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Exploring New Opportunities

COST AND BENEFITS OF DEEP DECARBONIZATION IN RUSSIA

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Abstract
With the new Paris climate agreement, 185 of 197 nations have committed to lower emissions of planet-warming greenhouse gases. The intent is to limit global temperature growth within 2 degrees Celsius (°C), with a hopeful target of 1.5°C. At the same time, a special report from the International Panel on Climate Change (IPCC) indicates that large emission reductions, in fact, must be achieved by 2030 if the temperature increase is to remain below 1.5°C. This goal requires every country to radically cut their greenhouse gas emissions by rebuilding both their energy supply and end-use sectors. Even bigger challenges confront those countries which export fossil fuel resources, as they must also find new sources of economic activity to replace revenues that will be lost from the significantly reduced energy sales. The overall economic impact of this transformation is hard to quantify. On the one hand, decarbonization requires an initial set of large-scale policy, program, and research and development expenditures. It will also entail higher upfront investments in energy efficiency and alternative energy resources. Based on conventional wisdom, these outlays will create an initial burden on the economy. On the other hand, the additional infrastructure investments will also stimulate economic activity, reduce future energy expenditures and also provide an array of other non-energy benefits. In this paper, we propose a thought experiment that explores the idea of prospective positive net economic impacts of decarbonization strategies for an energy-producing nation. Our results suggest that the positive productivity benefits of decarbonization strategies can overcome negative costs in both the short and long terms. We also note additional effects that are consistent with the officially announced long-term goals of modernization and reducing the Russian economy's dependence on revenues from energy and raw material exports.
Keywords: economy, climate change, energy efficiency, renewables.
JEL: Q50, Q54, Q49, Q20.

Introduction

There is a broadly increasing agreement that the global economy and its many individual nations must dramatically reduce total greenhouse gas emissions. With the new Paris climate agreement, for example, 189 nations have committed to lowering the level of planet-warming greenhouse gas emissions. The intent of these reductions is to limit global temperature growth within 2°C, with an ideal target of 1.5°C[1] (Conference of the Parties 2015). Perhaps more critically, a recent report from the International Panel on Climate Change (IPCC)[2] indicates that in model pathways which limit global temperature increases to 1.5°C above pre-industrial values, global net anthropogenic carbon dioxide (CO_2) emissions must decline by about 45 percent from 2010 levels by 2030, reaching net zero around 2050. Even before that historic 2015 agreement, as well as the special IPCC report, however, there had been a variety of reports and assessments to evaluate both climate and economic impacts of climate change and possible solutions[3]. One recent example of an ongoing assessment is the Deep Decarbonization Pathways Project, jointly prepared by the members of 16 country research teams[4]. The Russian Federation was among those 16 nations. The three pillars of Russia's deep decarbonization included greater levels of investments in "energy efficiency", together with the "decarbonization of electricity", and also the "electrification" of the economy. All such strategies depend on large-scale investments in both new and emerging technologies. As described below, the assessment found that the right mix of investments could drop Russia's energy-related CO_2 emissions from 1,422 million tonnes (Mt) in 2010 down to just 200 Mt in 2050. This is an 84% reduction in that 40-year period.

The emissions mitigation scenario was simulated using a technological model known as RU-TIMES [Lugovoy et al., 2014]. This is a so-called Bottom-Up (BU) partial equilibrium model designed to evaluate technological structure, required investments, and changes in the overall energy balance of an economy. Given emerging trends of new technology costs, the model suggested that a significant share of emissions reduction was, indeed, cost-effective. On the other hand, RU-TIMES

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[1] Adoption of the Paris Agreement. United Nations Framework Convention on Climate Change. Conference of the Parties, 2015. https://unfccc.int/process/the-paris-agreement/status-of-ratification.

[2] Edenhofer O., Pichs-Madruga R., Sokona Y., Minx J. C., Farahani E. *Climate Change 2014: Mitigation of Climate Change, Working Group III Contribution to the Fifth Assessment Report.* Cambridge, United Kingdom and New York, IPCC, Cambridge University Press, 2014.

[3] Investing in Climate, Investing in Growth. Paris, OECD Publishing, 2017. http://www.oecd.org/env/investing-in-climate-investing-in-growth-9789264273528-en.htm.

[4] The Deep Decarbonization Pathways Project (DDPP 2015) was convened with the support of the Sustainable Development Solutions Network (SDSN) and the Institute for Sustainable Development and International Relations (IDDRI).

was unable to address employment and economic growth effects. Alternatively, a Top-Down (TD) approach likely would be able to shed light on the overall macroeconomic impact of a given emissions mitigation scenario. In addition, computable general equilibrium (CGE) models are potentially helpful to rebalance economic flows in a static steady state. However, the simplified elasticity-based representation of the energy sector in such models is normally a very rough approximation which tends to overestimate emissions reduction costs[5]. And, based on the static nature of CGE models, they are not especially helpful in an analysis of long-term economic growth impacts.

Ideally, a more robust determination of economic impacts would use all three modeling approaches to address detailed technological changes, a balanced equilibrium, and any long-run growth effects of the decarbonization strategy. To our best knowledge, with number of efforts to develop such hybrid approach, there is no mainstream structure which can address short- and long-run economic costs and benefits of deep decarbonization policy, especially for an energy resources exporting country. Therefore in the paper we formulate three primary effects of decarbonization compared with a baseline scenario. These include: (1) higher level of required investments, (2) anticipated future energy savings, and (3) an economic restructuring away from natural resource-led growth to increased output from other sectors such as manufacturing and services. We propose a *thought experiment*, where we are trying to combine the three effects within a single framework and then evaluate the total impact of decarbonization on the Russian economy in both the long and short run.

