DNC POLICY BRIEF SERIES

ANTHOLOGY OF THE 2015 EDITIONS

Hiroshan Hettiarachchi, Editor

United Nations University
Institute for Integrated Management
of Material Fluxes and of Resources
(UNU-FLORES)

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FOREWORD

The relationship between demands on, the availability of, and constraints to environmental resources are complex, and therefore, effectively managing them is even more complex. To ensure that management practices are also sustainable, we need to clearly understand not only this complexity, but also the interconnectedness, the synergies, and the tradeoffs linked to them. This requires is a higher level integrated approach – a Nexus Approach.

Reza Ardakanian, *Director* (Source: Jan Rieger/clever pictures)

The United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) was established in 2012 to help address this challenge. In particular, UNU-FLORES develops strategies to resolve pressing problems in the sustainable use and integrated management of water, soil and waste. Focusing on the needs of the United Nations and its Member States, particularly developing countries and emerging economies, the Institute engages in research, capacity development, advanced teaching and training, as well as dissemination of knowledge.

Many research and academic organisations are currently working on different aspects of the Nexus Approach. To contribute to advancing the discourse, UNU-FLORES initiated in 2013 a biennial event to provide a platform for ongoing dialogue on the nexus concept and its implementation. In 2013 it was a limited gathering in the format of a workshop – the Nexus Kickoff Workshop. By 2015 it became an international conference – the Dresden Nexus Conference (DNC). DNC2015 provided an excellent opportunity to exchange ideas, get to know other nexus researchers, and increase knowledge and awareness of other ongoing initiatives.

As a United Nations entity, UNU-FLORES has a mandate to advance policy-relevant research and bring it to the attention of the matching policy circles. This small booklet is a living example of noteworthy findings we have selected to promote. Out of many effective and attractive policy-relevant contributions at DNC2015, we carefully selected few presenters and invited them to share their ideas in the format of policy briefs. This booklet is the culmination of that effort. We hope not only this knowledge will benefit policy circles, but also will encourage others to share their ideas in the future too.

Reza Ardakanian
Director, UNU-FLORES

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ECONOMIC GROWTH AND RESOURCE USE: EXPLORING THE LINKS

Dr. Janez Sušnik (UNESCO-IHE)

HIGHLIGHTS

- Historically, there is no denying the fact that Gross Domestic Product (GDP) and resource use are correlated. But an important question that arises is: What could be the resource use trend for the future with the developing GDP?
- Should there be policies aiming to either restrict future GDP growth to minimise resource use or decouple GDP and recent resource use growth trends?

This policy brief aims at exploring the relationship between GDP and GDP-per-capita with the resource metrics and projected resource use related to water, food and energy till the year 2100

THE CHALLENGE

In 2013 about one billion people lacked access to safe drinking water, and in 2006 over 2.5 billion lacked reasonable levels of sanitation (Moe and Rheingans, 2006; UN Water). Likewise, about 840 million people are chronically malnourished (World Hunger, 2010) and approximately one billion lack access to a reliable electricity supply (World Bank, 2010). In a fast growing world, population is projected to reach over nine billion people by 2050 (UNPD, 2013) and to meet the expected increase in demand for water, food and energy efforts to improve lifestyles must be more efficient (Population Institute, 2003; RAEng, 2010).

This scenario is further stressing the knowledge regarding finite global resources and over-exploitation of water resources around the world (Gleeson et al. 2012). The shortage of freshwater and land for viable agriculture competes with the demand for land for growing urbanisation and the undergoing desertification, as well as wastage and traditional energy supply, sources, security and prices (Falkenmark and Molden, 2008). The risk of a global water shortage is critical, especially when climate change is considered. Water scarcity is considered the most important societal risk because, it has knock-on implications for a wide range of sectors including food, energy, health and economic development (WEF, 2015). Water resource use predictions covering multiple sectors would lead to a better understanding of the severity of global water scarcity, enabling the formulation of plausible development scenarios. These scenarios may help strategic planning for natural resources shortages, thus leading to water scarcity mitigation though the reduction of resources exploitation. A main challenge for predicting these scenarios is to identify a standardized metric that can be globally used to tentatively estimate future resource use.

CURRENTLY USED METRICS

At the present, the common metric in use is the quantification of selected parameters as (citing a few of them) electricity usage is measured in kilowatt-hours (kWh, or some appropriate multiple), total energy in gigajoules (GJ), water in millions of gallons or cubic meters, food in tons of production. These quantifications require knowledge of the underlying processes and considerable data availability as well as continued monitoring efforts. Moreover, the data are often extrapolated from different sources that are not always consistent. For these reasons, we believe that the development of a global metric which would not require all the above cited information and that instead rationalizes datasets via the generation of relationships between GDP and water, food and energy use metrics could lead to a consistent measurement. This in turn would simplify the overall process for predicting global scenarios.

USE OF ECONOMIC METRICS AS A NEW AVENUE

The use of economic metrics, such as GDP or GDP-per-capita, is a promising avenue for the prediction of water withdrawals. Thus this idea is used and expanded upon for this work.

Retrieval of data from open-sources databanks (e.g. The World Bank, FAOSTAT and FAO AQUASTAT, the UN EIA database) was adopted in this study and relationships between economic metrics (GDP and GDP-per-capita) and resource-related statistics (water, food and energy related) were generated. All primary data used are at national level and on spatial and temporal (annual) resolution.

