050. The use of CCUS technologies is very important for China: about 75% of coal-fired power plants' capacity will be subject to them, and the annual storage of CO_2 should reach 1.8 $GtCO_2$.

Other sectors. Industrial emissions should decrease by 52% below the 2010 level by 2050, but this sector will remain the largest source of emissions (53% of the total). Emissions from the transportation sector will increase by 67% over the period 2010 to 2050, although electrical and fuel-cell vehicles are expected to be commercialized by 2030 and account for 60% of the passenger car fleet in China in 2050, with electricity consumption in transport growing 20-fold by 2050. Emissions in the building sector will decrease by 30% by 2050.

The scenarios analyzed show that transformation toward the deep decarbonization of the national economy is feasible and its goals can be aligned with development priorities, such as: 1) the reduction of national energy consumption; 2) the improvement of the

[13] The source of the deep decarbonization modeling results in this section is the DDPP project (SDSN–IDDRI, 2014; Teng, et al., 2015).

energy structure; 3) limiting coal consumption and advanced control of its use; 4) the increase of natural gas and non-fossil fuel energy sources to 35% of TPES; 5) stabilizing production of energy-intensive products after 2020; 6) improved energy efficiency, and more efficient and cleaner industrial production; and 7) high energy-saving standards for new buildings and for public consumption .

In the deep decarbonization scenario, China's energy-related CO_2 emissions will increase to a peak level of 11.5 $GtCO_2$ by 2030 with a gradual decline to 5.2 $GtCO_2$ by 2050 (37% below the 2010 level). Although this is a very ambitious scenario, it does not lead to a 50% emission reduction from the 1990 level which is consistent with the "2°C target".

Japan

Since 1990, the Japanese economy has been demonstrating a moderate rate of GDP growth: approximately 1% per year on average. By 2015 national GDP had increased by 25% from the 1990 level. At the same time, the total primary energy supply increased by only 3.5%, while energy-related CO_2 emissions increased by 18%, and total national GHG emissions grew by 7%.[14]

The energy and climate change mitigation policy in the country were severely affected by the Great East Japan Earthquake in 2011, the fourth most powerful earthquake in the world since 1900. The subsequent tsunami caused accidents at three reactors in the Fukushima Daiichi Nuclear Power Plant complex. The World Bank estimated the economic losses to be as much as US$235 billion. Japan's long-term energy plans were revised, as the previous plan of 2010 assumed expansion of nuclear power via the building of 14 new plants by 2030.

The revised Strategic Energy Plan in Japan published in 2014 (METI, 2014), which corresponds to the Fourth Basic Environment Plan, aims at the reduction of GHG emissions by 80% up to 2050. Japan's contribution for the Paris Agreement was published in July 2015 and set a long-term target of 26% below the 2013 level by 2030 (Japan INDC, 2015).

Japan's GHG emission target of 80% below the 1990 level by 2050 can be interpreted as a level of energy-related CO_2 emissions of 2.1 tCO_2 per capita in 2050 (a 75% reduction from the current level of 8.8 tCO_2 per capita) and mostly corresponds to the deep decarbonization goal (Kainuma, 2015).

Three main scenarios of deep decarbonization for Japan were analyzed (based on the assumption of continued economic growth):

1) Mixed Scenario: decarbonization via strong action on the large-scale reduction of energy demand through deployment of various energy-efficiency measures; a 97% reduction in the carbon intensity of electricity through the large-scale deployment of CCS and renewables; and extensive diffusion of low-carbon electricity in end-uses, reaching 45% of final energy. This scenario considers a partial phase-out of nuclear power under the assumption that all plants are operated for no more than 40–50 years, translating to a share of nuclear power in electricity generation of 19% in 2030 and 5% in 2050.

[14] The source of the deep decarbonization modeling results in this section is the DDPP project (SDSN–IDDRI, 2014; Kainuma, et al., 2015).

2) No Nuclear Scenario: decarbonization under a complete phase-out of nuclear power, following the assumption that no nuclear plant is restarted after 2014.

3) Limited CCS Scenario: due to uncertainties regarding the scale of CCS technologies, this scenario considers other options for decarbonization than extensive CCS use (50% less than in the Mixed Scenario).

In all scenarios, energy-related CO_2 emissions will decrease by 84% below the 2010 level by 2050, so that the 80% GHG emissions reduction target in 2050 can be achieved.

Energy sector. Fossil fuel use can be reduced substantially via a combination of a strong reduction of energy demand and a deployment of non-fossil fuel energy supplies, primarily renewable energy sources. In the decarbonization scenarios, fossil fuel consumption falls by about 60% below the 2010 level by 2050.

The structure of energy supply varies significantly across the scenarios. The share of renewable energy (including hydropower) in primary energy significantly increases, but the magnitude depends on the scenario considered. Renewables account for up to 35% of the total primary energy supply in 2050 in the Mixed and No-Nuclear Scenarios, and significantly more in the Limited CCS Scenario (49%).

Natural gas and oil will remain mainly in the industry and freight transport sectors, while coal should be almost fully phased out in 2050 via a switch to renewables and natural gas. The role of nuclear power is significantly reduced in the Mixed Scenario and the Limited CCS Scenario, whereas renewable energy (including hydropower) will increase over the mid to long term, reaching approximately 59% and 85%, respectively, of total electricity generation.

The scenario of large-scale deployment of solar PV and wind power was considered in the No-Nuclear Scenario, where natural gas and renewables play an increasingly important role in the absence of nuclear power, especially in the mid-term. The share of electricity generation from natural gas with CCS rises after 2030 and reaches about one-third of total electricity generation in 2050 in the Mixed Scenario and the No-Nuclear Scenario. The LNG power plants without CCS act as a bridge technology in all scenarios. Electricity generation from coal without CCS is entirely phased out by 2050 because of its high carbon intensity. Due to large-scale deployment of renewable energy and/or natural gas equipped with CCS, the carbon intensity of electricity falls to nearly zero in 2050 in all scenarios.

Buildings/construction. In the buildings sector, energy consumption should decrease substantially, with final energy demand being reduced by 60–70% below the 2010 level in 2050. Due to electrification and electricity decarbonization, CO_2 emissions in the buildings sector (both residential and commercial) can become almost zero in 2050.

Transport. In the transport sector, CO_2 emissions should decline by 82% below the 2010 level in 2050. This can be reached via a 10% decrease of overall passenger mobility as a result of a decrease in population, a 28% increase in total freight mobility and a 22% decoupling of freight transport and GDP. A major driver of this drop in emissions is the 69% reduction of energy demand in aggregate for transport resulting from the diffusion of efficient vehicles leading to 77% and 63% less energy content in passenger and freight transport, respectively. These efficiency gains are associated with the switch from fossil fuels to electricity and hydrogen. Electrification plays an important role, and electricity accounts for about half of the total final energy consumption in the passenger transport sector. In freight transport, electrification in 2050 will be relatively moderate because in this study it is not assumed that heavy road haulage will adopt electric vehicles (EVs). However, demand for liquid fossil fuels falls substantially thanks to improvements in fuel economy and a switch to hydrogen and natural gas.

Industry. The industrial sector is by far the largest source of residual emissions in 2050, representing almost 60% of energy-related emissions at that time. This can be explained by fuel demand for high-temperature heat being hard to replace using low-carbon sources. Energy consumption in 2050 can decrease by 35% compared with the 2010 level despite GDP growth, thanks to the deployment of energy-efficiency measures. However, the improvement of energy efficiency is relatively moderate compared with other sectors, since industrial processes are already efficient in Japan and energy-intensive heavy industry maintains a substantial share of total industry in 2050.

Investment costs and savings. From 2025 to 2030, annual average investment reaches approximately 4 trillion yen, or about 0.5%–0.7% of GDP in 2030, with marginal benefits in terms of energy savings in all three scenarios. However, on a longer time horizon, the increase of investment to 6 trillion yen is paid back in full by the energy savings, leading to zero or negative costs in the Mixed Scenario between 2045 and 2050. The aggregate result of very low or even negative energy system cost is valid in the three scenarios. In the Limited CCS Scenario, average investments increase compared with the Mixed Scenario due to the additional deployment of renewable energies in the long term, but energy savings are also significantly higher because of lower costs for fossil fuel imports. All deep decarbonization scenarios showed a very modest decrease in the average growth rate, leading to an average growth rate of around 0.93% per annum from 2010 to 2050.