To make assumptions clear, we evaluate our thought experiment with a framework that relies on Input-Output Tables (IOT) which take into account the many linkages among industries and other sectors, but which do not require assumptions regarding consumers' preferences and trade. Our goal is to provide a structural framework for evaluation of decarbonization strategies. More effects can be considered with application of CGE and other kinds of growth models. As participants of the Deep Decarbonization Pathways Project (DDPP)[6], the authors use the [Lugovoy et al., 2014] results of the modeled DDPP scenario as an input to an IOT-analytical thought experiment, estimating the macroeconomic impact of a low-carbon scenario on economy. We apply a

[5] An observation that TD models normally show higher economic costs of CO_2 emissions reduction has been reported by Stanford Energy Modeling Forum study #25 (Huntington H. *EMF 25: Energy Efficiency and Climate Change Mitigation.* Stanford, Energy Modeling Forum, 2011, vol. 1). See also an overview of BU and TD modeling approaches assumptions and how they address fuel switching, and energy efficiency in a summary paper of China Energy Modeling Forum #1 [Lugovoy at al., 2018].

[6] Pathways to Deep Decarbonization 2015 Report. Deep Decarbonization Pathways Project, SDSN-IDDRI, 2015. http://www.deepdecarbonization.org.

stochastically extrapolated IOT for Russia to assess potential uncertainty in the data and the overall outcome of the considered effects[7].

1. Deep Decarbonization and Economic Growth

The use of greater energy efficiency investments and low-carbon energy resources is expanding rapidly. Indeed, there are positive indications that growth in the global economy may be diverging from growth in energy consumption as well as energy-related carbon dioxide (CO_2) emissions[8]. For example, the global economy grew by 3.2% in 2015 but energy demand stayed relatively flat (increasing only 0.3%). This is an especially positive trend, as the International Energy Agency notes, since "the size of the global economy could double between now and 2040 with only a marginal increase in energy demand"[9]. Renewables accounted for nearly half of all new power generation capacity in 2014, led by growth in four major economies, namely China, the United States, Japan and Germany, with investment building momentum at $270 billion. Even better, the costs are continuing to fall. The energy intensity of the global economy dropped by 2.8% in 2015. This was more than twice the average rate of decline over the last decade, stemming from improved energy efficiency and structural changes in a number of economies, including China. But can we accelerate this prospect in a cost-effective way? McKinsey[10] suggested that, yes, with energyefficiency measures, Russia can grow GDP up to 6 percent per annum with no increase in energy consumption or carbon emissions. The McKinsey report shows that by 2030 Russia could cut its energy usage by 23 percent and reduce its greenhouse gas emissions by 19 percent by implementing 60 economically attractive efficiency measures. At the same time, Russia could achieve its GDP growth aspirations while remaining at its current levels of energy consumption and emissions. An Ecofys report from [Blok et al., 2015] indicates that this is a continuing possibility. It notes that, as an example, the Russian Federation has seen energy productivity-based boosts to GDP of 29% over a recent 10-year period (2001–2011).

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[7] A much shorter version of this paper was published in 2015 as a working paper in the Russian journal *Russian Entrepreneurship*. It has now been translated, improved, expanded and updated as we now use new calculations.

[8] Energy and Climate Change: World Energy Outlook Special Report. International Energy Agency (IEA), 2015. P. 39. https://webstore.iea.org/weo-2015-special-report-energy-and-climate-change.

[9] Energy Efficiency 2018: Analysis and Outlooks to 2040. International Energy Agency (IEA), 2018. P. 3. https://webstore.iea.org/market-report-series-energy-efficiency-2018.

[10] Pathways to an Energy- and Carbon-Efficient Russia. Opportunities to Increase Energy Efficiency and Reduce Greenhouse Gas Emissions. McKinsey and Company, 2009. http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/pathways-to-an-energy-and-carbon-efficient-russia.

2. Lower Energy and Material Costs as a Driver of GDP and Jobs

For very understandable reasons, business leaders and policymakers have followed an energy-supply focus in promoting a more vigorous level of economic activity. They reason that a nation's labor, infrastructure, and equipment all require some form of energy to power the production of needed goods and services. The assumption by many policymakers and businesses is that an economy needs an adequate supply of low-cost fossil fuels to ensure some desired level of economic well-being. Part of that thinking is also to ensure the development of new jobs and incomes for the nation's resident population.

At the same time, they believe that if there is a need to focus on deep decarbonization pathways, the logical conclusion is that nuclear resources and different forms of carbon capture and sequestration (CCS) would provide the needed resources to maintain economic well-being. And the further thought is that if there are costs to the economy, the negative impacts on gross domestic product (GDP) would be minimal; indeed, the assumption is that economic growth would still be possible even as national leaders outline those deep decarbonization pathways[11].

Yet the emerging evidence also suggests a vital and more surprising role for greater levels of energy efficiency improvements at all levels of economic activity, and likewise for significant investments in a large portfolio of renewable energy resources. Even better, there is a growing number of studies which suggest the possibility of an investment-led infusion of energy efficiency and renewable energy technologies as a positive stimulus to the economy. A recent OECD assessment notes that low greenhouse gas emission pathways, including investments in renewables and energy efficiency upgrades, could stimulate long-run economic output by up to 2.8 percent, on average, across the G20 countries in 2050[12].