This work includes over 170 countries for 1960-2008, and includes multiple water-related metrics. Whereas previous works often focus only on selected countries and only on single-year based statistics. Moreover, while other studies (Gleick, 2003; Duarte et. al. 2013; Katz, 2015) have also used big datasets, the focus was centred on per-capita water withdrawals and per-capita GDP, whereas our work make use of many other water, food and energy metrics, and it also includes total national GDP.

THE METHOD

Economic metrics and huge resource datasets are exploited to come up with plausible predictions for resource use in the future. GDP and GDP-per-capita are related to 19 different resource metrics from the water, food and energy sectors (e.g. the amount of water withdrawn per-person and nationally, food production and the amount of electricity generated and used). From robust historical trends, predictions to 2100 are generated based on seven likely GDP growth scenarios. This research makes use of extensive open-source data from the FAO 'FAOSTAT' and 'AQUASTAT' databases, the World Bank, the International Monetary Fund and the US Energy Administration.

THE OUTCOME

Main outcomes from the data elaboration are:

1. There is no apparent long-term global level relationship between GDP-per-capita and any of the 19 resource metrics.
2. GDP was shown to be related to the 19 metrics, with the strength of the relationships varying by metric (e.g. see Figure 1). Correlation equations between GDP and each metric were derived.
3. Using the correlation equations between GDP and the resource metrics, global historical trends were well replicated (e.g. Figure 2) when compared against the test set of data. This helped confirm the validity of the relationships so that they could be used for estimating future scenarios.

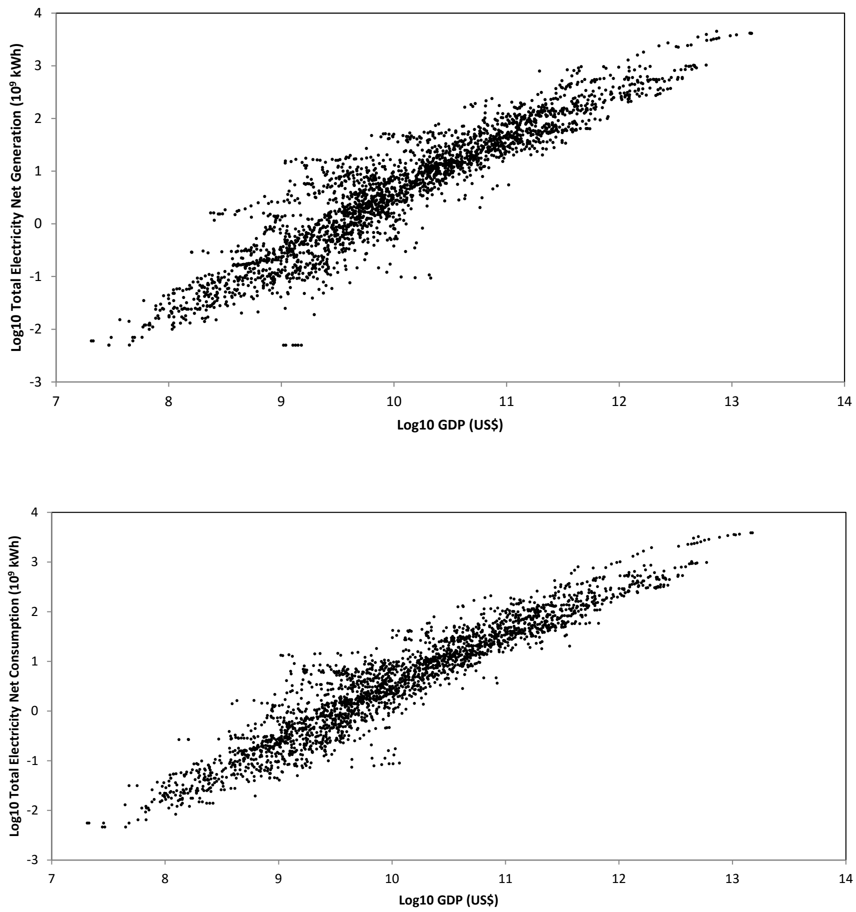

Figure 1: GDP related to net electricity generation (top) and consumption (bottom)

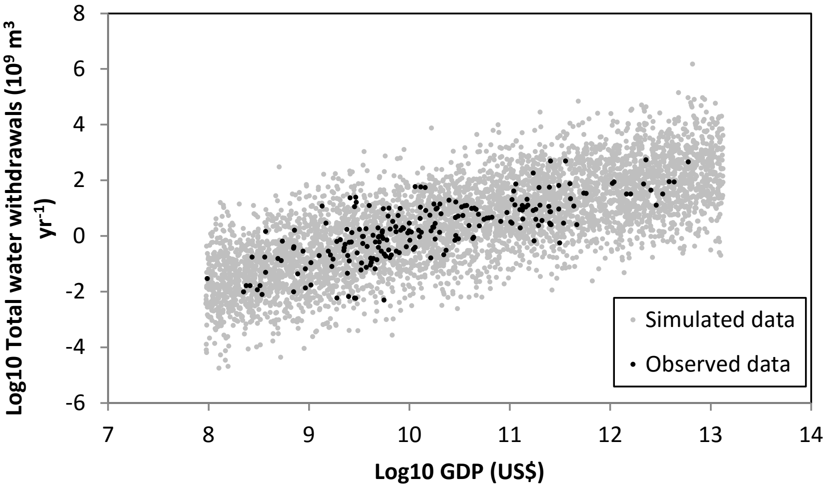

Figure 2: Replicated historical data for GDP and total global water withdrawals

4. These correlations were used for each of the seven GDP growth projections[1] in order to forecast resource use to 2100 (e.g. Figure 3). Results are within the same range of other studies using different methodologies and show that sustainability of resource use is strongly linked to the GDP growth scenario assumed.