Mongolia

During the period 1990–2015 the Mongolian economy experienced substantial fluctuations in its annual GDP growth: from an 8–9% decline in the early 1990s to growth of 1.2% to 10.6% in 1995–2008, a sharp drop in 2009 to −1.2%, and an unprecedented surge of 17.3% in 2011 followed by a subsequent slowdown to 2.3% in 2015. The structure of the national economy has changed significantly over this period and is deeply dependent on international commodity markets, specifically those for coal and metals which provide a huge proportion of national income: natural resource rents reached 59.3% of GDP in the record high year of 2011 (World Bank, 2016).

The country struggled to solve its development and economic challenges during the transition period which started in the early 1990s. Despite the initial recessions and gradual recovery of the economy, the country was able to achieve a degree of progress in a wide range of issues. For instance, life expectancy at birth increased from 60.3 years in 1990 to 69.5 years in 2015. The population increased by 36% from 2.18 million in 1990 to 2.96 million in 2015. Nominal GDP increased 4.2-fold from US$2.8 billion in 1990 to US$11.8 billion in 2015. Gross national income per capita went up 2.7-fold from US$1,430 in 1990 to US$3,830 in 2015. The poverty rate declined from 38% of the population in 2010 to 21% in 2014 (World Bank, 2016).

Currently, the Mongolian economy is facing strong external shocks (deep price drops on the international markets for coal, metals, and minerals), a very high external debt (since 2005 public and private debt has grown exponentially to US$20 billion or 175% of GDP), and the effects of the slowing down of Chinese economic growth and of the decline in the Russian economy.

The energy sector is experiencing substantial transformation, and the total primary energy supply increased from 3.4 Mtoe in 1990 to 5.2 Mtoe in 2013. Coal is the main source for energy supply in Mongolia. Total energy-related CO_2 emissions reached 18.7 $MtCO_2$ in 2013. The power and heat sector is a predominant source of carbon emissions at 11 $MtCO_2$ per year, while the manufacturing, transport, and residential sectors each account for approximately 2 $MtCO_2$ per annum (as of 2013). However, the share of renewable sources in electricity production is increasing and renewables accounted for 3.1% of the total in 2015, with wind energy accounting for 72% of total renewable energy generation (ERC, 2015).

The expectations for future development are affected by the current economic downturn and lack of positive signs of recovery on the international commodity markets. However, World Bank projections show expected GDP growth of 2.7% in 2017 and 6.3% in 2018. Further economic growth can be leveraged on the country's abundant natural resource base: the country has huge reserves of coal, copper, gold, iron ore, lead, molybdenum, uranium, and other minerals. The main coal deposits are located in Sharyn Gol (about 70 billion tonnes) and Tavan Tolgoi (about 10 billion tonnes).

Currently, the economic development perspectives are closely linked with the expansion of mineral resource extraction and exports. Extractive exports reached 89.2% of total exports in Mongolia in the boom year of 2011 and fell to 78.8% of the total in 2015 (NSO, 2015). However, the sustainability of Mongolia's further economic growth will also depend on how effectively Mongolia spends its mineral revenues to diversify its economic base from the current mineral-based economy.

Long-term projections for carbon emissions were made at the Second National Communication (MNET, 2010). GHG emissions are expected to rise in industry (4.3 times in 2020 and 7 times in 2030 compared to the 2006 level), in the residential sector (1.8 times by 2020 and 2.6 times by 2030 compared to 2006), as well as in transport (2.5 times by 2020 and 4.9 times by 2030), especially if the large-scale mining projects, such as Oyu Tolgoi and Tavan Tolgoi were to expand.

Overall energy-related GHG emissions were expected to increase from about 5 $MtCO_2$ in 2010 to 17.5 $MtCO_2$ in 2030. Transport was projected to be predominant (approximately 45% of total GHG emissions from energy use), industry and households being responsible for approximately 20% each, and about 5% for commercial and agricultural sources. The aggregated GHG emissions were projected to grow from 20 to 51 $MtCO_2e$ during 2010–2030, with an average annual growth rate of about 9% (MNET, 2010).

These estimates are currently considered as excessively "optimistic", as economic development has not been going as fast and sustainable as it was assumed in 2006. Moreover, the dependence on external markets for minerals and other raw materials will likely continue limiting economic growth and energy consumption in Mongolia, while the trend for using more advanced technologies (e.g. solar PV, hydropower, and expansion of hybrid vehicles, etc.), as currently observed, may help to support the decoupling of GDP growth and carbon emissions.

A "decarbonization scenario" is possible for Mongolia, although it is hard to expect fast progress in this direction without international cooperation projects. As an example, the

Gobitec project, with a potential of 100–120 GW of installed capacity for wind and solar power generation in the southern part of the Gobi Desert, is considered a large-scale initiative, which can fully satisfy the energy needs of the country and provide huge revenues from "green" energy exports to Northeast Asian countries. To that end, the Asian Super Grid project, linking Mongolia, China, the ROK, and Japan with a highly efficient electricity network has been proposed and extensively discussed in recent years.

There is an alternative to such "green" energy development, however. Local businesses are highly interested in developing Mongolia's coal reserves, and propose large-scale coal projects with the installation of over 100-GW coal-fired power plants near the border with China to export electricity, while keeping carbon emissions accounted for domestically. Certainly, such a development pathway would undermine the decarbonization prospects in both Mongolia and China, as it will dramatically increase overall CO_2 emissions.

When planning energy projects in Mongolia, it is of utmost importance to undertake an environmental impact assessment, as should be the case for coal-fired power plants, or the hydropower projects that may affect Lake Baikal to the north of the country. In many cases, economic development projects may support both adaptation and mitigation in the Mongolian regions (aimags), as it could be the case for adaptation in western Mongolia which suffers from negative climate change impacts and lacks water resources. Similar challenges are faced by the southern, central, and eastern parts of the country.

We consider the decarbonization scenario of reducing CO_2 emissions per capita from the current 6.6 tCO_2 per capita toward 1.7–2.0 tCO_2 per capita as fairly realistic. But it is understandable that such a scenario can only be achieved with external and international support for implementing investment projects in the energy, industry, transport, agriculture, forestry, and other sectors.

Russia

Russia is the biggest country in the world by land area, occupying 1.6 billion hectares. It has the largest forested area in the world, covering 871 million hectares (51% of the country's territory) or 20.1% of the global forested area. By share of global timber reserves, Russia is second behind Brazil, with 81.5 billion cubic meters (approximately one-quarter of global reserves). Its agricultural area is 220.6 million hectares (10% of global arable land).

Since 1990, the national GHG emissions (excluding land use and forestry) declined by 29%: from 3,940 $MtCO_2e$ in 1990 to 2,812 $MtCO_2e$ in 2014, primarily due to the deep restructuring of the Russian economy after the crisis in the 1990s, structural and technological changes in industrial production (a decline in the military sector, heavy industries, and modernization of the technological base), and the growth of low-carbon sectors (services rose from nearly 20% to over 50%).

Fossil fuels extraction, transportation, and consumption constitute the leading source of GHG emissions in the country. In 2014, GHG emissions from the energy sector amounted to 2,355 $MtCO_2e$ (84% of total GHG emissions), including fuel combustion (51%) and fugitive methane emissions (33%). CO_2 emissions are predominant in total GHG emissions, reaching 59.5% in 2014. The land use and forestry sector is very important for the country. Carbon sequestration in the LULUCF sector reached 513 $MtCO_2$ of net-removals in 2014.

The economic modeling of Russia's CO_2 emissions was carried out for power and heat production, industries (metallurgy, cement, chemical and petrochemical), residential and commercial buildings, and transportation.[15]

The targeted emission level for the decarbonization scenarios was set at 1.7 tonnes of CO_2 per capita by 2050 (84% below the average level of 10.8 tCO_2 per capita in 2010–2013). The analysis was based on the RU-TIMES model developed by a research team from RANEPA and the Higher School of Economics.