3. Energy Efficiency and Renewable Energy Resources

The International Energy Agency (IEA) is now issuing a new annual publication called the Energy Efficiency Market Report. Its sixth annual release was in October 2018 and noted that routine investment in energy efficiency markets worldwide in 2017 was USD 236 billion, maintaining an upward trend in recent years[13]. In fact, the routine annual investment in energy efficiency was larger than supply-side investment

[11] See the IPEEC analytical manuscript [Laitner et al., 2018] for a complementary discussion in this regard.

[12] Investing in Climate, Investing in Growth.

[13] Energy Efficiency 2018. P. 14.

in renewable electricity or in coal, oil and gas electricity generation, and around half the size of upstream oil and gas investment. Hence, energy efficiency is already a major catalyst within the world energy markets. But because past studies have not tracked such investments, business leaders and policymakers are generally unaware of such opportunities. An earlier assessment further suggested that energy efficiency investments would actually boost global GDP. For example, in the Efficient World Scenario of the 2012 *World Energy Outlook*, an 18% worldwide energy savings through efficiency gains was shown to boost global GDP 0.4% higher by 2035. According to IRENA[14], "increasing world's share of renewable energy would boost global GDP up to $1.3 trillion". As we noted earlier, the OECD suggested a more recent but similar trajectory.

Even a cursory review of recent studies shows that large-scale reductions in greenhouse gases can both enhance energy security and make economic sense. For every dollar invested in the clean-energy technologies that drive large emission reductions, nearly 3 dollars in fuel costs are avoided by 2050[15]. And those reductions are made possible with a portfolio of technology options including energy efficiency, renewable energy, carbon capture and storage (CCS), fuel switching and nuclear energy—exactly as shown by the several deep carbonization pathways described elsewhere in this chapter.

Energy efficiency produces multiple benefits well beyond fuel cost savings alone [Campbell et al., 2014]. Indeed, there are layers of benefits which can drive net positive increases in GDP. In the case of electricity system energy efficiency gains, for example, there are three primary layers of returns. These include: (1) utility system benefits, (2) utility customer or participant benefits, and (3) societal benefits. Among the several utility benefits (or benefits to energy supply companies more broadly) are diversifying energy and power resources of supply, and maintaining an adequate level of transmission or distribution capacity. In the case of natural gas or petroleum providers, greater levels of energy efficiency can improve the management of system capacity and infrastructure such as pipelines and other transportation needs [Lazar, Colburn, 2013].

In the case of electric utilities the environmental benefits also include the avoided or reduced costs to meet existing or future pollution control standards. These might include regulations associated with sulfur dioxide and nitrogen oxide emissions as well as the control of mercury emissions, the production of ash and other waste products, and the protection of water supplies. Indeed, environmental costs

[14] International Renewable Energy Agency (IRENA), 2016. https://www.irena.org/publications/2016/Jan/Renewable-Energy-Benefits-Measuring-the-Economics.

[15] Energy and Climate Change. P. 39.

might double total costs of energy production beyond the usual capital and operating costs associated with energy production [Lazar, Colburn, 2013]. In effect, the greater use of “clean technologies” through investments in energy efficiency and renewable energy resources can cut overall energy costs by half. Other savings might consist of reduced transmission line losses and the need for smaller reserve margins that are necessary to maintain a reliable system. At a minimum, a more diverse resource portfolio can lower the risk of supply disruption even as it can also lower the interest rate with which companies borrow money. All of these cost savings together improve the credit ratings of energy suppliers. It is likely that as overall costs of energy are reduced, the level of non-payment of customer bills will be similarly diminished. This, in turn, reduces the need for expenses associated with the collection of missed or past-due accounts [Lazar, Colburn, 2013].

Customer or program participant benefits are equally diverse though somewhat different. Again turning to savings on the electric utility bills, other fuel savings might also emerge. For example, if there is better insulation in homes and commercial buildings, that will reduce air conditioning needs in the summer, but it might also lower natural gas or other heating fuels in the winter. Other potential customer savings include lower water and sewer costs—especially in commercial buildings and industrial facilities. And energy efficiency upgrades can further reduce operating and maintenance costs as well as lower the costs associated with health impacts. In commercial and industrial facilities, a more pleasant and energy-efficient work environment might increase employee productivity. In residential buildings, an upgraded home can also increase overall comfort within a given dwelling [Lazar, Colburn, 2013].

The societal benefits of clean energy technologies range from improved air quality to greater protection of water supplies and reduced levels of solid waste. The more productive use of all energy resources will also increase energy security and economic development impacts. While it can be difficult to measure and monetize the multiple benefits summarized above, the International Energy Agency notes that the value of those multiple benefits, alongside the traditional measure of cost savings, can deliver returns as high as 4 euros for every 1 euro that is invested in those clean energy technologies [Campbell et al., 2014][16].