5. Results are strongly GDP growth dependent. Strong growth leads to excessive resource use. As an example, the 'safe global' limit for water withdrawals (Steffan et al. 2015) exceeded more frequently under strong GDP growth rates.

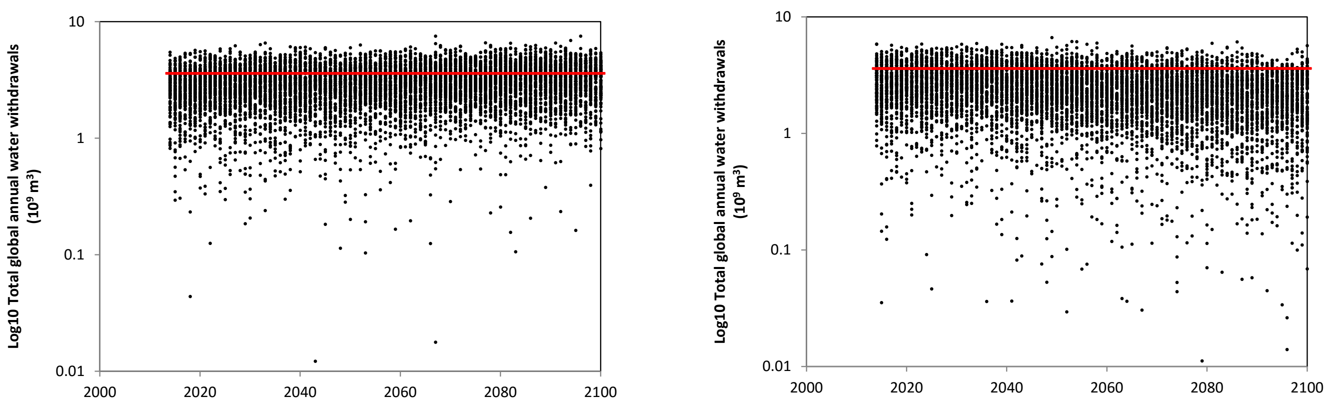

Figure 3: Example results for future global estimates of total global water withdrawals to 2100. Top figure assumes a 'business as usual' economic growth scenario while the bottom figure assumes a future negative GDP growth rate. Red line indicates the 4000 km3 yr-1 safe planetary boundary of Steffan et al. 2015. In scenarios of negative growth, the safe limit is exceeded less frequently

[1] Seven GDP growth scenarios were used to account for the most likely socio-economic development futures. One is based on recent historical average growth, one is based on the global average short term forecast from the IMF, two are constant positive growth scenarios, two are constant negative growth scenarios and the final scenario sums up short-term country-specific forecasts from the IMF

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POLICY RECOMMENDATIONS

Given the strong correlation between GDP and resource use globally, it seems wise to follow policy that either:

a. Limit economic growth such that resource use growth is also minimised; or
b. Aim to decouple resource use from the economy

Neither are easy options, but this work and recent work suggests ever-increasing resource use globally due to population change and improving lifestyles. If growth does indeed track GDP, and assuming it continues to do so, then option (a) must be sought. However, the possibility to decouple GDP from resource use is also plausible, but its implications are still unclear.

One glaring omission of this work is considering water, food and energy together. We are aware of their intimate interconnection on a global level and therefore it will be explored in further works.

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NATURAL RESOURCE USE AND ADAPTATION TO CLIMATE CHANGE IN THE NIGERIAN SAVANNA

Felix Olorunfemi (NISER), **Mayowa Fasona** (UNILAG), **Grace Oloukoi** (LCU), **Peter Elias** (UNILAG), **Vide Adedayo** (UNILAG)

HIGHLIGHTS

Nigeria is a country at high risk concerning food security, poverty, energy production, and most importantly, unsatisfactory infrastructure and economic development (FGN, 2008). In the near future daytime temperatures (mean maximum temperature) are predicted to rise between 3–5°C in most parts of Nigeria, and that a decrease in rainfall events will increase drought probabilities (Adejuwon, 2006). The effect of these events on the ecosystems will cause increasing water shortage, poor agricultural yield, food insecurity as well as malnutrition and health problems. The future climate projection, coupled with an expected increase in population, would present serious challenges for ecosystems and the associated livelihoods.

- The majority of dwellers the Nigerian savanna depend on firewood for cooking and heating, and the trees are not replanted by most of them.
- Slash and burn remains the dominant method of bush clearing for agriculture while free range grazing by nomadic pastoralists remains a key factor of ecosystem degradation.
- There is a lack of regulation or coordination of logging and charcoal businesses by the government.
- The intentions of various policy documents are not aligned with the actions or plans of natural resource management projects in the communities.
- There is need for joint ownership of projects on ecosystems management by government, development partners, and the community.
- Communities are willing to change or modify some of their farming practices, especially the slash and burn system, but they also want farming inputs and modern implements made available at highly subsidized rates.