The main decarbonization scenario showed a sharp decline of energy-related CO_2 emissions from 1,422 $MtCO_2$ in 2010 to 200 $MtCO_2$ in 2050. Reaching this goal will require a decline of the TPES by 27% during 2010–2050, while the structure of energy production will substantially change: coal use must drop down to 3% of the TPES (half of it with CCS); natural gas should reach 36% of the TPES (half of it with CCS); petroleum should decline to 7%; while the share of renewables should rise to 33% and nuclear to 22%.

Final energy consumption (FEC) declines from 20 EJ in 2010 to 15 EJ in 2050, and should also be transformed substantially: coal use decreases to 2%; gas to 23%; and liquid fuel (including biofuels) will be 17% of the FEC. The share of renewables other than large-scale hydropower in the energy balance must rise to 10% in 2050 from practically 0% in 2010.

The electric power sector is key to the decarbonization of the Russian economy. The Russian electric power sector has 700 heat and power plants (mostly combined). The total installed capacity accounts for about 255 GW, of which zero-emission capacities include 46 GW of hydropower and 23 GW from nuclear power plants. However, only approximately 150 GW of that capacity is used at peak demand.

The envisaged retirement of the majority of natural gas and coal-fired power plants and boiler houses (70% of which are over 40 years old) in the coming decades constitutes a huge challenge for industry, as well as a unique opportunity. Modernization based on the up-to-date highly-efficient technologies, primarily with carbon-free options, would not only improve energy efficiency, but substantially reduce GHG emissions in the sector in the long-term perspective. Otherwise Russia may fall into the carbon lock-in situation, when the newly installed fossil fuel-based energy facilities would have to operate for 40–50 years, sustaining industry's high carbon footprint.

A range of long-term development options are envisaged to decarbonize the domestic power sector, including a possible increase of nuclear and large-scale hydropower (planned by the "Rosatom" and "RusHydro" corporations, but lacking investment resources currently) as well as a growth of renewables' share in the energy mix. The analysis showed that growth of renewables can primarily be made in wind and solar PV, while small-scale hydropower, tidal, and geothermal power may play a more modest role in the overall national energy mix (although being very important for local energy supplies).

Based on the IEA prospective technologies' review (IEA, 2014), it is assumed that CCS

[15] The source of deep decarbonization modeling results in this section is the DDPP project (SDSN–IDDRI, 2014, Russia Chapter by O. Lugovoy, RANEPA, G. Safonov, HSE, V. Potashnikov, RANEPA, ,and V. Gordeev, RANEPA).

can be commercially feasible and applicable in the power sector beyond 2030. Most of the fossil fuel-fired power plants will use CCS technology by 2050 to reach the deep decarbonization target in Russia.

Industry. The output of energy intensive industries is expected to grow significantly over the next four decades, by 26% for iron and steel production (from 66 Mt to 83 Mt), by 41% for cement (from 49 Mt to 69 Mt), and by 10% for others. Improvements in iron and steel production can lead to 33% or more in energy efficiency improvement, mainly due to the adoption of blast-furnace gas-recycling technologies to directly reduce iron with natural gas.

The processes of other energy-intensive industries are very diverse, and a moderate decarbonization potential for the remaining industries is considered, mainly by means of electrification of the industries and growth of energy efficiency.

Buildings/construction. The commercial and residential housing sector has enormous potential for energy efficiency improvement in Russia. Seventy-five percent of the heating supply is provided by centralized heat pipeline networks, 70–80% of which are currently fully amortized. The decarbonization scenario assumes a 30% growth in living space area per capita by 2050 (to approach the EU average living space). The decline in population by 2050 will be an important factor in this sector. The energy consumption of buildings is assumed to decline to at least a sixth, while the energy mix should change in favor of biomass, electrification, and extensive use of heat pumps.

Transport. The low-carbon technology options for transport include liquefied petroleum gas (LPG) engines in the mid-term and increasing biofuel use in the long term. Electric vehicles are experiencing a much slower expansion in Russian regions with cold conditions, although may get a boost if the technology improves. Plug-in hybrids with internal combustion engines using LPG or biofuel may be more competitive. Aviation can benefit from biofuel use and energy efficiency improvement. The domestic innovative technologies for production of second generation liquid biofuels are available, but still not commercialized. Freight transportation is expected to rise by 80% by 2050, and could be decarbonized using liquefied gas in the medium term and biofuels in the long term, as well as hybrid and electric engines. The largest GHG emitter in this sector is pipeline transport, due to technological energy consumption and fugitive methane emissions.

Forestry and land use. This sector is assumed to play an important role in the Russian decarbonization strategy. Currently, the net removal of CO_2 is approximately 500–600 $MtCO_2$, however due to the over-maturing of forests, increased timber harvesting, forest fires, and disease, CO_2 removal is expected to decline to 100 $MtCO_2$ in the 2040s. Therefore urgent forest management and adaptation policies and measures are required to maintain the carbon sequestration capacity of Russia's forests.

The ROK

The ROK's economic development has demonstrated outstanding results in the last three decades. The country transitioned from a very poor to a high-income ranked member of the OECD and G20. It still remains a fast growing economy. With no endowment of natural resources and a small land area, the ROK effectively implemented an export-oriented strategy for its economic development and became the world's seventh largest exporter.

The structure of the ROK economy consists of: agriculture, 2.6%; industry, 39.2%; and services, 58.2% (as of 2010). The ROK economy is heavily dependent on fossil fuels (85% of the TPES[16]). Ninety-seven percent of fossil fuels are imported into the country. Nuclear energy accounts for 13% of the total primary energy supply (as of 2010).

The ROK demonstrated substantial and fast growth of GHG emissions: from 260 to 637 $MtCO_2e$ during the period 1990–2012 (including LULUCF), which constitutes a 2.5-fold increase. In 2012 the GHG emissions from fuel combustion reached 600 $MtCO_2e$ (87% of total emissions, excluding LULUCF). The net carbon sequestration in forestry and land use amounted to 50 $MtCO_2e$ in 2012. Power generation and industry have been the main sources of energy-related carbon emissions.

The country launched a number of policy initiatives aimed at green economy development and climate change mitigation. In 2008 the ROK government launched the National Strategy for Green Growth (2009–2050), supported by the first 5-Year Plan for Green Growth (2009–2013). These long-term plans have three main objectives: 1) climate change mitigation and enhancing energy independence; 2) enhancing new incentives for economic growth via investments in green technologies and industries; 3) and improving environmental performance and "greening" of transport, lifestyles, and expanding the modern service sector to 2050. The subsequent second 5-Year Plan for Green Growth (2014–2018) focused on specific GHG emission reduction measures, a sustainable energy system, and adaptation to climate change.

The Framework Act on Low Carbon Green Growth (April 2010) set the national voluntary target of reducing GHG emissions by 30% below the BAU level by 2020. In July 2011 the government finalized sectoral and annual emission targets. In 2012, the ROK adopted the Act on the Allocation and Trading of Greenhouse Gas Permits and launched the GHG and Energy Target Management System (TMS) for selected sectors. In January 2014 the National Greenhouse Gas Emissions Reduction National Roadmap was announced, followed by the launch of a nationwide Emission Trading Scheme in 2015, which covered 525 business entities (68% of national GHG emissions).

The ROK's INDC provided a national target of reducing GHG emissions by 37% below the BAU level by 2030 (536 $MtCO_2e$, 106% above the 1990 level). In the longer term perspective, the ROK considers this 2030 target to be consistent with the global target of 40–70% emissions reduction by 2050 (Republic of Korea, 2015).

Analysis of the decarbonization pathways was based on the following main assumptions.[17] With the global target of 1.7 tCO_2 per capita in 2050, the illustrated decarbonization pathway for the ROK economy requires an 85.4% reduction of energy-related CO_2 emissions from 560 $MtCO_2$ in 2010 to 82 $MtCO_2$ in 2050.

Energy sector. It was found possible for a drastic decrease of energy consumption (−37.2% in final energy consumption) via the wide-scale improvements in energy efficiency and changes in the fuel mix: oil and coal use must be almost completely phased-out over the period. Other measures require an increase of the electrification rate of final use to 60.7% in 2050 (about 20% in 2010), a significant reduction of the carbon

[16] TPES stands for "total primary energy supply".