Despite the positive returns, there are also indications that energy efficiency and clean energy technologies can deliver a large-scale impact. In the United States, for example, the American Council for an Energy-Efficient Economy (ACEEE) documented sufficient cost-effective en-

[16] See also [Parry et al., 2014] for country-specific health and environmental impacts of energy use.

ergy efficiency improvements so that by the year 2050, that nation can reduce its overall energy use by 40 to 60 percent. The savings would benefit all parts of the economy including the residential, commercial, industrial, and transportation sectors. These savings come from many current and advanced technologies but also from improved optimization of building, transportation, industrial, and electric power systems as existing systems are renovated or replaced. Critically, that scale of efficiency investments would drive a net gain of almost 2 million jobs even as business and household consumers save an average of $400 billion per year [Laitner et al., 2012].

Extending that same perspective beyond the United States, the Regulatory Assistance Project (RAP) wrote that "Europe's top-line energy and economic goals can be met more reliably, at lower cost, and with lower environmental burdens if our traditional focus on supply-side solutions is reversed" [Cowart, 2014. P. 1]. In effect, a more positive economic outcome for the European Union would be supported through "a rigorous exploration of less expensive demand-side resources before more expensive supply-side commitments are locked into place". RAP refers to this policy as "Efficiency First" [Cowart, 2014. P. 1]. This echoes the theme of the IEA's Energy Efficiency Market Report which refers to energy efficiency as the world's "first fuel".

Renewable energy technologies provide an equally compelling magnitude of benefits. One of India's major advantages moving forward is a very large renewable energy potential that is still largely untapped. Recent assessments indicate that India's solar potential is greater than 10,000 GW, and that its wind potential could be higher than 2,000 GW. The combination of solar and wind resource potential is an order of magnitude larger than that nation's currently installed electric generation capacity. The enormous benefits of renewable energy investments—zero fuel, electricity prices free from volatility and external influence, reduced imports, and dramatically reduced pollution and water use—rival the improvements made possible by energy efficiency resources [Rosenow et al., 2016].

That same perspective led Nord-Pas de Calais, a heavy industrial region of 4 million people in northeastern France, to undertake the development of a master plan that focused on energy efficiency and renewable energy technologies. The resulting document suggested three things for that regional economy. First, the master plan highlighted the many ways that energy efficiency could reduce total energy needs by more than half by 2050. Second, the plan suggested that renewable energy technologies could meet all remaining energy needs, also by 2050. Finally, the economic assessment of that plan indicated a more robust economy would emerge through a productive investment in clean energy resources. Regional GDP, for example, would be about 8% larger in 2050 compared with a "business-as-usual" approach in the development of energy resources. At the same time, the combination of more productive investments, but especially the reduced energy costs, would drive a net employment benefit of 100,000 for the 4 million people living in that region [Rifkin et al., 2013].

More recently, the Grand Duchy of Luxembourg, including the Ministry of the Economy, the Chamber of Commerce, and the non-governmental organization IMS Luxembourg, collaborated on a similar plan as northern France, especially focusing on innovative finance mechanisms, a build-out of the digital infrastructure, a circular economy and an increase in e-mobility. As in France, these transition elements would enable a larger increase in energy efficiency across all sectors as well as move the region to 100 percent renewables by 2050 with a net positive economic gain[17].

A precipitous decline in the cost of computing power and data storage, and dramatic improvements in programming science have resulted in the potential for every device to become a connected, "smart" device. Such devices can collect and process enormous amounts of data, making possible higher levels of performance that were unachievable just a decade ago. A direct outcome of new performance levels is the reduced demand for energy even as greater levels of service are being provided. This expanded use of information and communication technologies (ICT) boost greater economic productivity while saving money and reducing environmental impacts.

ACEEE found, in a series of thought experiments of its own, that the near-term economic impacts which might follow from an accelerated deployment of ICT-enabled networks and services could boost U.S. GDP by a prospective $600 billion annually. This is the result of a more productive infrastructure, reduced health costs and traffic congestion, and an increased share of smart buildings and industrial processes. The larger productivity benefits are also driven, in part, by a 1.1 billion barrel energy efficiency gain that could reduce the U.S. annual energy bill by about $79 billion [Laitner et al., 2014]. A recent assessment for the Global e-Sustainability Initiative (GeSI) confirmed this emerging perspective about the energy and productivity benefits of ICT-enabled systems. Worldwide revenues associated with greater ICT investments are estimated to increase by $397 billion annually by 2030. A more dynamic economic structure would save a cumulative $2.8 trillion in avoided energy, environmental, health and social costs through 2030[18].

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[17] The 3rd Industrial Revolution Strategy Study for the Grand Duchy of Luxembourg. Luxembourg Economic Ministry, 2016. https://www.troisiemerevolutionindustrielle.lu/wp-content/uploads/2016/11/TIR-Strategy-Study_Short.pdf.

[18] #SMARTer2030: ICT Solutions for 21st Century Challenges. Global e-Sustainability Initiative (GeSI), Brussels, Accenture, 2015. http://smarter2030.gesi.org/downloads/Full_report.pdf.

Based on specific estimates for the Federation by the Institute of Energy Strategy[19], Russia has a huge technical potential for renewable energy generation—about 4.5 billion tons of coal equivalent (TCE) per year, which is many times more than current total energy consumption. Despite this enormous asset, the nation does not rely on renewable energy resources to any meaningful extent, producing less than 1% of all energy uses from those technologies.