THE CHALLENGE

In the Inclusive Wealth Report (IWR) assessment of 20 countries for the period from 1990 to 2008 released in June 2012, Nigeria is one of the 5 countries (with Colombia, Russia, Saudi Arabia, and Venezuela) that had negative growth rates for the Inclusive Wealth Index (IWI). This suggests an unsustainable track, as most of the country's GDP growth has come at the expense of the natural capital base (UNU-IHDP and UNEP, 2012). Livelihoods in Nigerian wooded savanna are substantially tied to the terrestrial ecosystem, and rainfall determines the rhythm of life. Future drier climate projections will have severe impact on the land and water that support food production and rural livelihoods. Many aspects of rural livelihoods in Nigeria have always been in conflict with the objectives of natural resource preservation. Given the vital role that natural resources play in sustaining growing human population, the governance framework and management systems at local levels are crucial. Ensuring sustainability, by meeting the challenges of livelihoods and preserving the ability of ecosystems to perform long-term regulating and supporting services, in natural resource-dependent, rural society is a challenge. Improving adaptive capacity of rural communities that are primordial natural resource users requires the integration of rural livelihood perspectives–which focus on people–with the natural resource management perspectives–which focus on natural resource production potential conservation and use.

The Nigerian Savanna is a densely settled zone where different social groups compete for access to finite natural resources. The question is how can small-holder farmers, migrant pastoralists, wood charcoal producers, hunters, fuelwood harvesters, leave collectors, and other economically marginalized populations be mobilized and galvanized to support the ecosystems management in order to safe-guard their own future? This brief highlights the climate change challenge and declining natural resources, effectiveness of existing policies in addressing these challenges and the viewpoints of households who directly suffer from these pressures.

STATUS OF FORESTS AND WOODLANDS AND USE OF NATURAL RESOURCES

The wooded savanna is dominated by shrubs, grassland and woodlands interspersed by footprints of small-holder, rain-fed agriculture. Findings (Fasona et al, 2014) show that cashew, mango, and citrus are the common fruit trees locally grown in individual small plantations. Teak and Gmelina plantations ranging from about 400ha to 1500ha, either owned by the State Governments or some private firms, were sighted in several places. Twenty-four different species of trees contribute significantly to the local economy. Anogeissus leiocarpus, Prosopis Africana, Vitalaria Paradoxa, Kassia, and Azadiractathta Indica are the most preferred wood species for a variety of domestic uses including construction and herbs for managing health issues. Vitalaria Paradoxa is outstanding as the most preferred tree species for charcoal. It is also highly important for a lot of local construction, herbs, oil and therapy. The combination of these uses has placed Vitalaria Paradoxa as the most endangered tree in the wooded savanna. No local economic tree is cultivated on woodlot or plantation either by government, private organization, or individual. About 84% of rural dwellers depend on firewood for cooking and heating. Fifty-six percent of the respondents claimed that trees harvested for both charcoal and fuelwood are never replanted.

CROSS-CUTTING ISSUES IN THE EXISTING POLICIES

The Nigeria national polices and programme documents related to natural resources, ecosystems, rural livelihoods, and food security (water, agriculture, energy, forest, environment, climate change, etc.) are detailed, well intentioned and cross cutting. The nexus among these key issues is also well articulated. The thorn in the side seems to lie in the disconnection between the policies and the actual situation on the ground, even decades after implementation of some of these policies commenced (Fasona et al, 2014). In detail, a big gap exists between existing policies or programs and the status of the rural communities. The intentions of various policy documents are not aligned with the actions or plans of the projects in the communities.

The following cross-cutting issues of natural resource use, ecosystems services, rural livelihoods, and climate change were revealed in the various policy documents analyzed:

- Strengthening forest protection programmes to ensure adequate vegetation cover in critical areas and to discourage developments likely to cause harmful changes.

- Combining desirable features of the traditional approach (of ecosystems management) with modern scientific methods of conservation.
- Increasing support for non-governmental organizations (NGOs) and community tree-planting programmes.
- Encouraging viable afforestation and reforestation programmes using tested drought resistant and/or (local) economic tree species and conserving indigenous tree species that are endangered.
- Reducing the percentage of fuel wood consumption in the domestic agricultural and industrial sectors.
- Encouraging the use of alternative sources of energy e.g. coal briquettes, efficient wood stoves, solar energy, wind energy, biogas, etc.
- Integrated human development issues including income generation, increased local control of resources, local institution strengthening, capacity-building, and greater involvement of community based non-governmental organizations and lower tiers of government as delivery mechanisms.

RURAL COMMUNITIES PARTICIPATION IN THE MANAGEMENT OF THE ECOSYSTEMS

Community members expressed readiness and willingness to embrace alternative livelihoods that will improve the ecosystems in relation to forest conservation and food production. All the local government authorities (LGAs) expressed willingness to partner with communities and other stakeholders to drive the process of natural resources management. There are trends of functionality gaps and a dearth of management schemes and tools. For instance, about 49% of the LGAs are not aware of methods for preserving their forest land and animals; 70% of households have never had any training concerning forest management and 40% are not aware of future threats to the sustainability forest and woodland that may result from their actions. In over 70% of the LGAs there are no systematic procedures for applying for logging, felling of trees for charcoal and fuelwood harvesting. This suggests a lack of regulation or coordination of logging and charcoal businesses by the government (Fasona et al, 2014).