[17] The source of the deep decarbonization analysis results in this section is the DDPP project (SDSN–IDDRI, 2014; ROK Chapter by Young Soogil, et al.)

intensity of electricity generation (from 531 to 41g CO_2/kWh), extensive use of carbon capture and storage (CCS) technologies, wind, solar PV and other renewables, as well as nuclear power. Only in such a case can the carbon intensity of electricity be reduced from 531 to 41g CO_2/kWh. The scale of the introduction of renewables is to be huge: wind should provide 14% of total power generation (a 51-GW capacity is needed) and solar PV 31% (193 GW). The rest of the energy can be covered by nuclear energy (about 47 GW). The deployment of renewable energy requires a shift to a large-scale distributed renewable electricity system, which raises the issue of network balancing, the availability of backup facilities and energy storage.

Structural shifts. Low-carbon economic development will likely affect the structural changes in industrial sub-sectors: the share of metal industries may increase, while the share of cement, petrochemical, iron and steel and other heavy industries may decrease.

Manufacturing is to be almost fully decarbonized by 2050 (16.4 $MtcCO_2$) via efficiency improvements resulting in a 3–6-fold decrease of the energy intensity in light and heavy industries; a substitution of 20% of fossil fuels in the distributed combined heat and power (CHP) in heavy industries; a 30% deployment of CHP to fuel light industries, and an increase to 28% and 72% of the shares of electricity in light and heavy industries, respectively.

Buildings: diffused LED lighting (100% of all lighting by 2050), new technologies with a higher efficiency in heating and cooling, the substitution of fossil fuels in the distributed CHP primarily with biomass, and renewable energy use are needed.

Transport: efficiency improvement in fossil fuel vehicles, biofuel deployment, deep electrification of the car fleet (80% of the stock), a 70% substitution of passenger cars by public transport, and a 78% substitution of road freight by rail freight are needed.

The alternative scenarios for decarbonization are focused on the deployment of CCS technologies, e.g. the introduction of CCS for 76% of coal power generation by 2050, and renewables and nuclear power for the remainder. In addition, a pathway based mainly on nuclear power was identified, requiring an 84 GW nuclear power installation by 2050, 29 GW of wind power and 14 GW of solar PV.

The DPRK

The structure of the DPRK economy is characterized as follows (as of 2008): agriculture, forestry, and fisheries, 22%; mining, manufacturing, electricity, gas and water, 38%; construction, 8%; and services, 32%. The long-term projections for the DPRK's economic development are very limited, and it would be unlikely for them to be considered reliable. The biggest uncertainty lies with the future of the regime of sanctions imposed on the country, and the Koreas' possible integration process.

The country has huge untapped potential: an abundant and competitive labor force; and large potential deposits of minerals, including zinc, copper, nickel, magnesite, coal, uranium and iron ore, with an estimated total value of about 140 times the DPRK's GDP in 2008 (Goldman Sachs, 2009). Consequently there is potential for the capitalization of these resources and enhancing economic growth in the long-term perspective, including the expansion of the mineral extraction and processing industries, energy generation, transport, and the services sector, etc.

Table 8. The General Assumptions for Decarbonization Scenarios in the DPRK

	Recent Year	2050	2050/2010
Population (million people)[1)]	25.2 (as of 2010)	26.9	107%
Real GDP per Capita (2010 US$ per capita)	1,067 (as of 2008)[2)]	N/A (Could potentially rise 5-6 fold)[4)]	-
Share of Rural Population	40% (as of 2008)[2)]	N/A (could decline to 10–20%, comparable to the ROK) [4)]	-
Share of Service Sector in GDP	32% (as of 2008)[2)]	N/A (could rise to 40–60%, comparable to the ROK) [4)]	-
Energy-related CO_2 emissions, $MtCO_2$	48 (as of 2013)[3)]	N/A (could reach 60–80 $MtCO_2$ in the case of rapid growth) [4)]	-

Sources: [1)] UN, 2015; [2)] Goldman Sachs, 2009; [3)] IEA, 2015b; [4)] authors' estimates

The national GHG emissions declined from 207.5 to 81.9 $MtCO_2e$ in 1990–2000, which demonstrates an unprecedented 61% reduction (the DPRK's National Inventory Report to the UNFCCC). At the same time, energy-related CO_2 emissions declined from 117 to 70 $MtCO_2$ in this period, and continued to drop to 48 $MtCO_2$ in 2013 (EIA, 2015). We would estimate the current GHG emissions to be as much as 58–60 $MtCO_2e$, or approximately 75% below the 1990 level, which means that the country has already deeply decarbonized its economy, although at the cost of scarring its economic growth.

The official projections to 2020 show that the total national GHG emissions will rise to 121.2 $MtCO_2e$, which is 37.4% below the 1990 level, but 84.4% above the 2000 level (DPRK, 2012). By 2020, the energy sector will continue to be the largest emission source, accounting for 89% of national GHG emissions.

The GHG emission reduction potential is estimated to be as much as 35.7 $MtCO_2e$ per year by 2020. The GHG mitigation strategies, policies and measures which can support the decarbonization processes in the medium and long turn, include:

- *Energy supply:* technical modernization of existing energy facilities, and development and utilization of renewable energy resources.
- *Transport:* modernization and improvement of transport management systems, and introduction of heavy rail and modernization of railways; heavy-duty and high-speed roads; public transport; walking and bicycle use.
- *Buildings/construction:* improvement of energy efficiency; efficient lighting; saving of residential fuel; solar heating and hot water supply; geothermal energy for heating and cooling; improvement of the heat insulation of buildings; and energy efficiency standards.
- *Industries:* clean production and improvement of energy efficiency; energy saving; and modern production technologies.
- *Agriculture:* naturally flowing irrigation systems; mechanization in rural households; advanced farming methods; and effective use of fertilizer and irrigation.
- *Waste management:* integrated solid waste management; composting of organic waste; recycling of waste; and controlled waste-water treatment.
- *Forestry:* conservation and management. CO_2 removal by forest sinks can reach 32.4 $MtCO_2e$ in 2020 with a projected annual average growth rate of 2.7%.

The DPRK has experience in developing CDM projects: six projects were registered and more were considered for validation and further implementation. Such mitigation projects and climate change adaptation projects are considered as not subject to sanctions, and potentially can generate hard currency income for the country, in addition to "green" technology supplies, and the environmental and socio-economic benefits associated with such projects.

If all the available emission reduction potential were utilized, and economic growth were realized in the forthcoming decades, we would estimate that energy-related emissions will reach a maximum of 60–80 $MtCO_2$ by 2050(Table 8).

Chapter 5. More Can Be Done Together

5.1. Regional cooperation options: “Duty” vs “clean” development

The current economic development strategies and programs in the Northeast Asian region overwhelmingly include plans for expanding traditional energy systems, based on fossil fuel extraction, transportation, and consumption. There are numerous examples of this, including large-scale international projects, such as: exploitation of the huge coal deposit of Tavan Tolgoi in Mongolia with supplies to China and, in the future, to Japan, the ROK, and other Asian countries (Brletich, 2015); the “Power of Siberia” gas pipeline project from Yakutia and Irkutsk in Russia to China, as well as LNG projects in Sakhalin and Primorye; the increase of oil extraction in Yakutia and Sakhalin, and the modernization of crude oil export terminals in Nakhodka and De-Kastri (Mastepanov, 2015); and a three-fold increase of the capacity of the seaports of the Russian Far East for coal exports to Japan, China, the ROK, and Taiwan (Maritime News of Russia, 2013).

These activities will enhance the use of coal and gas in the region, and eventually lead to sustaining higher levels of carbon emissions, and the “carbon lock-in” situation, where the new capital investments in fossil-fuel-fired power plants and delivery infrastructure will reduce the willingness to switch to no-carbon technologies for the 40–50 years of their lifetime.

Examining the data on renewable energy sources, they showed enormous potential in all the Northeast Asian countries. Table 9 provides an overview of the technically available potential in wind, solar PV, hydropower, geothermal, tidal energy sources and biomass. These renewable sources have outstanding potential: the capacities of onshore and offshore wind energy generation can reach over 6,300 GW; solar PV, over 10,000 GW; hydropower and biomass, over 850 GW each; tidal, over 168 GW,; and geothermal, over 34 GW. These data may look very extreme, as the overall technical potential of over 18,000 GW is 12 times more than the total installed capacity in the world’s largest energy system, China, with 1,505 GW as of 2014 (CIA, 2016), and 72 times more than in Russia (255 GW currently).