Over the last years, however, Russia has taken different steps to promote renewable energy development, including the creation of several ambitious targets. For example, the share of renewable (excluding hydropower over 25 MW) electricity capacity in the total electricity generation should have reached 2.5 percent by 2015 and 4.5 percent by 2020 (according to version 2009[20]). After several corrections, the target was changed to 4.5 percent by 2024 (5.9 GW including 3.6 GW wind, 1.5 GM solar and 0.8 GW hydro less 25 MW). It is now only 0.2 percent (257 GW). At the same time, the Russian Government issued decree No. 861-r that established a 2020 goal of almost 6,000 MW of installed new renewable energy capacity. In 2013 the total installed renewable energy capacity was less than 2,200 MW. Yet, this promising sector is curbed by various institutional barriers that keep it at the rudimentary level of its development. Public demand for renewable energy in Russia is low, and so is public attention to the environmental threats. Many consumers are afraid that rapid growth of renewable energy in Russia may lead to the increase of electricity tariffs[21]. The lack of renewable energy equipment manufacturers in Russia makes it difficult to produce energy from renewables, as project developers are required to purchase Russian equipment even if foreign equipment costs less, due to strict localization requirements. Supporting innovation will drive down costs and expand opportunities.

Innovations were suggested as a new growth paradigm in Russia in the late 2000s. The new economic structure and the new principles of economic development, aimed at economic diversification and life quality growth, were stated in the Innovation Development Strategy of the Russian Federation 2020, validated in December 2011. Energy efficiency, energy saving and nuclear power were proposed as the top-priority sectors for science, technology and industrial development, due to several governmental programs: "Development of Science and Technology 2013–2020", "Development of the industry and an increase in its

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[19] Energy Strategy of Russia for the period up to 2030. Institute of Energy Strategy. Moscow, 2010. http://www.energystrategy.ru/projects/docs/ES-2030_(Eng).pdf.

[20] Order of the Government of the Russian Federation of 08.01.2009 № 1-r. "Main Areas of Government Policy in terms of Improving Energy Efficiency in the Electric Power Industry using Renewable Energy Sources up to 2020". http://www.en.np-sr.ru/en/srnen/legalbase/governmentdecrees/index.htm.

[21] Fomicheva A. Who Will Pay for the Green Tariff. *Vedomosti Newspaper*, 22 September, 2013. https://www.vedomosti.ru/newspaper/articles/2013/09/23/kto-oplatit-zelenyj-tarif.

competitiveness up to 2020", "The Ecology Program 2012–2020", the "Integrated program of biotech development in the Russian Federation by 2020" etc.

For the moment, Russia cannot yet be classified as one of the leading innovative countries of the world although it traditionally has a highly developed network of both human capital and effective think tanks. The business environment in Russia has been improved greatly in the last several years and the ICT technologies have spread widely, but the institutional problems are still one of the main deterrents of innovation development.

The innovation policy as highlighted in [Lugovoy et al., 2014] is aimed at creating favorable institutional conditions for innovations. These include: (1): market competition (entrepreneurship, support for small and medium-sized enterprises (SMEs), and low market entry barriers); (2) development of science and education (Federal universities and research institutions, governmental programs, grants etc.); (3) support for innovation activities (Federal programs or direct company financing/subsidizing); (4) public-private partnership mechanisms; (5) effective tax system (including tax incentives for high-technology firms, and other tax preferentials) and legislation system (promoting Federal innovation strategies); (6) intellectual property rights; (7) technical regulations (especially energy saving and efficiency regulation standards); and (8) innovation infrastructure (technical parks, transfer technology centers, business incubators etc.).

The working assumption is that the government helps to establish close ties between businesses and think tanks, which lowers the transaction expenses, enlarges and facilitates the use of new technologies and reduces their costs in general. As a result, Russia will be more able to attract new investments, to foster commercialization processes, to create the domestic innovations demand and to produce some competitive high-tech products, including those in the sphere of alternative energy resource use.

4. The Thought Experiment

We can examine the magnitude of possible benefits policies that promote the deep decarbonization pathway for Russia with an analysis that builds on a 15-sector input-output model for the Russian economy using key data from the main DDPP scenario [Lugovoy et al., 2014]. In this case, we look at the prospective GDP benefits for the years starting from 2016 to 2030, and 2050.

As discussed above, decarbonization policy affects economic activity in many ways. Here we consider the immediate economic effects of structural changes and the potential for improved overall productivity. Logically, the structural changes result from a transition from fossil fuel energy resources to greater levels of energy efficiency and the accelerated deployment of renewable energy technologies. Both changes stimulate new patterns of investments and annual spending across all sectors of the economy. More critically, to the extent there is a reduction in total energy expenditures from the DDPP scenario; construction, manufacturing, and service and household sectors will benefit from lower energy costs, while utilities and other energy suppliers will lose traditional sources of revenues.

A properly designed thought experiment can examine the net effects of all these spending changes. Moreover, to the extent that such changes also spur greater economic productivity, the effect of these savings will be amplified. The modeling of the DDPP scenario suggests a pathway Russia should take to reduce its carbon-related emissions more than 80% by 2050. At the same time, however, the more productive investments in the nation's overall energy system are expected to reduce Russia's total energy expenditures by about 38% compared with a business-as-usual scenario in 2050 [Lugovoy et al., 2014].

Deep decarbonization strategy induces and accelerates a set of effects which could be considered positive or even desirable for the Russian economy. The first effect is a direct growth of investment demand for manufacturing products and infrastructure development. As discussed earlier, decarbonization requires a higher level of investment which results in further energy savings. On the one hand, investment spending is a part of GDP (recall the GDP identity in which income Y equals investment I, plus consumption C, plus government spending G, and finally, net exports NX); stimulating investment growth, ceteris paribus, means the growth of total national income. On the other hand, additional demand for the products of investment goods-producing industries will also cause a multiplicative growth effect of total income. Certainly, sources of the additional demand should be considered, and whether other GDP components (i.e. consumption, government spending, and net export) are affected. Such a Keynesian view also involves assumptions of available unused capacities.