TRADE-OFFS IN IMPLEMENTED AGRICULTURAL PRACTICES TO IMPROVE RURAL LIVELIHOODS

Ensuring sustainability by meeting the challenges of livelihoods and preserving the ability of ecosystems to perform long-term regulating and supporting functions in the savanna requires adjustments and trade-offs. Groups engaged in harvesting of wood for charcoal and fuelwood require trade-offs. There is a need for innovations to devise local solar heating devices that will be inexpensive and yet locally available. Communities are willing to engage in agroforestry or silviculture and would provide land to government for mass silviculture. In turn they ask for a strong assurance that such will be community managed and with no intention from the government to excise their lands. Communities are willing to change or modify some of their farming practices, especially the slash and burn system, but they also want farming inputs such as herbicides, fertilizers, and modern implements such as tractors made available at highly subsidized rate (Fasona et al, 2014).

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POLICY RECOMMENDATIONS

Climate services: Local climate information must be made available to farmers in the rural communities to aid or improve their decision-making and adjustment options. This means a densification of existing meteorological networks as well as plans to present farmers with seasonal forecasts.

Building partnership and using existing local networks: Partnerships between the community, government and research institutes should be developed. The capacity for programs and projects implementation strengthened to manage rural ecosystems and improve rural livelihoods and food security.
Opportunity for partnership should be offered by existing community-based networks (especially local and international institutes) including trade association, age groups, women societies, and cooperatives should be involved. The traditional rulers and community leaders have enormous potential to drive grass-roots participation at the community levels. Local and international institutes located close to the wooded savanna have much to contribute. In addition, the capacities of relevant departments in surrounding universities also present workable partnership prospects.

Encourage and strengthen local resource conflict resolution: Already existing innovative methods of resolving conflicts over resources by some of the communities should be encouraged and upscale to other communities.

Actionable research: Action projects on ecosystems management that will be community-driven or substantially involve community participation with opportunity for livelihoods or alternative livelihoods should be conceptualized and executed. Such research should target increased agricultural productivity, climate resilience, and sustainability, particularly for the rural smallholder farmers. But the community should be part of such projects from their inception.

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ENERGY RESOURCE USE OPTIONS FOR IMPROVED ENERGY SECURITY IN ETHIOPIA

Dawit Diriba Guta (AAU)

HIGHLIGHTS

- Investigated Ethiopia's least cost investment for integrated energy source diversification
- Assessed impacts of drought expected from future climate change on hydroelectric generation
- The country would need to invest in the development of alternative energy resources
- This would enhance the sustainability and reliability of energy generation, but also increase costs
- A greater rates of technological and efficiency innovations improve electricity diversification and reduce production costs; and are thus key for enhancing energy security

THE CHALLENGE

Ethiopia's energy sector faces critical challenges to meet a steadily increasing energy demand. This is due to the low development of electric restructure, the countries strong dependence on imported oil, and drought vulnerable hydroelectric power. Likewise, Engidawork et al. (2009) indicated that shortage of electricity during 2007–2009 brought a 3% GDP loss.

An overwhelming share of energy consumed by Ethiopia in 2009 (92%) was derived from biomass sources, fossil fuels accounted for 7%, and other forms of electricity generation were only 1% (See Figure 1). High economic growth for the past decade had a high correlation with the increased fossil fuel demand. The report of the Ethiopian petroleum enterprise (2011) indicated that fossil fuel import doubled during 1998/99–2009/10. The challenge in the electricity sector is mainly caused by the high electric transmission rates and heavy losses in its distribution, and homogeneous mix of electricity (World Energy Trilemma, 2013). Heavy reliance on hydropower poses energy security concerns due to vulnerability to frequent and persistent drought that is characteristic of the region. The concern is also related to trade-offs with potable, industrial, and agricultural water needs; the effects of siltation and sedimentation on dams and reservoirs; and conflicts over water rights.

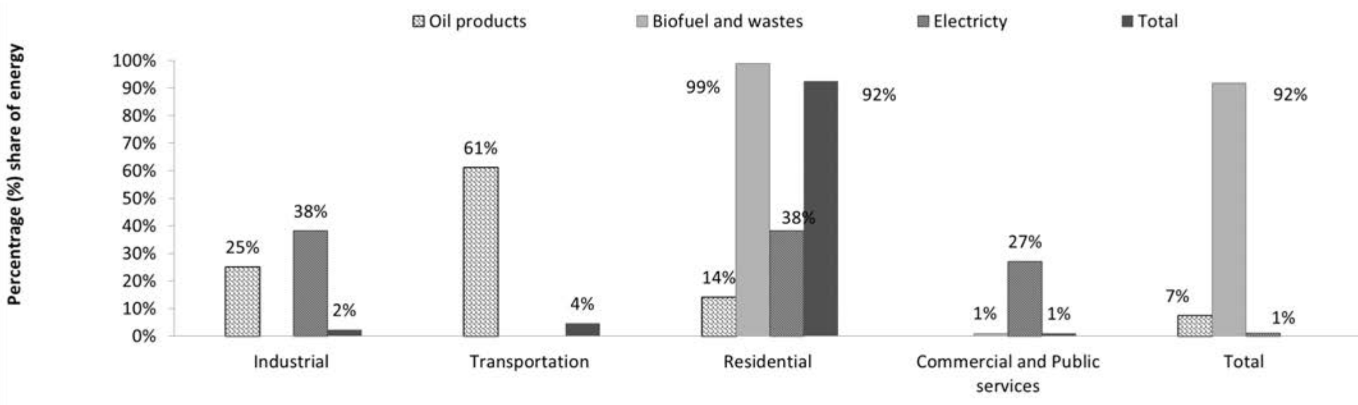

Figure 4: Distribution of energy consumption in Ethiopia by end-user, 2009 (Source: International Energy Agency, 2009)

RENEWABLE ENERGY POTENTIAL

Despite this challenge, Ethiopia could dramatically improve its situation by becoming a renewable energy producer. Located in the tropics, the country has a considerable potential for production of green energy in terms of diversity (see Table 1). The presence of several large rivers draining the highlands and the Great East African Rift Valley (GEARV) could be respectively used for hydroelectric, wind, and solar power production.