Not all technical potential can be utilized at a reasonable cost. However, there are several reasons to consider these no-carbon energy options seriously.

Costs. Unlike the scientific arguments about the need for climate friendly development, the costs are a strong incentive to take practical steps in choosing specific technology options. In the last three decades the cost of renewables has been falling dramatically. For instance, in the last 40 years the price of solar PV panels dropped by a factor of 300, from US$76 to US$0.30 per watt of installed capacity. Cost reductions have occurred in wind, biofuel, and other renewables (but not in nuclear power, which continues to be very high). It is projected that the “learning curve” for renewables will lead to further cost reductions of 30–77% (for different technologies) up to 2050 (Safonov, et al., 2016).

Table 9. Technically Available Potential of Renewable Energy Sources in Northeast Asian Countries

Country	Wind	Solar PV	Hydropower	Biomass	Geothermal	Ocean Power
China[1)]	2,750 GW	>2,200 GW	>400 GW	273–648 Mtce/y	N/A	>174 GW
Japan[2)]	1,800 GW	350 GW	44 GW	N/A	14 GW	>44 GW
Russia (Siberia and Far East)[3)]	3,910 TWh/y	2,300 Mtce/y	1,441 TWh/y	>250 GW	>20 GW	>100 GW
Mongolia[4)]	900–1,100 GW	>1,000 GW	6.4 GW	N/A	N/A	-
ROK[5)]	186.5 TWh/y	10.4 TWh/y	N/A	N/A	N/A	>4 GW
Total Estimates	>6,300 GW	>10,000 GW	>850 GW	>850 GW	>34 GW	>322 GW

Sources: Authors' estimates based on: [1)] CNREC (2012), IRENA (2014b); [2)] Ministry of the Environment of Japan (2003), GENI (2012); [3)] IEA/OECD (2003); [4)] Oxford Business Group (2014); [5)] World Bank/Australian Aid (2013).
Note: Potential energy generating capacity is measured in different units (GW, TWh, and tce (tonnes of coal equivalent)) as provided in the original sources.

If the carbon pricing mechanisms came into force on a global scale,[18] and the carbon price reached a sufficiently high level (over €30/tCO_2 or thereabouts), then the comparative advantage of carbon-free energy would be boosted and the fossil fuel-based technologies would face an unavoidable "shrinking effect". Such an impact on traditional energy producers has already been observed in Germany, where the national energy giant RWE suffered huge losses in money and capitalization due to the regulation for the priority purchase of "green energy".[19]

On a macro level, the investment costs of the deep decarbonization of the world economy, aiming at "well below the 2°C target" and a reduction of GHG emissions by 50% by 2050 in 16 leading economies, were estimated to be as much as 0.8–1.3% of GDP (SDSN–IDDRI, 2015). To some extent, these capital investment costs can be considered as incremental to GDP growth in these countries, and not just the "costs of decarbonization". Also they relate not only to the energy sector, but to transport, infrastructure, construction, agriculture, forestry, metallurgy, cement production and other industries. These "costs" can be considered as a fairly affordable price for avoiding the damage from climate change impacts, estimated at 5–20% of global GDP per annum in the "no mitigation" scenario (Stern, 2006).

Investment and financing. Since 2013, the installation of new renewable energy capacity has exceeded that of fossil fuel capacity. As for 2014, the gross investment in

[18] A Carbon Pricing Leadership Coalition was officially launched at COP21 in 2015, with support from 74 countries and more than 1,000 companies. More than 380 investors representing over US$24 trillion have urged governments to "provide stable, reliable and economically meaningful carbon pricing that helps redirect investment commensurate with the scale of the climate change challenge." (UNGC-UNEP-UNFCCC-WRI, 2015).

[19] RWE's capitalization declined from €54.2 billion in December 2007 to €9.7 billion in July 2016 according to the most recent annual and quarterly financial statements.

new renewable electricity generating capacity (including large hydropower plants) amounted to over US$265 billion, over twice as much as the annual investment in fossil fuel power capacity.

The widely declared global initiative for elimination of fossil fuel subsidies will likely affect both fossil fuels and nuclear power subsidies, which are estimated to be as much as US$550 billion–5.6 trillion per year, depending on how they are defined and calculated. In the case of "switching" just 10–20% of these subsidies from say coal to renewables, the latter would experience an even greater booster effect, similar to the introduction of a high carbon price.

The climate concerns and risks of strengthening carbon regulation have also been reflected in the investment strategies of some key global players. All international financing organizations, such as the World Bank, the IFC, the EBRD, and the ADB, have banned the financing of new coal projects worldwide. It led, for example, to the revision of the energy strategy of Vietnam and stopped the construction of ten new coal-fired power plants. Three Russian coal projects suffered from the ban on coal investment from the Government Pension Fund of Norway (with assets worth over US$1 trillion), which adopted a decarbonization policy. Some global insurance companies, e.g. Allianz, also decided to avoid carbon-intensive projects. By September 2015, 436 institutions and over 2,000 private investors from 43 countries, representing US$2.6 trillion in assets, committed to divest from fossil fuel companies (Arabella Advisors, 2015). The dynamics of this process are very impressive: in just one year decarbonized investments increased 50-fold.

Even private investors consider "clean" assets more attractive. For example, in the last five years, the index of the top 400 US "environment and climate friendly" companies (KLD) is performing much better than the Dow Jones Index: +51.91% as against +44.88% (as of 14 July 2016). The revision of the portfolios of institutional investors (worth more than US$50 trillion in the United States and EU) in favor of carbon-neutral projects and companies would further enhance the transition to a decarbonized economy. The new instruments of financing for clean energy have been expanding, including green bonds, crowdfunding for small companies and start-ups, self-labelled corporate bonds, and clean energy project bonds, etc.

Practical experience. Some Northeast Asian countries have already been demonstrating a leadership role in renewable energy use. They have strategies and policies aiming at specific renewable targets, adopted in the "Green Growth Strategy" of the ROK, Japan's "New Growth Strategy", China's 12th Five-Year Guideline, Russia's "Energy Strategy up to 2030" and "Energy Efficiency and Energy Sector Development Program" up to 2020, Mongolia's "Green Development Policy", and the DPRK's "Renewable Energy Law".

According to the data for 2014, ***China*** is the world's No. 1 leader in annual investment in renewable energy and fuels, hydropower, solar PV, wind power, solar water heating, and third in bioethanol production. In total installed capacity, China is the global No. 1 in hydropower, solar PV, wind power, solar water heating, and geothermal heating, and No. 2 in biopower generation (IRENA, 2015). The deployment of renewables was boosted by the adoption of the Renewable Energy Law in 2005. The total investment in renewables amounted to US$505 billion for the period 2004–2015, demonstrating a skyrocketing annual growth from US$3 billion in 2004 to US$103 billion in 2015 (UNEP, 2016).

Japan is among the world leaders in renewables. It was No. 3 in annual investment in renewables in 2014, No. 2 in investment in solar PV, No. 3 in total installed capacity of solar PV and geothermal heating, and No. 5 in biopower generation capacity (IRENA, 2015). The national target for non-fossil fuel energy by 2030 is set at 44% of total energy generation, including 20–22% for nuclear power and 22–24% for renewables (METI, 2014). In 2014 alone, Japan invested US$34.3 billion (excluding R&D), 82% of which was spent on small-scale solar PV projects (IRENA, 2015). Intensive scientific research, invention and innovation development processes are widely observed in the country. Significant efforts are devoted to modern cutting-edge technologies, such as new generation solar PV panels, "green crude oil" production from blue-green algae, offshore floating wind turbines (up to 5 MW), fuel cells and hybrid automobiles, and in many other areas (Schmidt, Watanabe, 2010). Each prefecture has a technology center that supports commercialization and promotion of technology worldwide. The country has various means for that, including a globally recognized Joint Crediting Mechanism for climate change mitigation projects (considered as a mechanism of the Paris Agreement).