Such assumptions do not look too strong for the Russian economy, which has been struggling for almost a decade around zero growth level, with very low investment activity levels. There is some interim good news, however, as the Russian economy is showing positive growth in 2017 and 2018. At the same time the foundations for a continuing recovery are still fragile[22], hence the need to ensure a climate solution that also enhances economic productivity.

[22] Russia. OECD Economic Outlook, 2016, no. 2.

Second, as discussed earlier, productive investments in energy efficiency will result in further lower fossil energy demand, a reduction in the variable costs of production, and lessened need to worry about the volatility of energy prices for energy-consuming industries. All of these elements together mean a higher level of robustness and competitiveness. Renewal of obsolete fixed assets in energy-consuming industries also means upgrading equipment toward higher quality products with greater added value. Higher demand for the industries' products can make it happen.

In summary, then, deep decarbonization scenarios have several distinct differences from the traditional business-as-usual (BAU) scenario:

- higher investment demand with lower following spending on traditional (fossil) energy sources;
- net energy bill savings that logically follow from investments in less costly alternatives;
- possible higher overall growth in total factor productivity (TFP) due to technological upgrade with modern, progressive technologies, and structural changes in the economy in favor of higher share of manufacturing industries and R&D.

The changes of investments pattern and energy spending flows up to 2050 have already been calculated for the DDPP project based on "Bottom-Up" Reference Energy System model of the Russian economy. We use the estimates as an input to our thought experiment. However, as discussed above, the Bottom-Up (BU) model is a partial-equilibrium model which does not operate with the concepts of GDP and employment. To assess the two macro-level short- and long-run effects we apply an Input-Output recursive modeling approach. The simple concept of IOA with a minimal set of assumptions provides more certainty in tracing of the involved interdependencies, and interpretation of the results. More complex approaches, such as computable general equilibrium (CGE) model and dynamic general equilibrium models, can certainly be applied, though due to more flexibility provided results may also be a function of parametrization of the models with following losses in transparency, which require additional consideration.

Effect 1. Direct multiplicative effect of higher investment demand and future lower energy spending. This two-folded effect will have positive (investment spending multiplier) and negative (lower demand and/or lower expenditures for domestically produced energy) components, with uncertain overall impact. This is mostly a short-term impact effect, as it considers immediate spending on investments, energy expenditures, and short-term multiplier.

Within the IOT framework, the first effect can be summarized as follows:

$$\Delta GDP_1 = (\frac{VA}{X}) \times (I - IOT)^{-1} \times \Delta Dem,$$

where ΔGDP_1 represents differences in GDP (vs. BAU) as a result of changes in the demand vector; ΔDem stands for changes in final demand; VA/X is value added per unit of output; I is identity matrix; and IOT is input-output table.

Note that this same effect can be applied to the net creation of jobs (Labor) by substituting the variable ΔLab_1 for ΔGDP_1, and also Lab/X for VA/X. Here we apply Russian IOT for 2015, extrapolated with probabilistic methods for 15 Russian industries and sectors. The application of probabilistic IOTs is a requirement, based on lack of official data. Though instead of one-point estimate, which can be obtained with mainstream RAS-related or maximum entropy methods, the result of probabilistic estimate is a set of IOTs, consistent with the data. Therefore our estimates will also be probabilistic with the advantage of natural sensitivity analysis to uncertainties in the data.

Some assumptions are required to link "Bottom-Up" estimates of investment and energy flows with the IOT framework. Here we assume that changes in energy spending (demand vector in the IOT analysis) will result in demand changes for sectors C (extraction of energy resources) and E (production and distribution of electricity, natural gas, and water) with the same ratio, as we observe from the RES-modeling results. This is similar to the approach suggested by [Hanson, Laitner, 2009]. Differences (vs. BAU) in investment spending are split between the three sectors:

- 30% additional demand for output of manufacturing industries (D-sector);
- 40% of the investment demand goes to construction industries (F-sector);
- remaining 30% goes for import of technologies, which are required to fulfill decarbonization, energy efficiency, and overall modernization of the industry, and are not available yet on domestic market.

Effect 2. Productivity growth effect due to structural economic changes towards manufacturing industries, higher demand for R&D, innovations, and high-skilled labor. Productivity is a critical and major factor of GDP growth. A number of studies [Baumol, 1986][23] suggest that the manufacturing sector has higher productivity growth potential as opposed to energy extraction industries. The opposite effect of suppression of long-run economic growth as a result of booming natu-

[23] Russia, OECD Economic Outlook.

ral resource exporting sector is known as "Dutch disease" or "natural resource curse" [Bruno, Sachs, 1982; Gylfason, 2001; Mehlum et al., 2006; Sachs, Warner, 1995; 1997].

In the simulation of our thought experiment, and drawing on recently published data Russia KLEMS[24], we assume that manufacturing industries (sector D) and other sectors have twice higher productivity growth potential compared with energy-related sectors in the BAU scenario, and 3 times higher in DDPP scenarios due to more productive investments and greater R&D in the industries. All other sectors are assumed to have the same productivity growth level for simplicity.