THE NEED FOR ENERGY SOURCE DIVERSIFICATION

The primary challenge of Ethiopia's energy sector is the low performance in developing renewable energy resources that ensures competitive advantages as well as energy security. The country needs to invest in sustainable energy to keep pace with the unprecedented growth in energy demand. Correspondingly, this study aspired to investigate the optimal least cost investment decisions for integrated energy source diversification. Particular attention was given to relevant literature on the cost of investment decisions, role of public policy in renewable energy, and underlining evidences of uncertainties implication on the country's future energy security.

ELECTRICITY DEMAND GROWTH RATE

The electricity demand growth rate varies, in the long term, due to future uncertainty in the electricity market; which was assumed in this article as a function of the economic and population growth. The annual demand growth rate varied between 6% to 9% in the period 2010–2045 and assumed to grow only of 2.5% due to the expected stabilisation of economic and population growth between 2045 and 2110.

POWER GENERATION BASELINE SCENARIOS

The outcomes of the model indicate that hydroelectric power continue to dominate the country's energy mix without intervention with respect to technological progress and efficiency innovations. Under high electricity demand growth, Ethiopia would generate about 388 Terawatt hours (TWh) by 2110, compared to 183 TWh under low growth. Under low electricity demand growth, Ethiopia continues to heavily rely on hydroelectric power. In the high demand growth, alternative energy sources (geothermal, wind, solar and biomass) will be exploited after fully exploiting hydroelectric sources.

Table 1: Ethiopia's current and potential or projected renewable energy resource capacity (Source: Ministry of water and energy, 2013; Global Methane Initiative, 2011)

Energy source	Unit	Potential reserve	Exploited as of 2010	
			Amount	%
Hydroelectric	MW	45,000	2,100	5%
Solar	kWh/m²/day	4–6		
Wind	GW	1,350	268MW	<3%
Geothermal	MW	5,000–7,000	7.3	<1%
Woody biomass	t (millions)	1,120	560	50%
Agricultural waste	t (millions)	15–20	≈6	30%
Municipal solid waste	t (millions)	2.8–8.8	50 MW (under construction)	

IMPACT OF EXPECTED FUTURE CLIMATE CHANGE ON POWER GENERATION AND ADAPTION MEASURES

In the short and mid-term, climate change is likely to have negligible effects on Ethiopian's hydroelectric energy production. However, it is predicted that the adverse effects of droughts on the reliability of hydroelectric energy are more likely to manifest in the long term; and consequently the cost of energy will increase. This prediction calls for investing in expensive alternative renewable energy sources.

Costs are projected to rise above the baseline model by about 0.1% under a 0.11 standard deviation of water availability, 2.5% under a 0.25 standard deviation and 7% under a 0.40 standard deviation. There is great uncertainty about how future climatic change will affect energy production in Ethiopia. Ethiopian highlands' precipitation may increase rather than decrease, thus increasing water availability for hydroelectric power generation. However, the increase of precipitation might not always result in a benefit for the country unless it occurs during the dry season. Likely, the increases in the intensity of precipitation in the rainy season may increase the risk of flooding, siltation, and sedimentation, which directly affect the capacity of hydroelectric reservoirs adversely.

It is expected that the construction of small-scale hydroelectric projects would allow the country to mitigate the risks of climate change or drought. On one side the construction of small hydroelectric plants could increase the country's capacity to adapt to the effects of climate change. On the other side, according to the statistics of the Ethiopian Electric Power Corporation (EEPCO) (2011) on selected existing plants, the cost of power generation per unit of power is significantly higher than in large hydroelectric plants. However, small hydroelectric plants designed as decentralised power providers for rural communities require less transmission and distribution networks and therefore less related costs and electricity loss.

All in all, the primary adaptation measure for shortage electricity during dry years in Ethiopia is the increased use of fossil thermal, to cope with power rationing or blackouts. National statistics revealed that when the country faces shortfalls in electricity in dry years, private and governmental organisations increase their use of diesel generators (EEPCO, 2011).

IMPLICATION OF TECHNOLOGICAL PROGRESS AND EFFICIENCY INNOVATION

To cope with the expected effects of climate change on hydroelectric power generation, the country needs to invest more in alternative renewable energy resources. Newer energy technologies were expected to have greater advantages and innovation rates than more mature (hydroelectric and geothermal) technologies (Winkler et al., 2009). In terms of energy security this would not only improve both sustainability and resilience, but also increase production costs. A study indicated that promoting adaptive research and development and supporting technological transfer could be especially valuable for developing countries, as new markets emerge for renewable energy technologies (Popp, 2011).