Russia is the fifth leading country in installed capacity of hydropower generation (45 GW), with 102 hydropower plants, providing about 20% of the national electricity supply. Most of the assets of production are concentrated in the "RusHydro" company. Geothermal power has been used in Russia for a long while, specifically in the regions of the Caucasus and Kamchatka, and some technologies were developed by Soviet scientists and engineers. However, the share of geothermal power in the energy mix is still negligible. The largest geothermal power plants are located in the Far East (Kamchatka and the Kuril Islands) with a total installed capacity of 80.1 MW (Degtyariev, 2013). Russia produces biofuels, primarily from wood and agricultural residues, and is the third largest exporter of wood pellets to the EU after the United States and Canada (as of 2014), although most of the production is located in the western part of the country (IRENA, 2015). The potential of biofuel production and exports in the eastern part of Russia is enormous, and the wood-waste production in the Far East alone amounts to 240 million cubic meters per year (ERINA, 2016). Solar power generation is expanding, and PV plants are installed and planned in Altai, Yakutia and other federal subjects, but the overall installed capacity is very modest, with 1.5 GW to be reached by 2020 (Usachev, 2015). Wind power use is also very limited as yet, although some experiments have been undertaken in the Far East (e.g. Bering Island). Tidal energy projects are considered for implementation in the Russian Far East in two unique natural locations on the Sea of Okhotsk (the Penzhin Tidal Power Plant Project of over 87 GW; and the Tugursky Bay Project with an 8-GW capacity). There has been experience in tidal energy projects since the 1960s, when the Kislaya Guba Tidal Power Station was constructed in the northwest of Russia (1.7 MW).

The ***Republic of Korea*** is very active in realizing its tidal energy potential. In 2011 the world's largest tidal power station, the Sihwa Lake Tidal Power Station, was launched with a total power output capacity of 254 MW. The electricity production cost at Sihwa is €0.02/kWh. Currently, the largest ever tidal power station, the Incheon Tidal Power Station, is under construction with an expected 1,320 MW of generating capacity (2.41 TWh of annual energy production), and is to be completed in June 2017. Another, the Garorim Bay Tidal Power Station, is proposed for construction, with a 520-MW generating capacity. Five more potential projects have been identified in the country (IRENA, 2014). The country is also very active on the international biofuels market, importing biomass raw materials, and producing and consuming biofuels. It is one of the world leaders in technology development in fuel cells and hydrogen, solar thermal and photovoltaic power, energy efficiency, and energy materials and processes.

DPRK. 70% of electricity is generated by hydropower plants (IEA, 2016a). There are four large hydropower plants with an installed capacity of 1,305 MW, operated by both China and the DPRK. The domestic supply of primary solid biofuels increased from 39.9 to 45.7 PJ in the period 1990–2013 (IEA, 2016b). Wind and solar power are moderately used on an experimental basis, but have been increasing in the last few years. The DRPK has its own production of wind and solar PV equipment. The national long-term plan is to raise energy production to 5 GW in 30 years utilizing hydropower, wind, solar, tidal, biomass, and fuel cell power (IFES, 2016).

Mongolia has outstanding potential in solar and wind energy resources. In 2011, the Japanese company Kyocera installed two of the world's largest off-grid solar power systems in the Gobi Desert as part of the World Bank's "Renewable Energy for Rural Access" project in Mongolian villages in Govi-Altai Aimag and in Bayantooroi (305.1 kW). "The 100,000 Solar Gers" program has been successfully implemented in rural areas of the country since 1999, providing energy to 500,000 nomadic people (World Bank, 2013). Since 2009, the Gobitec Initiative has been proposed aiming at renewable energy production through photovoltaics, concentrated solar power and wind farms in Mongolia (estimated potential is 2,600 TWh/year) and its transportation through a wide high-voltage direct current electricity grid to Northeast Asian countries (China, Japan, and the ROK). Hydropower projects have also been identified in Mongolia, but some of them may have high environmental risks (e.g. Egiin Gol, Shuren and other projects on the Selenge River, which is part of the water drainage basin for Lake Baikal, a UNESCO site).

Environmental, health, employment, and gender co-benefits. Besides the large amounts of CO_2, the traditional combustion of coal leads to the pollution of the local environment by soot, ash, acid rain, sludge, mercury, radioactive compounds, and carcinogenic substances, etc. Use of diesel by automobiles increases the concentration of microscopic particulate matter, PM_{10} and $PM_{2.5}$, in the lower layer of air which people breathe (these compounds are very harmful for human health due to their ability to get into the bloodstream via the alveoli of the lungs). Even combustion of natural gas (often considered as the "cleanest" energy source) leads to substantial emissions of NO_x, which affects the environment and human health (lung disease, asthma, bronchitis, carcinogenic effects, and premature deaths). Switching from fossil fuel combustion to renewable energy sources in most cases leads to a substantial improvement in the quality of the local environment and reduces health risks for the population (Danilov-Danilian, 2003).

According to the Natural Resources Defense Council (NRDC) in Beijing, atmospheric air pollution from coal combustion was the cause of the premature deaths of 704,000 people as of 2012. $PM_{2.5}$ emissions are considered as the most hazardous, leading to lung disease, cancer, ischemic heart disease and injury. The overall damage from coal use in China is estimated to be as much as 3.5% of GDP, and includes the negative impacts of extraction, transportation and combustion of coal. Each metric tonne of coal produced and consumed in the country leads to US$72.62 of social, economic and environmental costs, while the market price for coal is US$40–50 per tonne (Safonov et al., 2016; IEA, 2016). Switching to carbon-free technologies is considered, among other reasons, as one of the key policy options for improvement of local air quality in China.[20]

The renewable energy sector has a significant impact on national labor markets in Northeast Asian countries. China leads world employment in renewables with 3.523 million jobs in 2015. It is a predominantly solar PV employer with 1.7 million jobs in both manufacturing and installation, and leads in employment in wind energy with approximately 550,000 jobs in 2015. Japan has 388,000 jobs in the renewables sector (a 28% growth on the previous year), mostly in the solar PV sector with 377,100 jobs in 2014. In the ROK solar PV manufacturing provides 2,800 jobs as of 2014 (IRENA, 2016).

The gender aspects of low carbon development have also been considered and are often included in the agenda of UNFCCC meetings and conferences. It is widely argued that low carbon development strategies must include the following triple benefits: ensuring continued economic growth, limiting emissions, and delivering on social and developmental needs. In addition special consideration should be paid to gender-sensitives issues, encompassing not only technologies, but also social transformation and changes in production and consumption patterns. In this respect the more reliable and "clean" energy can (but is not guaranteed to) have a positive impact on gender equality, improvement of the standard of living of households (women usually bear the burden of caring for children, and invalid and elderly members of families), less discrimination against women in employment, and incentives for better education, etc.[21]

Carbon pricing. The EU, Australia, Kazakhstan, the ROK, the Tokyo Metropolitan Area, the Northeastern United States (the nine states of RGGI), California and Quebec, and seven provinces in China have already established emission trading schemes. Many others are coming in the near future. The Chinese national emission trading scheme will enter into force in 2017, and a total of roughly 30 national and subnational schemes are envisaged worldwide by 2020, including in Ukraine, Turkey, Brazil, Chile, Mexico, and Vietnam (ICAP, 2015).

Russia is considering carbon pricing options (cap-and-trade, and project-based mechanisms, etc.) with the preparation of the Concept of Carbon Regulation to be adopted in 2018. Carbon tax experiments are practiced in various countries, such as Britain and Australia. In Russia, the company Rusal (a leading producer of metals) proposed the introduction of a global carbon tax at a minimum US$15/t$CO_2$e by 2017 (Deripaska, 2016).

Current carbon prices are very diverse: in the EU €4.5–5.9/tCO_2e; China US$3.5–4.5 / t$CO_2$e; California and Quebec US$12–13/t$CO_2$e; and, Tokyo over US$100/tCO_2e. France has announced that the floor price of carbon permits will be set at €30/tCO_2e in January 2017 to stimulate a boosting of low-carbon technologies domestically and within the EU context (Carbon Pulse, 2016).