In IOT framework, the productivity growth effect can be estimated based as:

$$\Delta GDP_2^D = \Delta TFP \times GDP^D.$$

Table 1 summarizes the estimates of the two effects on economic growth. Fig. 1 highlights the suggested impact of the DDPP scenario compared with BAU for key benchmark years 2015 through 2050.

Table 1

Decomposition of GDP Growth and Employment Impact in DDPP Scenario vs. BAU

Effects	Time Period	
	2020–2030	2030–2050
Total GDP growth gain in DDPP scenario vs. BAU	1.9%	1.1%
Effect 1: Direct multiplication effect	0.9%	0.2%
Effect 2: Productivity growth effect	1.0%	0.9%
Changes in employment (DDPP vs. BAU)	1.1%	0.8%

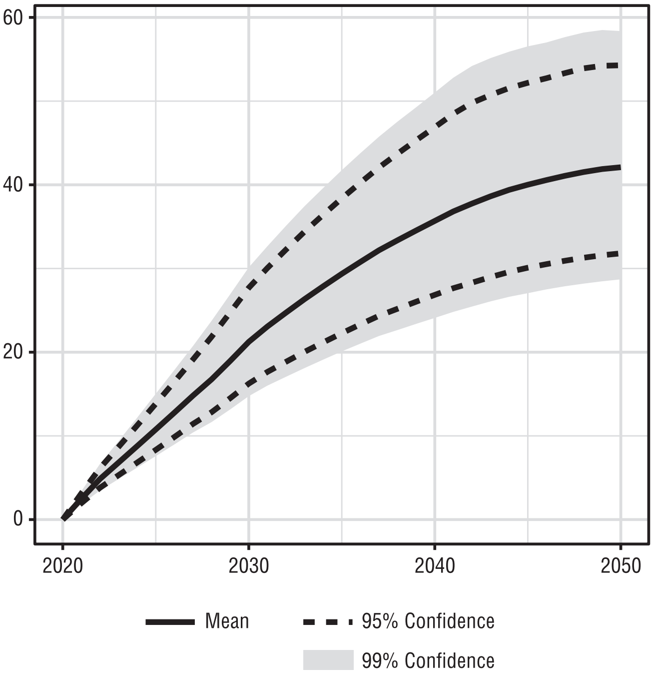
Source: authors' estimations.

Ultimately, as Table 1 suggests, this will increase the annual growth rate of GDP in comparison with the BAU scenario by 0.6% in the period from 2015 to 2030, and by 1.3% from 2030 to 2050. In the figure below is the relative change in GDP in the deep decarbonization scenarios compared with the BAU scenario. The production of machine building increased the most, and it allowed the share of the mining sector to be reduce to 5.5% from the current 11%.

Deep decarbonization leads to cumulative reduction of demand for fossil fuels, and 254 EJ of energy (or 800 million tonnes of oil (Mt) and 4.3 trillion cubic meters of natural gas) saved for the whole considered period.

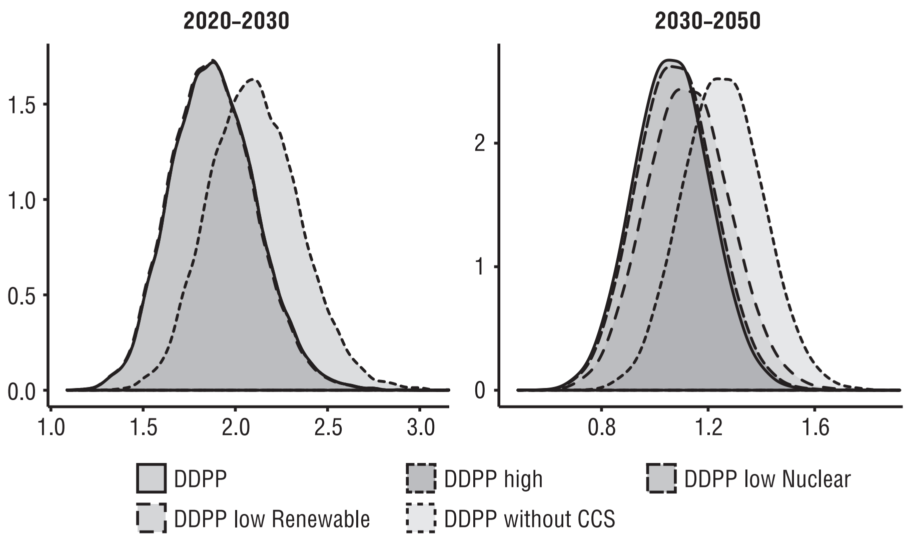
Fig. 2 shows the density distribution of GDP growth rates from 2030 to 2050, depending on the specific decarbonization scenario, whether DDPP includes carbon capture and sequestration technologies (CCS),

[24] Russia KLEMS. National Research University Higher School of Economics and Groningen Growth and Development Centre, 2017. http://www.worldklems.net/data.htm#regional.



Source: authors' estimations.