Innovations that improve the technology and efficiency of alternative energy sources, especially solar energy, would increase energy resource diversity and reduce production costs, shadow prices, and thus resource scarcity. Technology and efficiency innovations are therefore key for mitigating the expected effects of future climate change and improving energy security, and thus would likely serve as an engine of economic growth. Greater rates of cost reduction resulting from technological and efficiency innovation were found to promote substitution of new energy resources for hydroelectric energy sources.

Adoption of technology and efficiency related innovation are useful to diversify energy sources and reduce cost of energy production. Under the "best innovation scenario", Ethiopia was projected to undergo a massive shift from hydroelectric power sources to alternative sources such as wind, biomass, and solar energy. Moreover, relative to the "baseline scenario", it is projected that the discounted minimized cost of energy production would decline by about 10% (US$ 0.08 billion) and 18% (US$ 0.42 billion) under high and low electricity demand growth rates respectively. The mean shadow price of energy resources would declines from US$ 0.003/kWh in the "baseline scenario" to US$ 0.001/kWh in the best-case scenario. In a world of constrained resource availability, technological and efficiency innovations can thus clearly contribute to growth by reducing resource scarcity.

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POLICY RECOMMENDATIONS

Ethiopia needs to invest in renewable energy resources to ensure green energy development, achieve poverty alleviation and improve energy security; however, such an effort is hindered due to the high capital costs of these alternative energy resources. The following policy measures are recommended:

- Introduce policy measures that support innovation through research & development.
- Create a secure environment for private investors or decentralized renewable energy investment.
- Support for renewable technologies should be directed at closing technical, financial, and efficiency gaps that exist in the country's energy sector.
- Use tools such as capital subsidies that enhance the competitiveness of alternative energy sources.
- Provide incentives for integrated natural resource (forest, land/soil, ecosystem) and river basins management programmes, to cope with impact of drought and various risks (flooding, siltation, and sedimentation) which affect the capacity of hydroelectric reservoirs.

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ENERGY IN ICELAND: ADAPTATION TO CLIMATE CHANGE

Dr. Oli G. B. Sveinsson (Landsvirkjun)

HIGHLIGHTS

Even in the era of climate change, Iceland is a pioneer in the use of natural resources for the production of renewable energy. Iceland is already 100% renewable in both heat and power with geothermal energy being the primary energy source for space heating and hydropower being the primary energy source for electricity generation. Primary energy use in Iceland of 85% is from domestic renewable sources, with the remaining 15% mainly due to the transport sector and shipping fleet. Iceland indeed has done and is applying modifications for present and future hydropower assets to cope with and take advantage of climate change.

Iceland demonstrates that a 100% renewable electricity system is possible and not only for small isolated systems or for a minimal level of access to electricity. Renewables can and do supply sufficient electricity for industry and economic growth of a country.

THE CHALLENGE

In Iceland, the biggest hydroelectric power stations are fed by glacial rivers. Over the last decades, increased flows and changes in the seasonal distribution of river flows have been observed. Further increases in flows are expected from melting glaciers due to global warming.

A peculiarity of the Icelandic power system is the non-interconnections to other grids. In this regard, if the climate continues warming with corresponding increases in glacial runoff volumes, then not accounting for climate change may lead to wrong investment decisions regarding the operation and expansion of the power system.

On the other hand, if adaptation measures are to be taken, multiple questions should be first addressed:

- What temperature increases should you anticipate?
- For operational rules for your power system how should you adjust your existing historical inflow series?
- For prospective investments how far should you look into the future to make sure that your investment is climate resilient with respect to climate?
- What is the risk if you overestimate or underestimate future flows?

ADAPTATION OF ENERGY PRODUCTION TO WARMING CLIMATE

Climate change is a reality that the world has to face. The historical global temperature trend over the period 1880–2012 has been at 0.85 ˚C and is estimated to increase by between 0.3–4.8 ˚C at the end of the century (IPCC, 2014). The change in climate due to anthropogenic impacts affects distributional properties of climate processes and calls for sophisticated risk analyses to evaluate climate change in both the near and far future (IPCC, 2012). The rise of global temperature is also accelerating the melting of glaciers around the world, implying that the operational regime for hydroelectric stations fed by glacial water should be under continuous review. In watersheds fed by large glaciers, the impact of climate change is expected to accelerate the process of ice melting and increase flow rates of many rivers. On the other hand, in watersheds fed by glaciers that have already lost the majority of their mass, the flow rates may decrease. Additionally, the decreased glacial pressure causes the elevation of the surrounding land, potentially altering coast lines and having serious effects on sea erosion.

In future scenarios, the projected changes in precipitation and temperatures will have diverse implications for hydroelectric generation since some regions will get wetter while others drier. Along with water availability, the regional demand for electricity is also likely to vary due to climate change, with potentially lower heating demand during winter but higher cooling demand during summer.

In some cases, careful management strategies make existing hydro-resources climate resilient. In other cases, even with thoughtful management, it will not be enough to cope with the climate changes. In these cases, assets modifications are needed.

A common asset modification need is increasing storage capacity of the reservoir and/or increasing installed turbine capacity to handle larger volumes of water.