[20] The environmental and health benefits from the reduction of carbon emissions in the EU by 80–95% by 2050 are estimated to be as much as a €50-billion annual saving in pollution control, with improved health benefits estimated as being up to €38 billion to 2050 (GGBP, 2014).

[21] Germany's International Climate Initiative (IKI) has established a special portal for consideration of the gender issues of low-carbon development: http://www.gendercc.net/.

If the carbon price globally reached €30/tCO_2e, it would absolutely change the rules of the game in the energy and other markets. The non-carbon technologies would become strongly competitive without any subsidies and dominate the markets. It would inevitably affect the international competitiveness of countries, regions, and industries worldwide and particularly in the Northeast Asian countries.

International competitiveness and financial flows. The risks to international competitiveness are linked to the rising cost of carbon emission reduction, which will put pressure on companies and force them to relocate their production to overseas jurisdictions with lower costs or weaker carbon regulation. The investment risks are associated with the large upfront capital investments required for decarbonization and transition to a low-carbon economy, and the consumers and the private sector unwilling to make such investments would suffer the most. The process of divestment from carbon-intensive assets and projects has already been observed. International financial organizations have banned implementation of all new coal projects, as has the government of China. Construction of new coal-fired power plants and new coal-based chemical installations is not permitted until 2018 and that should cut the share of coal in the energy mix from 64% to 58%. The Chinese government also plans to phase out 500 Mt of coal production by 2020 (EnerData, 2016).

The examples of private businesses are also numerous. In 2014 the French energy giant Total SA announced that it shelved a US$11-billion Alberta oil sands mine due to the high costs and risks of high-carbon and environmental impacts. The biggest US coal company Peabody Energy went bankrupt in 2016. Even the top anti-Kyoto corporate lobbyist ExxonMobil has included the carbon tax in its strategic planning, assuming the proxy cost in some regions of US$80/$tCO_2e$ (Cohen, 2015).

5.2. Synergies for enhancing decarbonization efforts

Although most of the decarbonization potential can be realized by the individual efforts of countries, there are impressive opportunities for joint projects, which could contribute greatly to the shift to a low-carbon economy in the region.

These include megaprojects in the energy, transport, infrastructure and other sectors, related to carbon-free energy resources and technologies. For example, the Gobitec Project and Asian Super Grid Project can allow the installation of over 100 GW of wind and solar generating capacity in Mongolia's Gobi desert and export over 5,800 TWh per year of "green" electricity to China, the ROK, and Japan. Russia's potential in green energy projects is also very impressive: from 100–120 GW of tidal energy on the Okhotsk Sea to bioenergy, wind, thermal and hydropower in the Far East and Siberia.

Linking the Asian Super Grid with the electricity networks of Russia under the "Energy Circle" project was discussed at the "Eastern Economic Forum" on 2–3 September 2016 in Vladivostok, Russia. The "big energy" corporations including Gazprom, Rosneft, RusHydro, BP, Total, and many others seriously consider this initiative from a medium-term perspective.

The transportation sector development policy may also play an extremely important role in the decarbonization of local economies, if adequately designed. Such projects as the Northern Sea Route in the Russian Arctic, the western regional transport corridor in

Mongolia directly linking China and Russia in that area, and the integration of the neighboring national transport systems into the "Silk Road Initiative" can boost traffic and freight in the region in the foreseeable future. They might also reduce the carbon footprint of transportation, but only if strict low-carbon standards are applied.

The structural change in the regional economies in favor of low carbon-intensive sectors can make a dramatic input to decarbonization as well. The plans for boosting tourism, including the border provinces are impressive in all Northeast Asian countries. For example, the Mongolian tourism development strategy aims at 1 million visitors per year by 2020 (400,000 in 2015). Russia has ambitious plans to develop tourism in the Far East and Siberia, as do China, Japan, and the ROK.

Naturally a big challenge for all megaprojects, including those in energy and transport infrastructure, has to do with the underestimation of the costs of their implementation and an inaccurate assessment of the demand/usage/activity levels associated with them. It has been identified that for the last seventy years cost underestimation and overrun characterizes most of the megaprojects on all continents, and there is a "learning" process taking place. In some cases, the costs are underestimated moderately, e.g. the Panama Canal with a 200% cost overrun, while in others it is huge, e.g. the Suez Canal with a 1,900% cost overrun. It is hard to disagree with the expert view that "the cost underestimation and overrun cannot be explained by error and seem to be best explained by strategic misrepresentation, namely lying, with a view to getting projects started" (Flyvbjerg et al., 2003).

Besides such megaprojects, there are numerous lower scale opportunities for reducing carbon emissions, related to distributed renewable energy use, changing consumer behavior, and production standards, etc. In addition afforestation projects, advanced forest management and land use practices can enhance the sequestration of CO_2 from the atmosphere and prevent emissions on a considerably large scale, mitigating climate change.

However, without strong political will and a comprehensive strategy, allowing the harmonization of policies and the efforts of individual countries and international development projects with global decarbonization pathways, it would be impossible to get the Northeast Asian region on the "well below 2°C target" pathway.

The cooperation opportunities for decarbonization in energy and other sectors in Northeast Asian countries are plentiful. On the one hand, there are world-leading technology companies in renewable energy in Japan, China, and the ROK, who are eager to export their high-tech products and expand their markets, particularly in solar PV, wind, hydropower, and tidal power, bioenergy, as well as energy efficiency, and smart energy systems, etc. (JASE-W, 2015). On the other hand, the renewable energy resource-rich countries, like Russia and Mongolia can provide a substantial basis for the increase of green energy supplies to their neighbors.

One of the bottlenecks for quick expansion in this direction is due to an absence of green energy infrastructure. The efforts to enhance fossil fuel supply infrastructure, especially in Russia, have been quite active in recent years (gas pipelines, and coal facilities in ports, etc.), which may be considered "stranded assets" in a decarbonized world within several decades. The Northeast Asian regional initiatives for the creation of a super-efficient integrated electricity network, which would link solar, wind and other power generation facilities around Northeast Asia, are considered feasible and highly desirable. In 2016 the State Grid Corporation of China proposed a US$50 trillion investment project to establish a global power network by 2050 (NBC, 2016), which may start from the Northeast Asian region, based on the Gobitec and Asian Super Grid initiatives (Von Hippel, 2015).

Evidently, with such a super-grid in place, and a continuing boost in investment in renewables by China and others, the Northeast Asian regional potential would be uncorked and the goals of deep decarbonization would be reached by early in the second half of this century. The investment cooperation process has already started in Mongolia. Sharp, Japan's Shigemitsu Shoji Co. and Mongolia's Solar Power International LLC have completed the construction of a 291,000-m^2 plant with 10 MW capacity in 2016. The Korea Electric Power Corporation (KEPCO) signed an asset management agreement to establish a 50 MW solar power plant in Mongolia. The Russian Deputy Prime Minister Yury Trutnev announced the initiative for the creation of a carbon-free zone in eastern Siberia, which can be considered the first proposal for decarbonization of the economy in the eastern part of the country, with a huge territorial extent of over 10 million km^2, and aiming at the attraction of investors to low-carbon technology projects.

In non-energy sectors, new technologies are also appearing for reducing the carbon footprint of products and services. For example, the nanotubes produced by the Russian "Rosnano" corporation can be added to basic materials (such as plastics, rubber, metals, and cement, etc.) and enhance their technical features. There are about 20,000 patents for products using nanotubes already, but their supply was limited due to the high cost of production up until Rosnano's invention. Basic materials are responsible for 28% of global GHG emissions, relating to production, transportation and use, so it is critical for the decarbonization strategy to cover this sector in addition to the energy industry (CENEf, 2015).

If the Northeast Asian region is to stay within the boundaries of its carbon budget in compliance with the global 2°C target, most fossil fuels need to be replaced with renewable energy or other zero-emission alternatives by 2050. The renewable energy potential in Northeast Asia is sufficient to meet all the energy needs and the decarbonization of the regional economy. But the process of decarbonization would be faster and more effective if the Northeast Asian countries enhance cooperation in this area so as to realize the existing potential and implement joint investment projects, including the megaprojects in establishing "green" energy infrastructure.