Fig. 1. **Accumulated GDP Growth Difference, DDPP Scenario vs. BAU** (%)

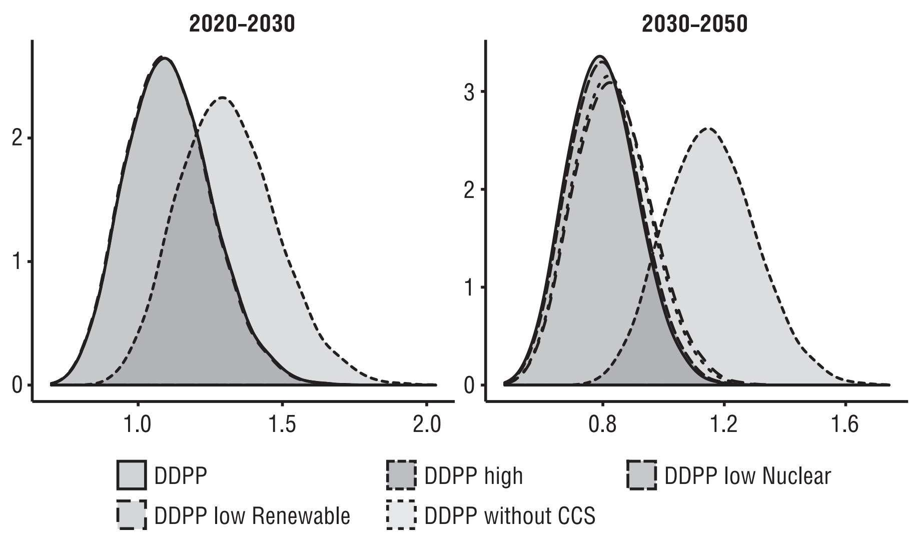


Source: authors' estimations.

Fig. 2. **GDP Growth Rate Compared to the BAU Scenario** (%)

lower levels of either nuclear or renewable energy technologies, and even higher levels of GDP as Russia continues to meet overall emissions reduction targets.

At the same time, there is a demand for new highly skilled jobs, and a reduction in demand for low-skilled jobs. For simplicity of calculating labor demand, only structural changes in the economy were taken into account. It is assumed that growth of TFP does not change the demand for labor. In each sector of the economy, the ratio of capital to labor is assumed to be constant and uses the assumption of labor productivity growth with constant rate 2.5% [Inklaar, Timmer, 2013]. The demand for labor may increase by 7.3 million jobs, of which 2.2 million are in industry, which eventually leads to an increase in the average rate of labor demand by 0.8% from 2030 to 2050. Fig. 3 shows the density distribution of the growth rates of labor demand in different scenarios.



Source: authors' estimations.

Fig. 3. **The Rate of Growth in Demand for Labor Compared with the BAU Scenario**

The estimates given are only a part of the positive effects listed above, and, for example, do not include a reduction in healthcare costs.

As 2018 indicates, and drawing on other forecasting projection for Russia, it is initially assumed that the Russian economy is expected to grow 1.3% annually in the business-as-usual (BAU) case. With the more productive use of resources in the DDPP scenario, especially in the manufacturing sectors, our findings suggest that the annual growth might be increased to 2.5% through 2050 even as significant emissions reductions continue through that period.

Table 2

Russian GDP for BAU and DDPP Scenarios (billion constant 2012 US$)

	2020	2030	2050	Annual Growth
BAU	1,781	1,908	2,661	1.3%
DDPP	1,781	2,342	3,718	2.5%

Source: authors' estimations.

The positive impact on GDP is driven by two primary effects. First, an increased investment in new technologies will drive gains in the construction, manufacturing, and other industries—even as businesses and households enjoy an overall lower set of heating and power bills. There are savings in the transportation sectors as well. Second, productivity in the manufacturing sector, spurred by the demand for carbon-free technologies, is expected to be one third larger in the DDPP scenario compared with business-as-usual.

Working Conclusions

Consistent with the framework of the thought experiment we described previously, and assuming Russia's investment-led reduction in carbon emissions is done in a cost-effective manner, both the nation's economy and the global climate are likely to benefit. Of course, both the modeling framework and the cost assumptions need to be further confirmed and validated, but the evidence discussed here, together with a growing documentation in the public literature, seems to support a win-win opportunity for Russia. Thus, the DDPP scenario is not only feasible from a pure technology perspective (as indicated by [Lugovoy et al., 2014]), but it requires dramatic change in the Russian economic structure that might actually strengthen the robustness of the Russian economy. In other words, the deep reductions in greenhouse gas emissions anticipated in the DDPP scenario need not be a burden on the economy; rather, they can be a stimulus, and a driver of more vigorous economic activity.

At the same time, the paper does not address two critical questions: (1) how to improve investment climate within the Russian Federation, a problem which will need to be solved to ensure the right magnitude of productive investments over the next three or four decades; and (2) how big an effort may be needed in Russia to actually move from an 84% reduction in energy-related CO_2 emissions to a 100% reduction of all net anthropogenic emissions by 2050. Yet, there is good news in twos. New studies are emerging to suggest that energy efficiency may be an even bigger resource than previously believed. [Grubler et al., 2018; Lovins, 2018], for example, indicate that energy efficiency improvements could provide 40% or more energy productivity gains compared with today's baseline energy demands. And as both policymakers and investors realize the scale of the economic returns, it is more likely that the investment climate will be shaped to capture the larger scale of reductions.

It should also be noted that the proposed methodology does not pretend to be a comprehensive assessment of the full range of factors that influence decarbonization on GDP growth. Its goal is to give an additional look at possible economic effects that simply go beyond the "costs" associated with decarbonization. And these "costs", as calculations show, can make a significant positive contribution to the restructuring, modernization, diversification of the Russian economy, and economic growth, which fully agrees with the repeatedly voiced goals of the concepts of long-term development.

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