ICELAND AS A CASE STUDY

Landsvirkjun, the National Power Company of Iceland, is one of the few companies around the world that have justified modifications to management strategies and design specifications for present and future hydropower assets. To achieve that, Landsvirkjun together with other companies, institutions and scientists from the Nordic region has in the last 15 years been studying climate change effects on river flows. Landsvirkjun has focussed the efforts on the evaluation of the impact of climate change on renewable hydropower generation (Sveinsson et al., 2008 and 2012; Ouranos, 2016). Climate change projections for temperature precipitation and its impacts on glacial melt were generated and the study has shown that since 1950 both the volume and seasonal distribution of flows changed mainly because of glacial melt (Fenger, 2007; Johannesson et al., 2007; Thorsteinsson and Bjornsson, 2012).

Convincing the Landsvirkjun executives to take the first steps towards adaptation to climate change impacts was a step-by-step process; surely being a part of a larger Nordic study did help to eventually get to where we are today. In 2006 Landsvirkjun started using only the latest 20 years of historical records instead of the time series records dating back to 1950. The argument for the change was that climate change impacts were already being perceived in Iceland and that the cold period of the years 1965–1971 was unlikely to repeat.

In 2010 Landsvirkjun took the full step of using climate adjusted historical records to reflect current and future climate conditions. Combining the estimates of historical temperature and precipitation trends with the projected future climate trends and future shape of Icelandic glaciers, Landsvirkjun created different sets of flow scenarios for 2010 and for the future periods 2015, 2025, 2035 and 2050.

In detail, the flow scenarios were created using calibrated rainfall-runoff models for historical records, both observed and from regional models. The historical temperature and precipitation records were corrected using seasonal climate trends to create climate representative of each of the period to be analysed. The generated record length of each period has the same length as the historical record, where the observed natural variability has been corrected using current climate or future climate. Every five years these flow scenarios are updated using latest hydrological models and climate scenarios.

MODEL SCENARIOS OUTPUT

Looking at the 2010 scenarios created back in 2010 for operational use. This flow scenario incorporated climate changes that were considered to have already occurred and used the current size of Iceland glaciers. Not only did the flow rate of certain glacial rivers increase, but also the seasonal distribution was significantly altered with spring floods arriving earlier and the glacial melting season being extended later into the fall and more frequent winter melting events. The current power system was able to utilise 85% of the increased flow, increasing the annual generating capacity by 8% through the modification of reservoir management strategies.

Looking at the future scenarios by 2050, the volume of inflow will increase by an additional 15% with respect to 2010. The existing power system can only utilise 30% of that increase and the rest is expected to be spilled over the spillways. This is because the existing power system is already seeing higher utilisation than expected by design after adopting the 2010 scenario. To increase the utilisation of increased flows the installed capacity of the existing systems will need to be increased and reservoir storage will also need to be increased to accommodate higher flow rates.

Looking at the future scenarios by 2080, the glaciers in Iceland will have reduced so much in size that the flows will start decreasing. By 2200 we expect that the glaciers have disappeared. With the glaciers gone the annual volume of flows is likely to be similar to what it was around 1990 when the glaciers were in equilibrium, since the expected increase in precipitation with the future climate is expected to be largely offset by a similar increase in evaporation. On the other hand the seasonal distribution of flows will be markedly different, characterised by precipitation induced flow events throughout the year instead of summer dominated glacial melting season. This altered seasonal flow cycle should make better use of storage facilities with reduced spill volumes.

LESSONS LEARNED

The issue of climate change is today a matter of great importance to Landsvirkjun and research on climate change is now an intrinsic part of Landsvirkjun's operations. However, to get to where Landsvirkjun is today, it took time. A step-by-step approach was necessary to get a full buy-in at Landsvirkjun and reach the level of awareness that we have today. The results have been used to give valuable information for decisions makers on future investments in Iceland. Moreover, adaptation measures have been currently undertaken at Landsvirkjun, namely:

- Present and future flow scenarios have to be created by correcting historical climate series with expected future climate trends.
- For current day operation the optimisation of reservoir management strategies make use of time series applicable to today's climate.
- The design of future power projects, including refurbishments and capacity increases, accommodates the expected increased flow rates 15–20 years into the future. In addition the design takes into account that capacity may have to be increased further in the future to increase climate resilience of the power projects.
- Landsvirkjun has adopted an action plan to reduce emissions from its operation and to become a carbon neutral company.

Today in Iceland, 77% of all generated electricity goes to power intensive industries. This makes Iceland the largest generator of electricity in the world per capita, even though more than 90% of space heating in Iceland makes use of geothermal resources directly.

Since the electricity in Iceland is 100% renewable, it can be argued that Iceland is mitigating greenhouse gas emissions for the same number of industries generating electricity with thermal sources placed elsewhere outside Iceland.

Feasibility of interconnections with Great Britain is currently being explored. This would aim at further increasing the efficiency of the Icelandic power system and also towards shared storage capabilities and supply security with Great Britain, thus mitigating some greenhouse gas emissions from thermal sources in Great Britain.

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POLICY RECOMMENDATIONS

- Climate change is already happening and the past climate is not necessarily a good measure of future climate. Climate dependent Infrastructure needs to use updated corrected climate information to reduce its vulnerability to climate change.
- Climate change mitigation and adaptation have to go hand in hand. Through combined effort, where dependence on fossil fuel is reduced, some of the expected climate change impact may be mitigated. Adaptation should be aimed at making infrastructure resilient to climate change and increased natural variability.
- Hydropower is the largest renewable electricity source today, in addition to being extremely flexible for balancing of complex power systems. Hydropower with reservoir storage can act as a battery storing energy, while at the same time providing flood control and water storage for municipal and irrigation use.

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