5.3. Concerns and ways forward

The research undertaken allows us to conclude that the Northeast Asian region is very well-positioned to take the deep decarbonization pathway, support and enhance each other's efforts to develop a carbon-neutral economy, gradually upgrade the industrial technological basis, infrastructure, and the energy and transportation systems, utilizing the resources, know-how, and investments available in the region.

Naturally, Northeast Asia cannot be considered as isolated from the rest of the world, and conversely, it should take into account the processes going on in North America, Europe, and other parts of the world. One of the indicative processes, very closely related to the decarbonization goals, deals with divestments from fossil fuel projects and assets. Investors from the United States, Germany, Norway, Australia, and many other countries have adopted policies to stop investing in fossil fuel companies. However, not in Northeast Asia! None of the domestic investors has declared such an approach as yet!

Does it mean that climate change is not a real priority for the Northeast Asian countries (supported politically and in declarations)? Are they still interested in fossil fuels regardless of their Paris Agreement commitments? Or is this just slow progress in getting onboard the divestment process?

Our numerous expert meetings and discussions in Japan during the summer of 2016 showed a very weak perception of the climate change and decarbonization challenge even for large-scale investors. For instance, the leading investors in Japan consider the expansion of their engagement in oil and gas projects in Russia, Azerbaijan, Kazakhstan and others countries, without making any assessment of the risks associated with the strengthening of carbon regulation, the increase of direct and indirect carbon emissions, and investment in assets that will be stranded in the foreseeable future. Some of them were even unaware that methane is a powerful greenhouse gas included in the international treaties for accounting and regulation.

We also observe that the national commitments, determined under the Kyoto Protocol, Paris Agreement, or within other frameworks (G20, G8/G7) are not well articulated by policy makers to the main economic agents in all the Northeast Asian countries. For example, you can scarcely find businesses in Japan which are aware of the national commitment to reduce greenhouse gas emissions by 80% below the 1990 level by 2050 (adopted by the Fourth Basic Environmental Plan).

In recent years, Russia's expansion in fossil fuel extraction, transportation, and combustion, specifically in eastern Siberia and the Far East, is also inconsistent with "climatic" targets. It can adequately be explained by the interests of coal, gas, and oil producers with strong lobbying power.

An interesting example in this regard is the energy dialogue in Northeast Asia, particularly the "Energy Circle" initiative, actively supported by the Russian energy giants (Gazprom, Rosneft, RusHydro, and others) and their partners in Northeast Asia (it is often discussed along with the "Asian Super Grid" project). Linking the energy systems of Northeast Asian countries is considered by some stakeholders as an opportunity to promote expansion of coal and gas use, boosting the supply of electricity generated by coal- and gas-fired power plants (e.g. in Russia and Mongolia) and exports to Japan, the ROK and China. If such an approach materialized, it would sustain the situation of substantial incremental fossil fuel use for at least 40–50 years. The associated carbon emissions might be accounted for as Mongolia's or Russia's domestic emissions, without strict GHG reporting and regulation, and hence produce a large-scale release of carbon. The scale of such a release could reach dozens of billions of tCO_2e by 2050, which would dramatically undermine the mitigation efforts of Northeast Asia and other countries.

The deep decarbonization strategy would require an absolutely different approach. The Northeast Asian partners can agree to supply primarily green energy to the joint energy system, and the "Green Energy Circle" would play a role as a massive-scale catalyzer of the carbon-neutral technologies spreading through the region and beyond. The renewable energy sources (wind, solar, tidal, and biofuel, etc.) of Mongolia, Russia, China and other countries would receive new momentum for exploration and exploitation for the benefit of local communities, the environment, and climate. In addition it would generate an upscaling of demand for the technologies already produced in the ROK, Japan, and China, as well as the demand for inventions and know-how from Russia, which are currently lacking an inflow of investment due to the “different priorities” promoted by the fossil fuel lobbyists.

Carbon pricing mechanisms lead to absolutely new conditions for doing business with a high carbon footprint. China launches its national carbon market in 2017, and the ROK and Japan have already been experimenting with cap-and-trade and project-based emission trading schemes. Russia tried to use the Kyoto Protocol flexibility mechanisms, and earned over US$1 billion in 2008–2012, but put this mechanism on hold for an uncertain period. However, Russian businesses are well aware of the opportunities of attracting “carbon” investments and of carbon-related risks rising on international markets. In the case of setting a “global average” carbon price at US$15–30 per tCO_2e in the next 5–10 years, the commercial feasibility of most of the projects and businesses would dramatically change. But who bears this risk in mind currently in Northeast Asian countries?

In this respect, the international cooperation mechanisms launched by some Northeast Asian countries can help to hedge against the risks of a growing carbon price. For example, JCM of Japan may allow the fixing of the price of carbon certificates obtained in joint projects for the next few decades, as a side-effect of promoting domestic technologies, machinery, goods and services in partner countries, which stimulate production and exports in that country. The ROK has a range of international initiatives, under which it helps implement projects in developing countries (including Mongolia), so that they can also be designed to account for the carbon effect of investments. China launched the South–South initiative with the support of projects and activities which can have significant mitigation impacts, and they should get their fair share of the carbon effect as well. Russia announced its willingness to support climate adaptation and mitigation activities in neighboring countries, but has not yet specified clear rules, mechanisms and partners.

A very important direction for cooperation where the carbon implications are still missing is the development of transportation infrastructure in Northeast Asia. Above we have mentioned the very promising initiatives aimed at linking regional and national railway, road, maritime, and air transportation networks among China, Mongolia, Russia, the ROK, and Japan. But would these projects lead to reduction of carbon emissions or increase the burden on the climatic system on a huge scale? We could find neither estimates of such an impact, nor the decision-making positions on this issue.

Some measures can have both mitigation and adaptation significance. For example, the afforestation and reforestation projects in Mongolia, China, Russia, and Japan can bring substantial carbon sequestration benefits, while playing a supremely important role in biodiversity conservation, watershed protection, ecosystem services, protection from soil erosion and desertification, etc. A very illustrative example in this regard is the “Green Belt” program in Mongolia. Afforestation of over 80,000 hectares of degraded land to prevent rapid desertification in the southern and western regions (close to the Gobi Desert) would, in addition to plentiful environmental, social, and economic benefits, allow the absorption of approximately 1 million tCO_2 per year. However, the country has no resources of its own to invest in this program. The carbon investment with JCM or another similar program could activate the economic feasibility and technical implementation of this initiative. The beneficiaries of such a large-scale project would not only get the carbon credits, but could improve their own environment. Why? Because of the cross-border transportation of "yellow sand" from the expanding Gobi Desert to the ROK and Japan, which already affects human health in these countries. New forests in Mongolia are a perfect solution for all.

The on-going afforestation program in China is also considered as a meaningful approach to national mitigation policy and is included in the country's INDC. By 2014 the forested area and forest growing stock volume increased by 21.6 million hectares and 2.2 billion cubic meters, respectively (compared to the 2005 levels). China plans to continue afforestation and increase the forest growing stock volume by around 4.5 billion cubic meters by 2030 (compared to the 2005 level).

The afforestation and reforestation projects in Russia are also extremely important. For instance, in Altai Krai the cultivated steppe areas (Kulunda Steppe) suffer from wind and water erosion, as the forest soil-protective lines have been degraded and lost, which leads to the loss of the fertile layer of soil and affects the sustainability of agriculture for many subsequent decades. The capitalized carbon effect of the modernization of Altai Krai's forest lines would fully compensate the investment and operational costs and make this project sustainable for many decades.

In Japan afforestation and forest management projects can also play climatic and locally important ecological roles, as in the case of Niigata Prefecture and its renowned Sado Island, where carbon investments in the creation of new forest could help save both the climate and a rare bird species, the *toki* (*Nipponia nippon*), a symbol of Niigata.

We understand that many more issues have to be raised and analyzed regarding the decarbonization pathways for individual countries and for the Northeast Asian region as a whole. It is a new, very challenging question for all: governments, businesses, NGOs, and households. However, we have to start asking these questions now. As the then UN Secretary-General Ban Ki-moon stated at the start of the People's Climate March in New York City in September 2014: "There is no 'Plan B' for action as there is no 'Planet B'." Northeast Asian countries can make a meaningful input to combating climate change and show leadership to those countries which are still delaying their own actions.

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